STABLE AND EXOTIC BEAMS PRODUCED AT GANIL

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GANIL, Grand Accélérateur National d'Ions Lourds, Caen, France

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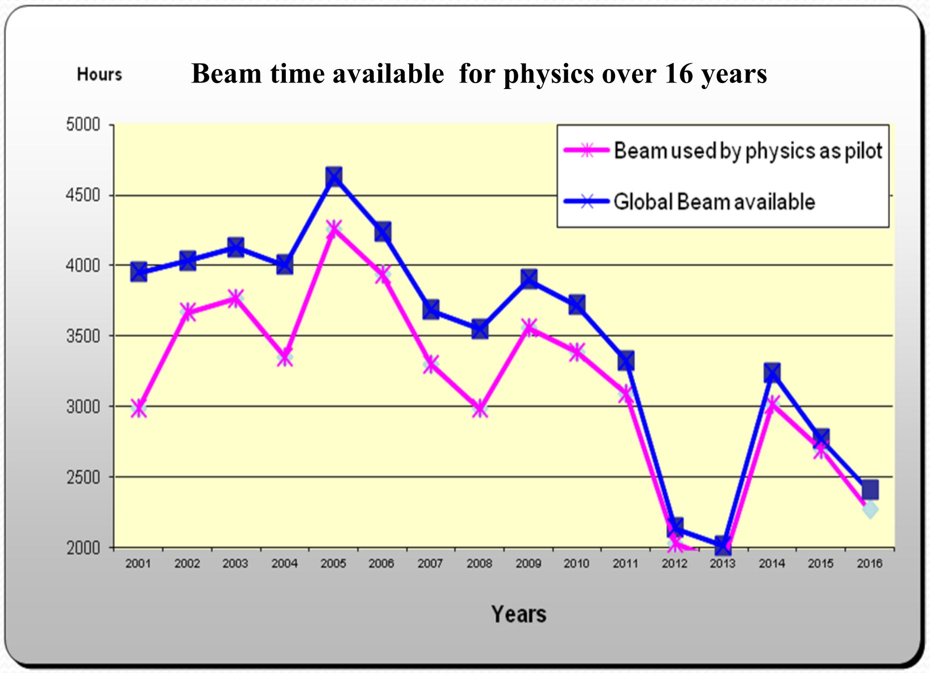
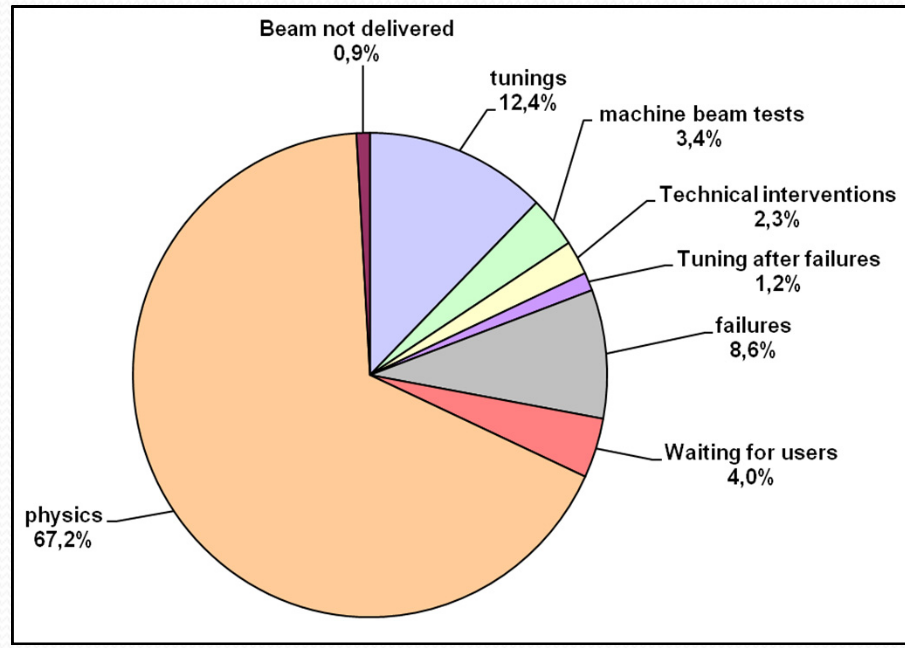
OUTLINE

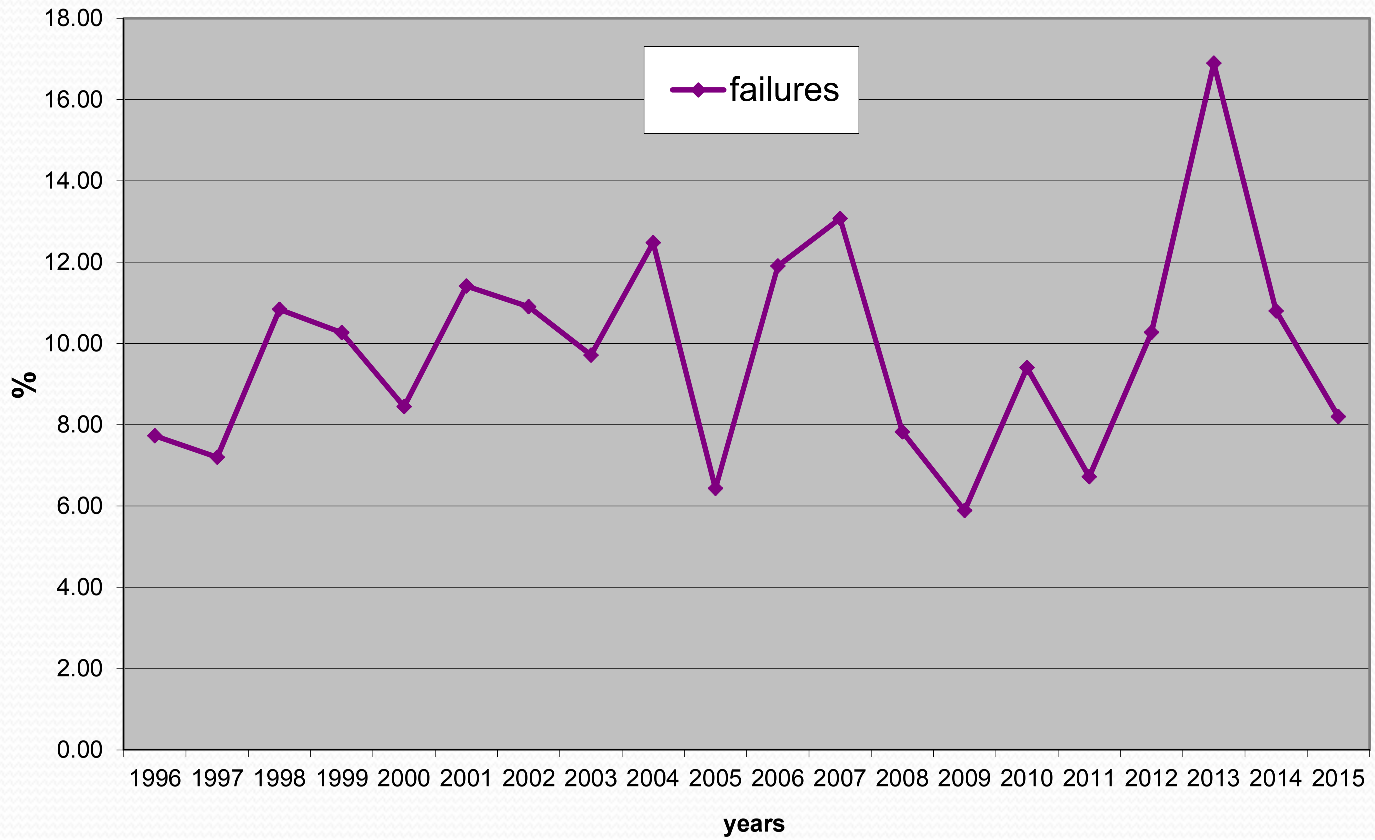
- Running statistic
- Water Leak issues
- Operating modes at GANIL
  - Beam Intensity
  - Spiral 1 (ECR source,…)
- SPIRAL 1 UPGRADE
  - Production Method
  - 1+FEBIAD source
  - Charge breeder
  - Schedule and organization.

