GANIL OPERATION STATUS, UPGRADE OF SPIRAL1 and SPIRAL2

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

ECPM 2017
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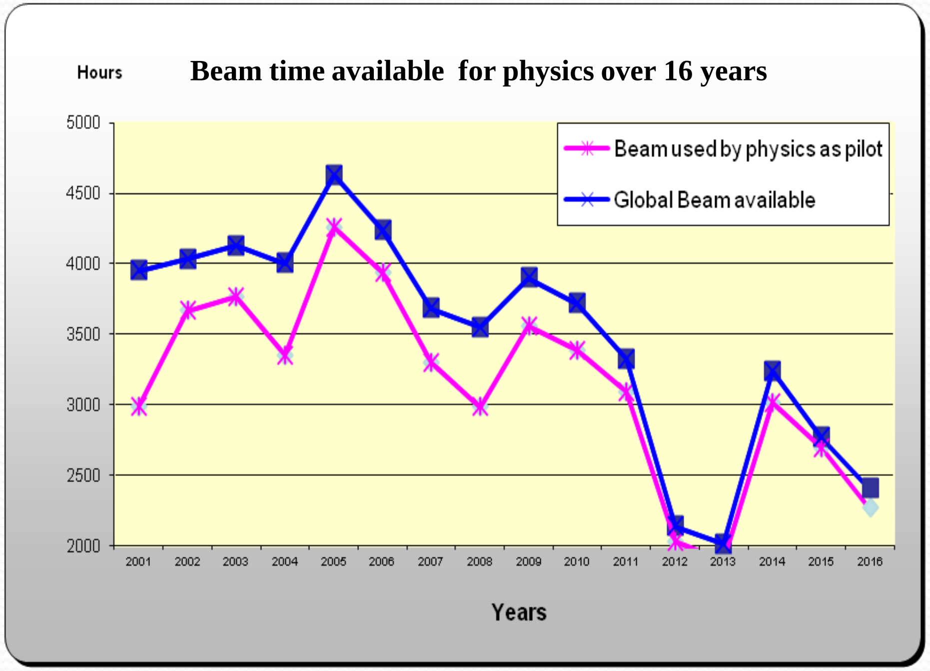
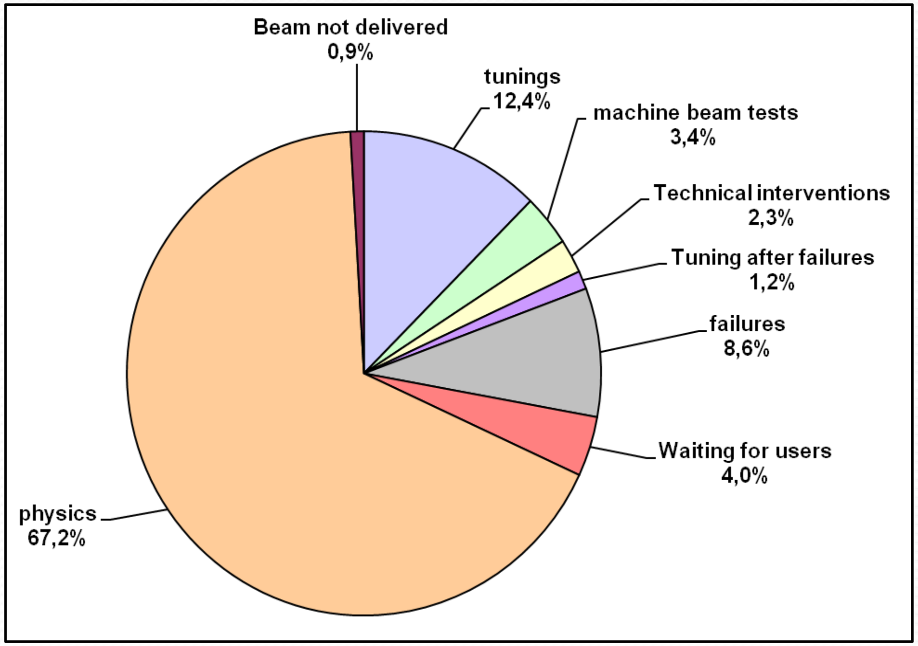
Legnaro

OUTLINE