Running statistic From 2001 to 2016





Failures



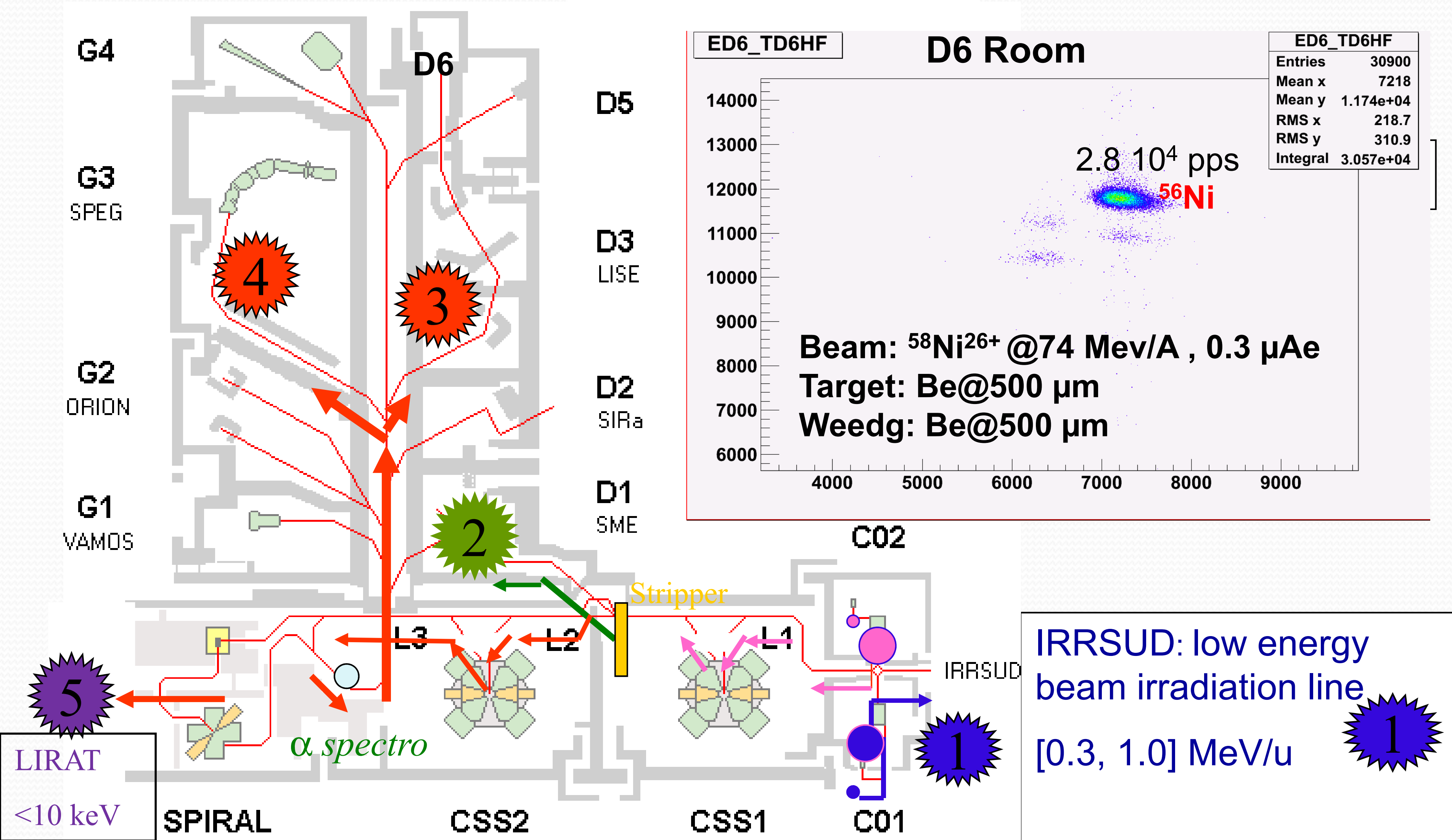
failures
%
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
years

Water leak problems

Corroded pipe cooling

C01 cavity

Operating Mode at GANIL



Intense Primary beams

2.10^13 pps Safety limitation reached (rows $^{12}C^{6+}$ to $^{26}Mg^{12+}$)

Possible improvement (rows $^{36}S^{16+}$ to $^{124}Xe^{46+}$)

Beam	Imax [μAe]	[pps] <2 10^13	Emax [MeV/A]	Pmax [W] <6kW	Used with Spiral
$^{12}C^{6+}$	18	$1.9\ 10^{13}$	95	3 200	
$^{13}C^{6+}$	18	$2.\ 10^{13}$	80	3 000	X
$^{14}N^{7+}$	15	$1.4\ 10^{13}$	95	3 000	
$^{16}O^{8+}$	16	10^{13}	95	3 000	X
$^{18}O^{8+}$	17	10^{13}	76	3 000	X
$^{20}Ne^{10+}$	17	10^{13}	95	3 000	X
$^{22}Ne^{10+}$	17	10^{13}	79	3 000	
$^{26}Mg^{12+}$	20	10^{13}	82	3 600	X
$^{36}S^{16+}$	11	$5\ 10^{12}$	77.5	1100	X
$^{36}Ar^{18+}$	16	$5.5\ 10^{12}$	95	3 000	X
$^{40}Ar^{18+}$	17	$6.\ 10^{12}$	77	3 000	
$^{48}Ca^{19+}$	4-5	$1.3\ 10^{12}$	60	600-700	X
$^{58}Ni^{26+}$	5	$1.2\ 10^{12}$	77	860	
$^{76}Ge^{30+}$	5	$1.2\ 10^{12}$	60	760	
$^{78-86}Kr^{34+}$	7.5	$1.4\ 10^{12}$	70	1200	X
$^{124}Xe^{46+}$	2	$2.7\ 10^{11}$	53	300	

Stable isotope beam tunning

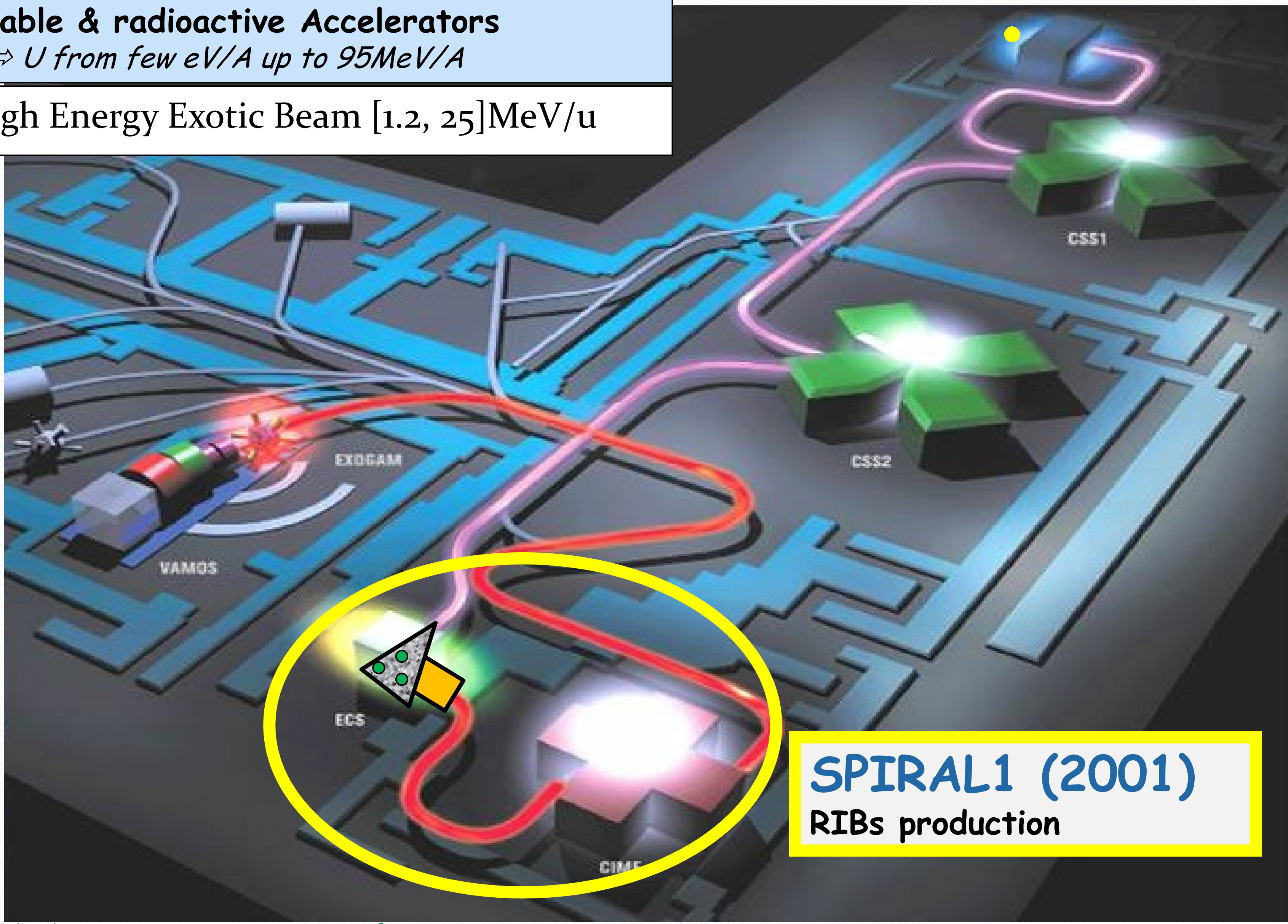
beam	Abondance isotopique [%]	Beam reference	□F/F	Energie [MeV/A]	Expected beam intensity at the exit of CSS1 [pps]	Measured beam intensityat the exit of CSS1 [pps]
$^{40}Ca^{7+}$	96,941	-	1	4,5	9.10^{11}	**9.10^{11}**
$^{42}Ca^{8+}$	0,647	$^{44}Ca^{8+}$	4.75%	5,32	4.10^{9}	7.10^{8}
$^{44}Ca^{8+}$	2,085	$^{40}Ca^{7+}$	+3.9%	4,85	$1,4.10^{10}$	1.10^{10}
$^{46}Ca^{8+}$	0,004	$^{40}Ca^{7+}$	-0.6 %	4,44	2.10^{7}	**5.10^{6}**
$^{48}Ca^{9+}$ $^{16}O^{3+}$	$^{48}Ca^{9+}$: 0,187	$^{44}Ca^{8+}$	3.12 %	5,16	9.10^{8}	$<10^{8}$

Frequency shift of C01 and CSS1 with BR constant

SPIRAL 1 Operating Mode

Stable & radioactive Accelerators
C ⇨ U from few eV/A up to 95MeV/A

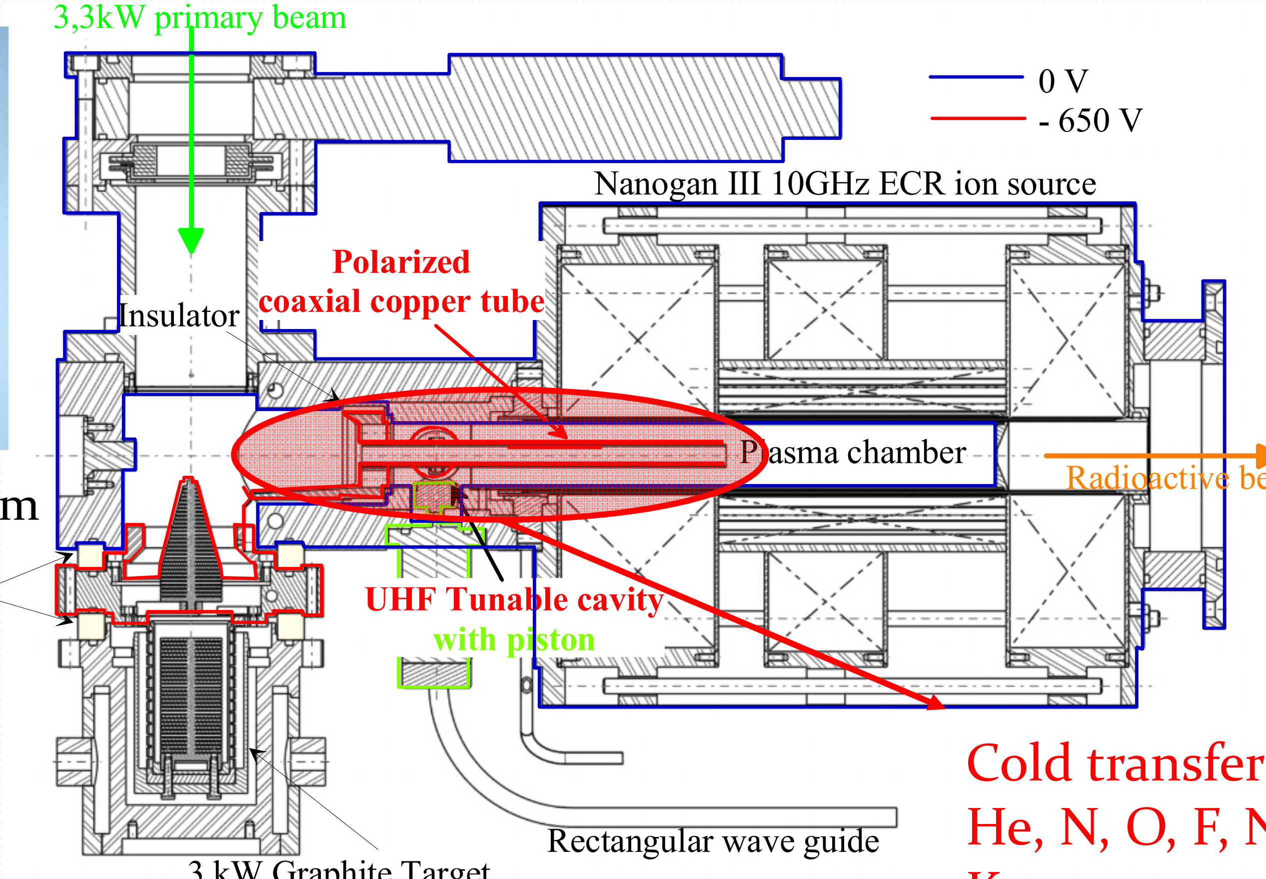
High Energy Exotic Beam [1.2, 25]MeV/u



SPIRAL1 (2001)
RIBs production

Current Target Ions Source ECR N+: Nanogan3+C

- Highest ionisation efficiencies for gases!



6 kW ^{12}C beam

Cold transfer tube
He, N, O, F, Ne, Ar, Kr

A. C. Villari et al., Nuclear Physics A 787 (2007) 126c–133c

To the cost of universality

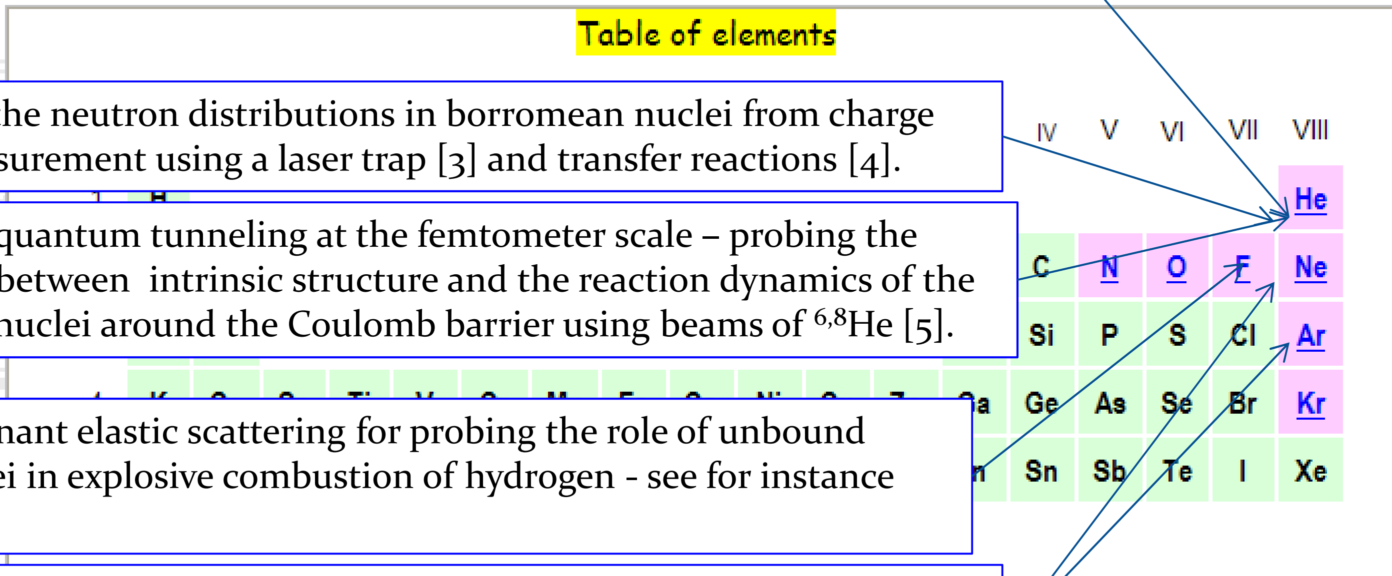
Exotic beams production

ions	W [MeV/u]	[pps]	ion	W [MeV/u]	[pps]
6He	3.8	$2.8\ 10^{7}$	20F	3	$1.5\ 10^{4}$
6He	2.5	$3.7\ 10^{7}$	17Ne	4	4.10^{4}
6He	5	3.10^{7}	24Ne	4.7	2.10^{5}
6He	LIRAT (<34 keV/u)	2.10^{8}	24Ne	7.9	$1.4\ 10^{5}$
6He	20	5.10^{6}	24Ne	10	$2\ 10^{5}$
8He	3.5	1.10^{5}	26Ne	10	3.10^{3}
8He	15.5	1.10^{4}	31Ar	1.45	1.5
8He	15.4	$2.5\ 10^{4}$	33Ar	6.5	3.10^{3}
8He	3.5	6.10^{5}	35Ar	0.43	4.10^{7}
8He	3.9	8.10^{4}	44Ar	10.8	2.10^{5}
14O	18	4.10^{4}	44Ar	3.8	3.10^{5}
15O	1.2	$1.7\ 10^{7}$	46Ar	10.3	2.10^{4}
19O	3	2.10^{5}	74Kr	4.6	$1.5\ 10^{4}$
20O	3	4.10^{4}	74Kr	2.6	$1.5.10^{4}$
20O	4	4.10^{4}	75Kr	5.5	2.10^{5}
18Ne	7	1.10^{6}	76Kr	4.4	4.10^{6}
18F	2.4	$2\ 10^{4}$			

SPIRAL 1 achievements: highlights

7 elements

Existence of unbound ^{7}He using the active target MAYA [1].



Probing the neutron distributions in borromean nuclei from charge radii measurement using a laser trap [3] and transfer reactions [4].

Study of quantum tunneling at the femtometer scale – probing the interplay between intrinsic structure and the reaction dynamics of the colliding nuclei around the Coulomb barrier using beams of $^{6,8}He$ [5].

Resonant elastic scattering for probing the role of unbound nuclei in explosive combustion of hydrogen - see for instance [6].

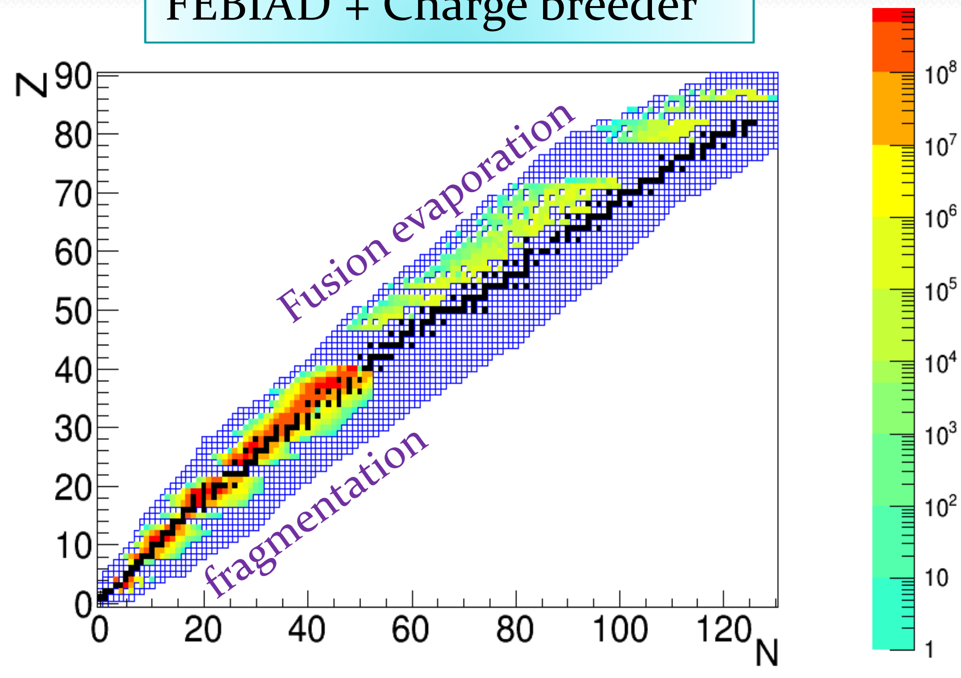
Evolution of N=20 and 28 shell closures far from stability and the emergence of new shell gap at N=16, using neutron rich beams of Ne [7] and Ar[8].

2001 – 2008:
70 physics articles
12 PhD Thesis
53 technical articles
7 PhD thesis

[1]: M. Caamaño et al, Phys. Rev. Lett. 99 (2007) 062502.
[2]: X. Flechard et al., Phys. Rev. Lett. 101 (2008) 212504.
[3]: P. Mueller et al., Phys. Rev. Lett. 99(2007)252501.
[4]: A. Chatterjee et al., Phys. Rev. Lett. 101(2008)032701.
[5]: A. Lemasson et al., Phys. Rev.Lett. 103 (2009) 232701.
[6]: W.N. Catford et al., Phys. Rev. Lett. 104(2010)192501.
[7]: L. Gaudefroy et al., Phys. Rev. Lett. 97(2006) 092501 and Phys. Rev. Lett. 99, 099202 (2007).
[8]: F. De Oliveira Santos et al., Eur. Phys. Jour. A 24 (2005) 237-247.

SPIRAL 1 upgrade

FEBIAD + Charge breeder



One of the main recommendations of scientific advisor comity for existing facility is to extend the radioactive ion beam variety available from the SPIRAL1 facility.

-> Condensable beams
-> Gaseous beams
-> Accelerated beams
-> Low Energy beams

-Increase the production rate

- Post-accelerate the RIB's by CIME cyclotron up to 20MeV/A
- Achieve a high purity of the beam ($\Delta m/m \approx 10^{-4}$)

SPIRAL 1 upgrade : Method

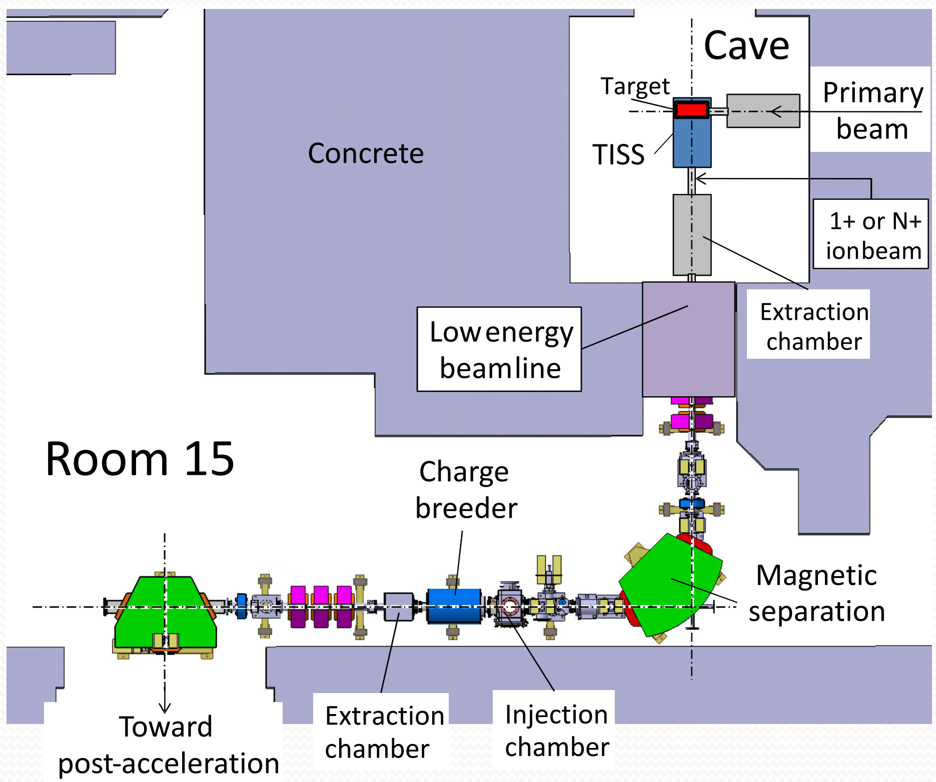
-Developing and operating new targets : shapes and materials

-Developing and operating new Ion sources (improve N+ one + New 1+ Ion Source)

-Operating a high performance charge breeder

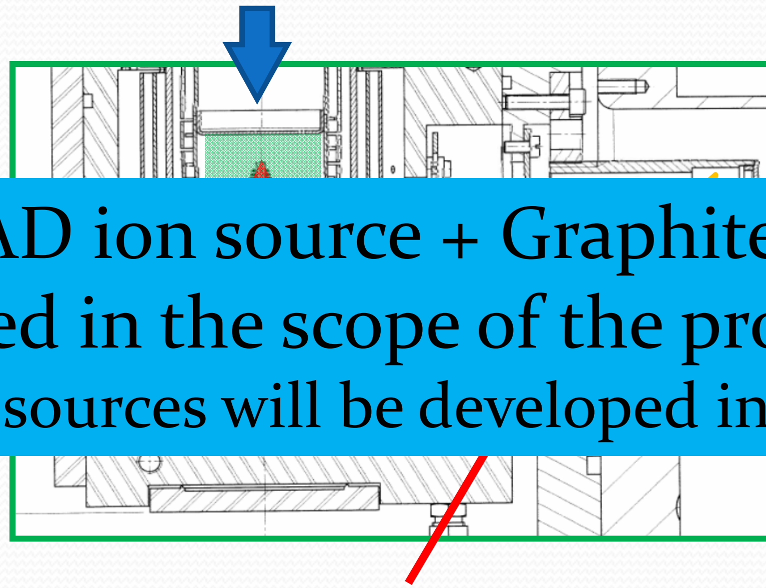
-Mass separating and accelerating the RIB with CIME cyclotron (K 265)

-Low energy beam with desir+HRS



SPIRAL 1 upgrade : Production

1 - Fragmentation projectile : Up to 6kW ➔ 95MeV/A on graphite target (current method)
2 - Fragmentation target : 3kW ^{12}C Primary Beam on to the target with A ≤ Nb
3 - Fusion – Evaporation : CSS1 ➔ Thin window

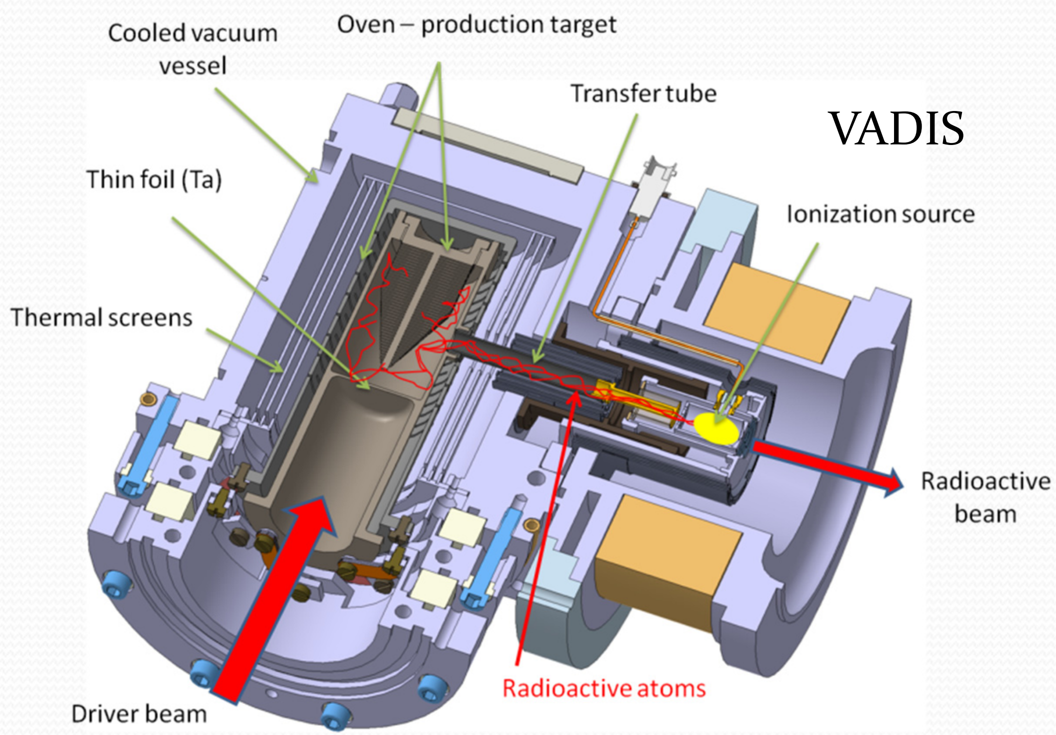


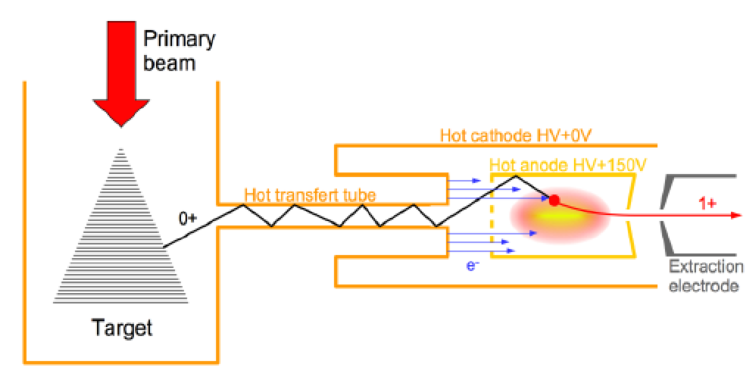
Only FEBIAD ion source + Graphite target is developed in the scope of the project…
But new ions sources will be developed in the future

Ion sources
- ECR 1+ or N+
- FEBIAD
- Surface ionization
- …

1+ FEBIAD source (type VADIS ISOLDE)

FEBIAD ion source development since 2011





- Non selective source : Mg, Ca, Sc, Cr, Mn, Co, Ni, Cu, Zn, Ga, Ce, As, Se, Al
- But no acceleration by CIME (Q/A too low)

FEBIAD: Forced Electron Beam Induced Arc Discharge

FEBIAD results with primary beam at nominal power

Metallic and non metallic beams

Isotope	Power (W)	Rate (pps)
21Na	984	3.00E+07
25Na	964	2.20E+07
23Mg	1299	1.33E+07
25Al	964	2.30E+04
28Al	981	1.55E+06
29Al	1301	1.40E+07
30Al	1287	4.40E+04
29P	1226	9.70E+03
30P	1287	4.20E+05
31Cl	1337	3.27E+03
32Cl	1024	6.50E+04
33Cl	1235	9.50E+06
37K	821	3.30E+07
38K	1214	6.40E+07
39Cl	1013	1.14E+04

Mostly >10^5 pps!

^{36}Ar@95AMeV, 1.5 kW

Noble gases

Isotope	Power (W)	Rate (pps)
23Ne	1299	2.20E+06
32Ar	891	5.50E+03
33Ar	1235	1.80E+05

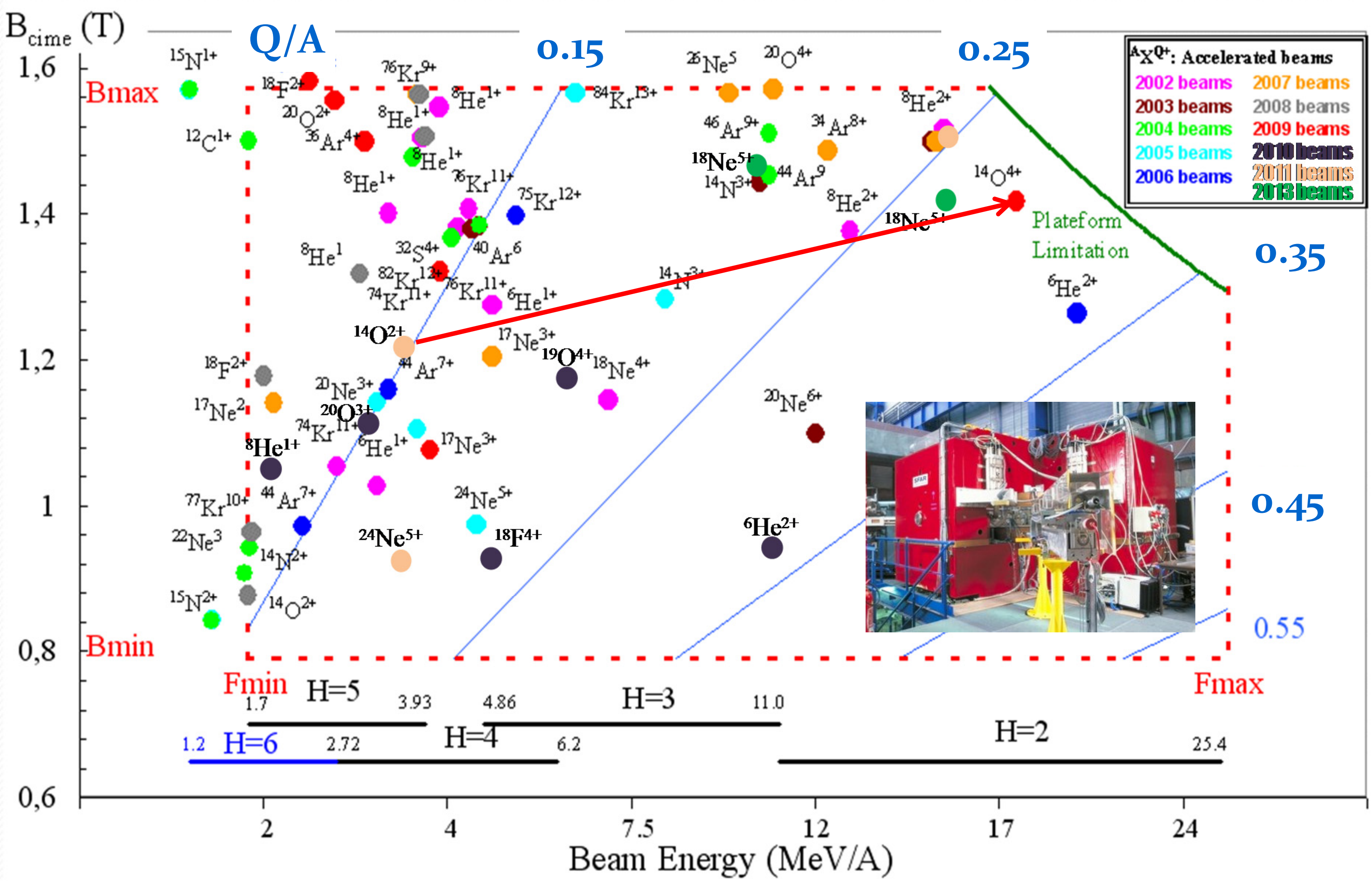
Molecules

Isotope	Power (W)	Rate (pps)
C17F	1226	4.60E+03
Be^{20}F	1385	2.50E+06
Be21F	1287	1.90E+05
Be33Cl	941	2.40E+05
H38mCl	1013	5.90E+02
H38Cl	1013	3.50E+03

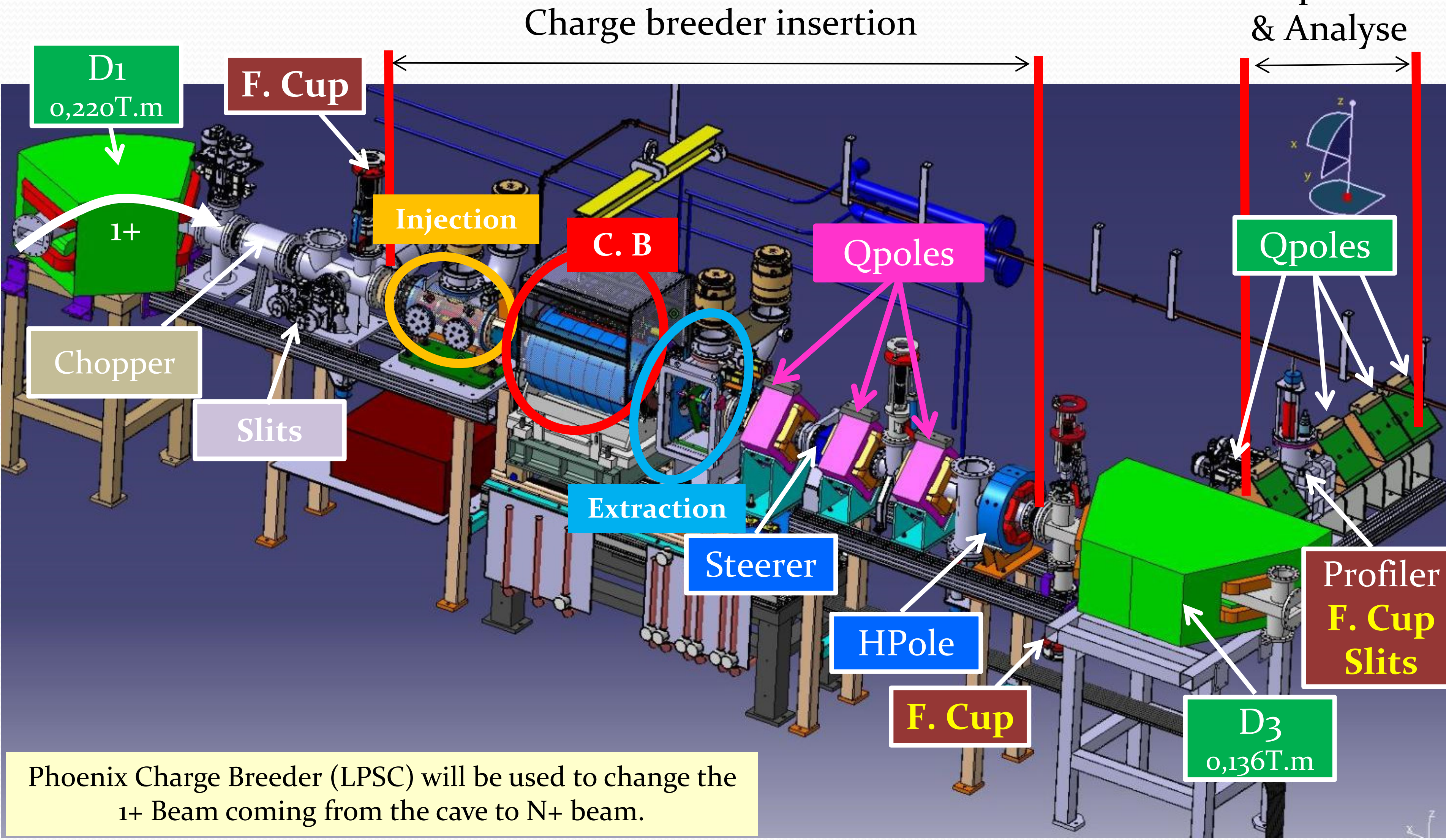
Results exhibiting with an efficiency less than expected by a factor of 4 :
Tests of New Version is in progress on SPIRAL 1 Tests Bench

P. Chauveau at al., submited to Nuclear Physics B

CIME : Post-accelerator requirements

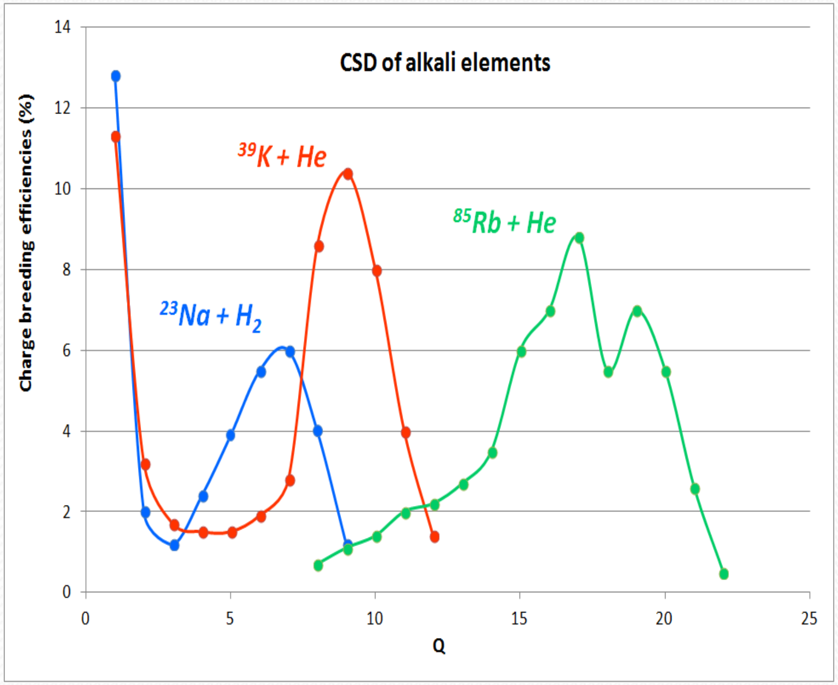


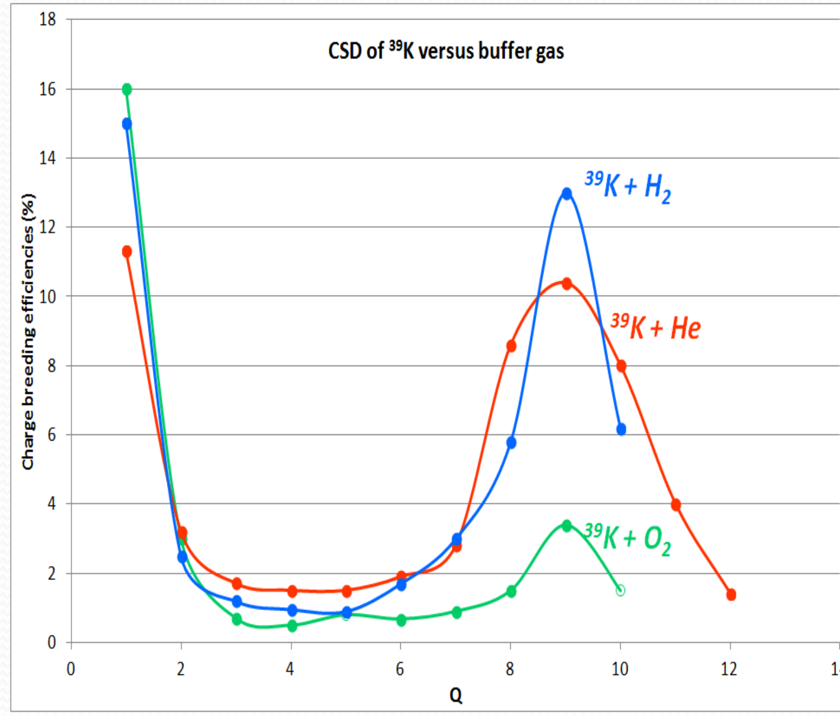
Charge Breeder Integration



Phoenix Charge Breeder (LPSC) will be used to change the 1+ Beam coming from the cave to N+ beam.

Charge state distributions of alkali elements





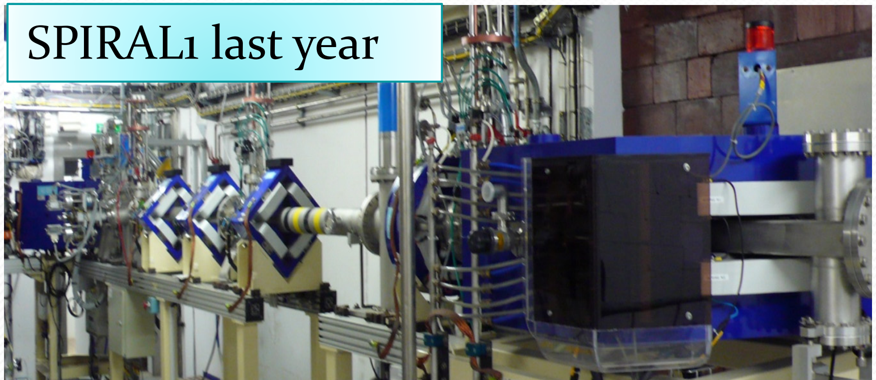
Mesurements done at LPSC

- Heavier is the element wider is the distribution
- Lighter is the buffer gas, higher is the maximum charge breeding efficiency of the ^{39}K and narrower is the CSD

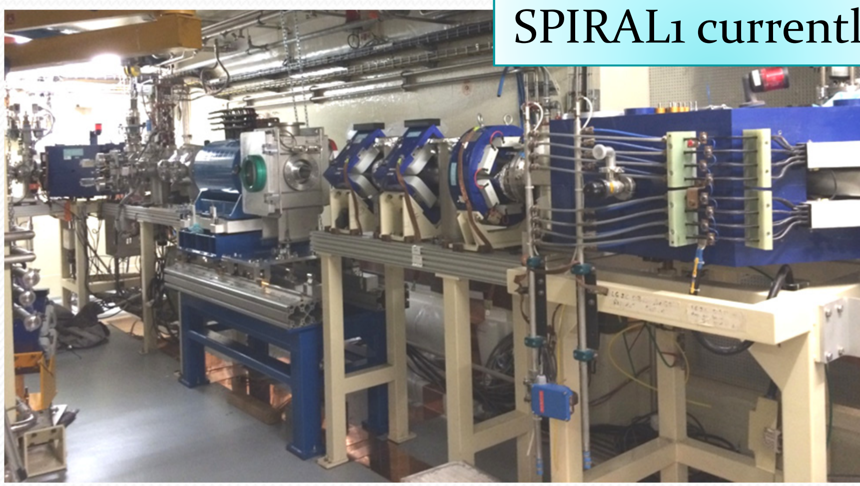
L. Maunoury et al., submitted to Rev. sci. Instr

Status and commissionning

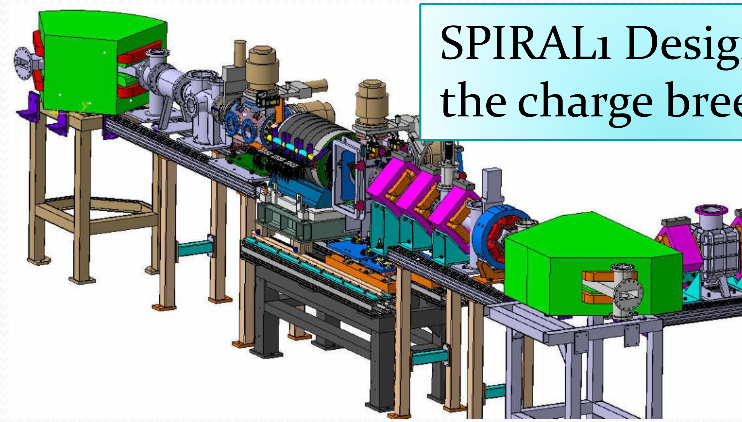
SPIRAL1 last year



SPIRAL1 currently



SPIRAL1 Design with the charge breeder



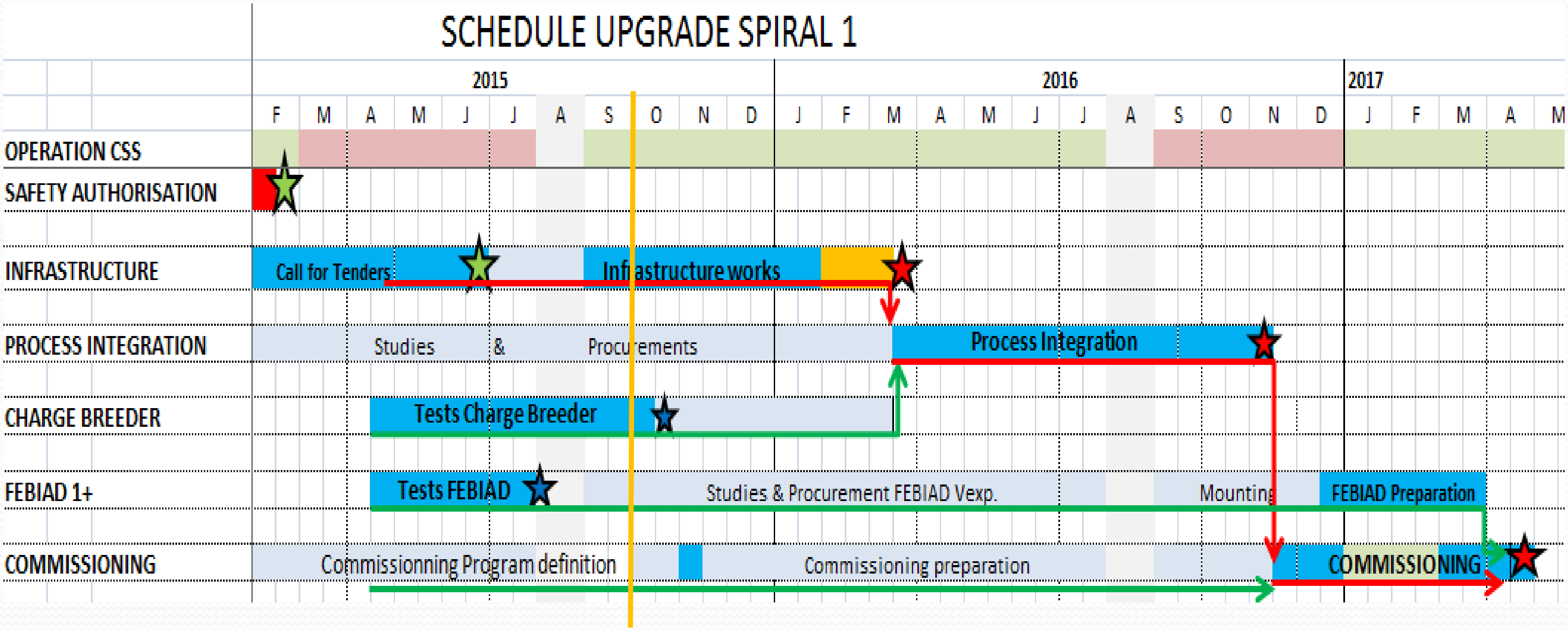
Day 1 RIB

Post-accelerated beams

^{38m}K 9 A.MeV Coulomb excitation experiment

^{17}F 7 A.MeV ACtive TARget (ACTAR) experiment

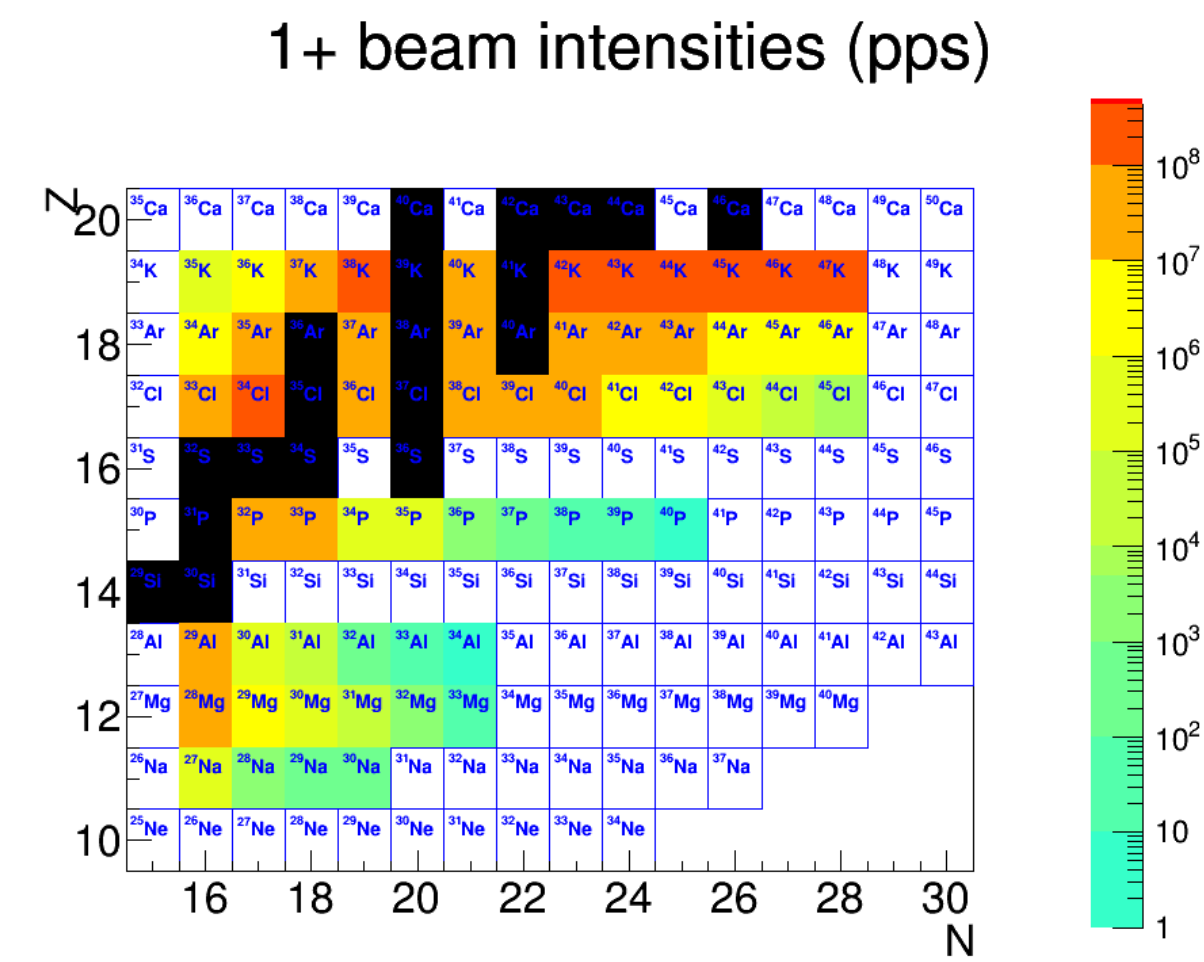
Schedule and organization



In 2017 : New RIBs availabe at GANIL, especially for the AGATA campaign.

Thank you for your attention

Status and commissionning



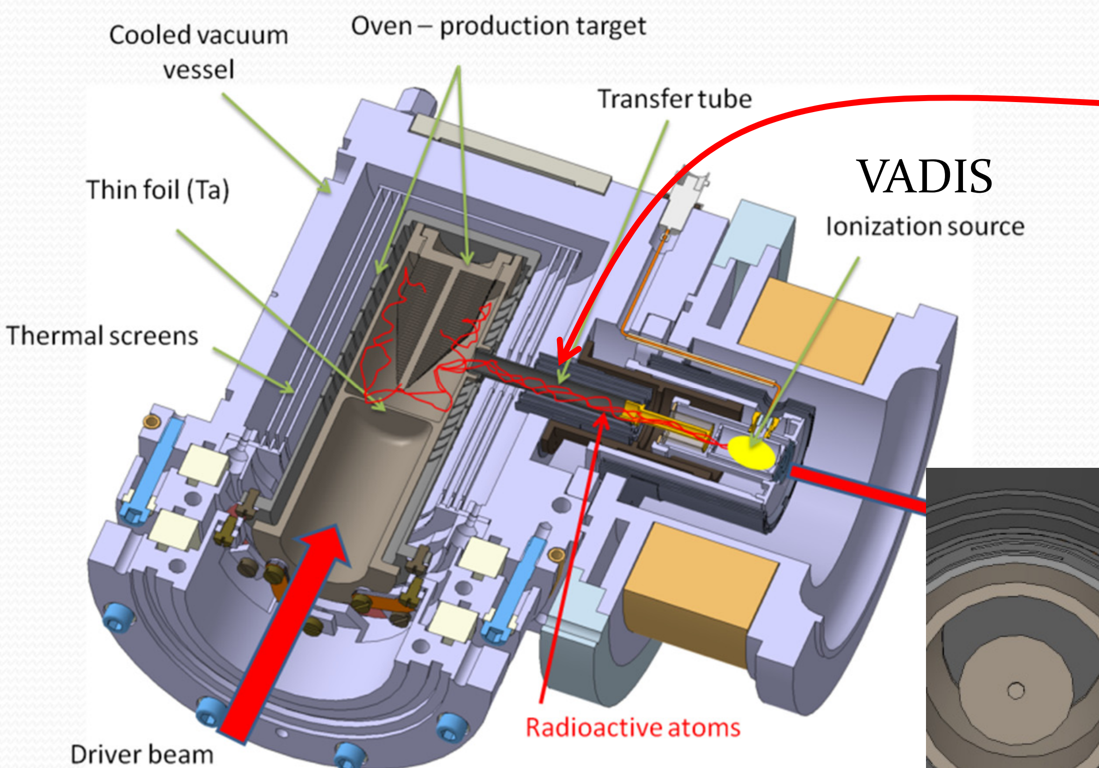
Post-accelerated beams

^{38m}K 9 A.MeV Coulomb excitation experiment

^{17}F 7 A.MeV ACtive TARget (ACTAR) experiment

1+ FEBIAD source (type VADIS ISOLDE)

FEBIAD ion source development since 2011

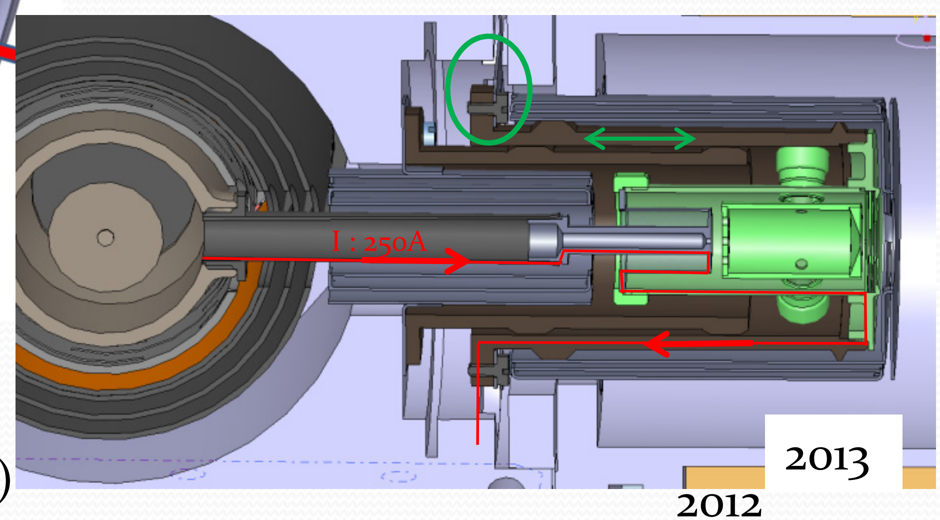


Main difficulty to overcome :
Thermal expansion of the transfer tube

Transfer tube length :

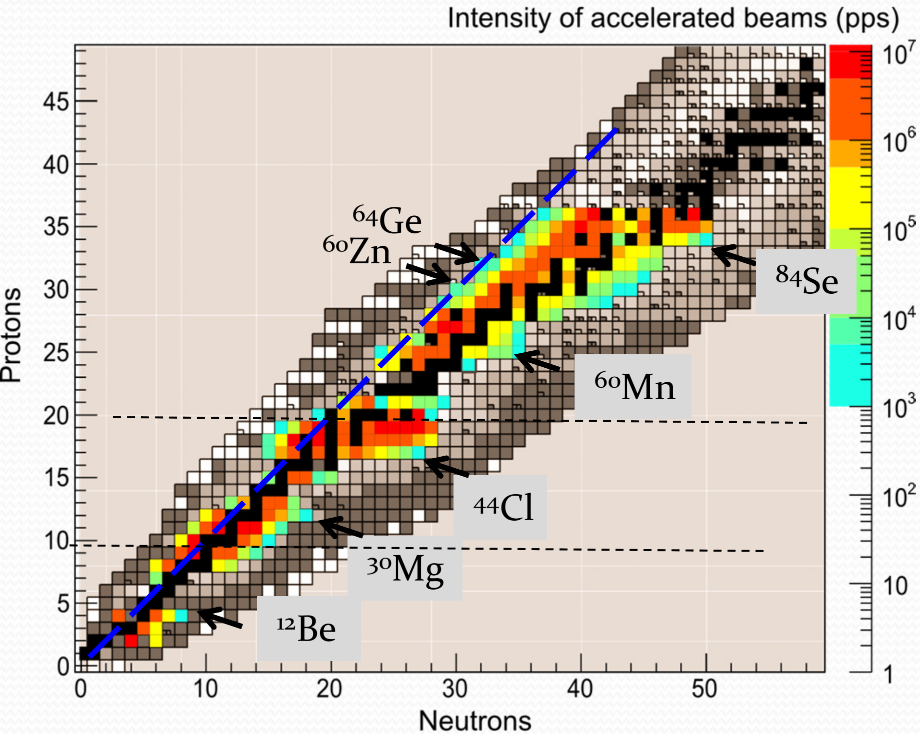
- 20° : 62.5mm
- 2000° : 62,5 + ***1.5mm***

Need to develop a system having a translation movement while conserving a good electrical contact (~250A)

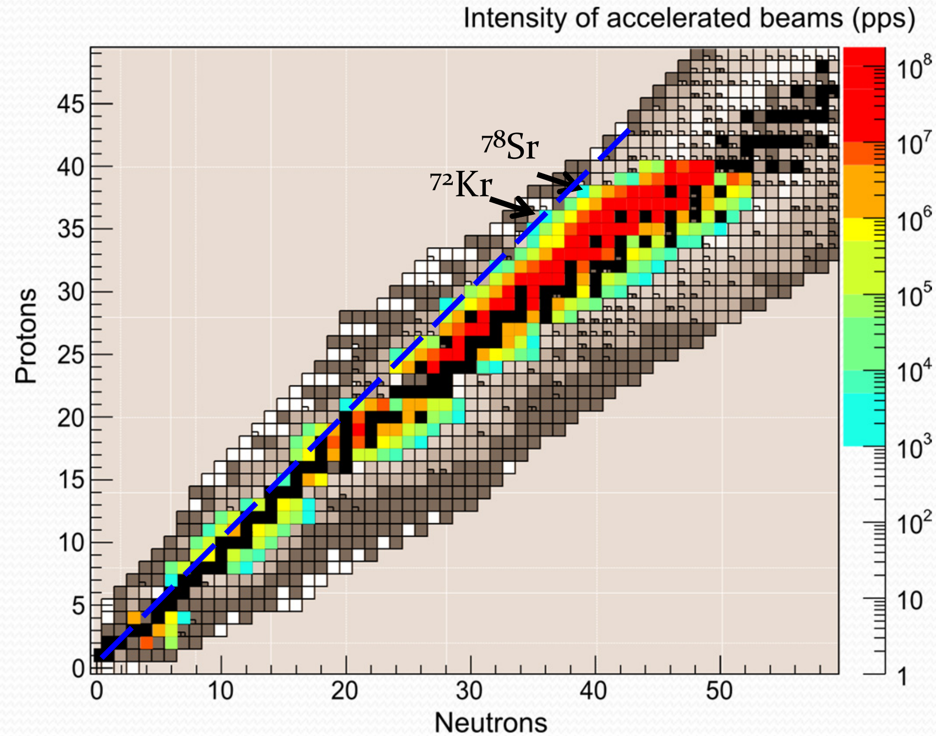


- Non selective source : Mg, Ca, Sc, Cr, Mn, Co, Ni, Cu, Zn, Ga, Ce, As, Se, Al
- But no acceleration by CIME (Q/A too low)

FEBIAD: Forced Electron Beam Induced Arc Discharge



SPIRAL: Expected production from 12C target



SPIRAL: Expected production from Nb target

Best accelerated intensities from fragmentation of 1.2kW when available of ^{13}C, ^{16}O, ^{18}O, ^{20}Ne, ^{22}Ne, ^{24}Mg, ^{26}Mg, ^{36}Ar, ^{36}S, ^{40}Ca (800W), ^{48}Ca (700W), ^{58}Ni (700W), ^{78}Kr, ^{86}Kr (800W) at maximum energy. A threshold has been set at 10^3 pps. 3kW targets could be eventually used for some beams where such power is attainable (intensities not depicted here).

Exemple: ^{62,63}Ga: 3.6 kW 12C+Nb: factor 6 /1.2 Kw 78Kr+C

The safty rules regulating the chose of primary beam-target combination.

Ion	A/Q	Buffer gaz	Charge Breeding Efficiency (%)	ΔV (V)	FWHM ΔV (V)	Charge Breeding Time (ms / q)
$^{23}Na^{8+}$	2.88	He	5.3	-6.5		
$^{23}Na^{7+}$	3.29	H_2	6.0	-5.3	3.7	7.4
$^{40}Ar^{11+}$	3.64	O_2	12.9	-60.0		9.8
$^{39}K^{10+}$	3.90	He	8.0	-5.5		
$^{39}K^{9+}$	4.33	H_2	13.0	-8.5	8.6	13.0
$^{39}K^{9+}$	4.33	He	11.7	-5.5	6.5	3.9
$^{85}Rb^{19+}$	4.47	He	8.4	-5.3	7.8	15.8
$^{40}Ar^{8+}$	5.00	He	18.9	-70.0		10.9
$^{86}Kr^{15+}$	5.73	O_2	8.30	-40.0		3.4

L. Maunoury et al., submitted to Rev. sci. Instr

		SPIRAL1		SPES		CARIBU		LPSC		ISOLDE	
Ion	A/Q	Efficiency (%)	Charge Breeding Time (ms / q)	Efficiency (%)	Charge Breeding Time (ms / q)	Efficiency (%)	Charge Breeding Time (ms / q)	Efficiency (%)	Charge Breeding Time (ms / q)	Efficiency (%)	Charge Breeding Time (ms / q)
$^{23}Na^{8+}$	2.88	**5.3**				**8.6**					
$^{23}Na^{7+}$	3.29	**6.0**	*7.4*			**10.1**					
$^{40}Ar^{11+}$	3.64	**12.9**	*9.8*								
$^{23}Na^{6+}$	3.83							**3.7**	*6.0*		
$^{39}K^{10+}$	3.90	**8.0**				**17.9**	*15.7*			**1.7**	*10*
$^{39}K^{9+}$	4.33	**13**	*13.0*			**15.6**	*16.7*				
$^{39}K^{9+}$	4.33	**11.7**	*3.9*								
$^{85}Rb^{19+}$	4.68	**8.4**	*15.8*	**7.8**	*28.2*	**13.7**	*77.9*				
$^{85}Rb^{19+}$	4.68					**12.9**	*12.1*				
$^{84}Kr^{17+}$	4.94					**15.6**					
$^{40}Ar^{8+}$	5.00	**18.9**	*10.9*	**15.2**	*9.1*			**16.2**	*9.8*	**13.5**	
$^{84}Kr^{15+}$	5.60					**10.7**				**4.0**	
$^{85}Rb^{17+}$	5.67					**11.5**	*10.6*	**7.5**	*13.3*		
$^{86}Kr^{15+}$	5.73	**8.3**	*3.4*								

L. Maunoury et al., submitted to Rev. sci. Instr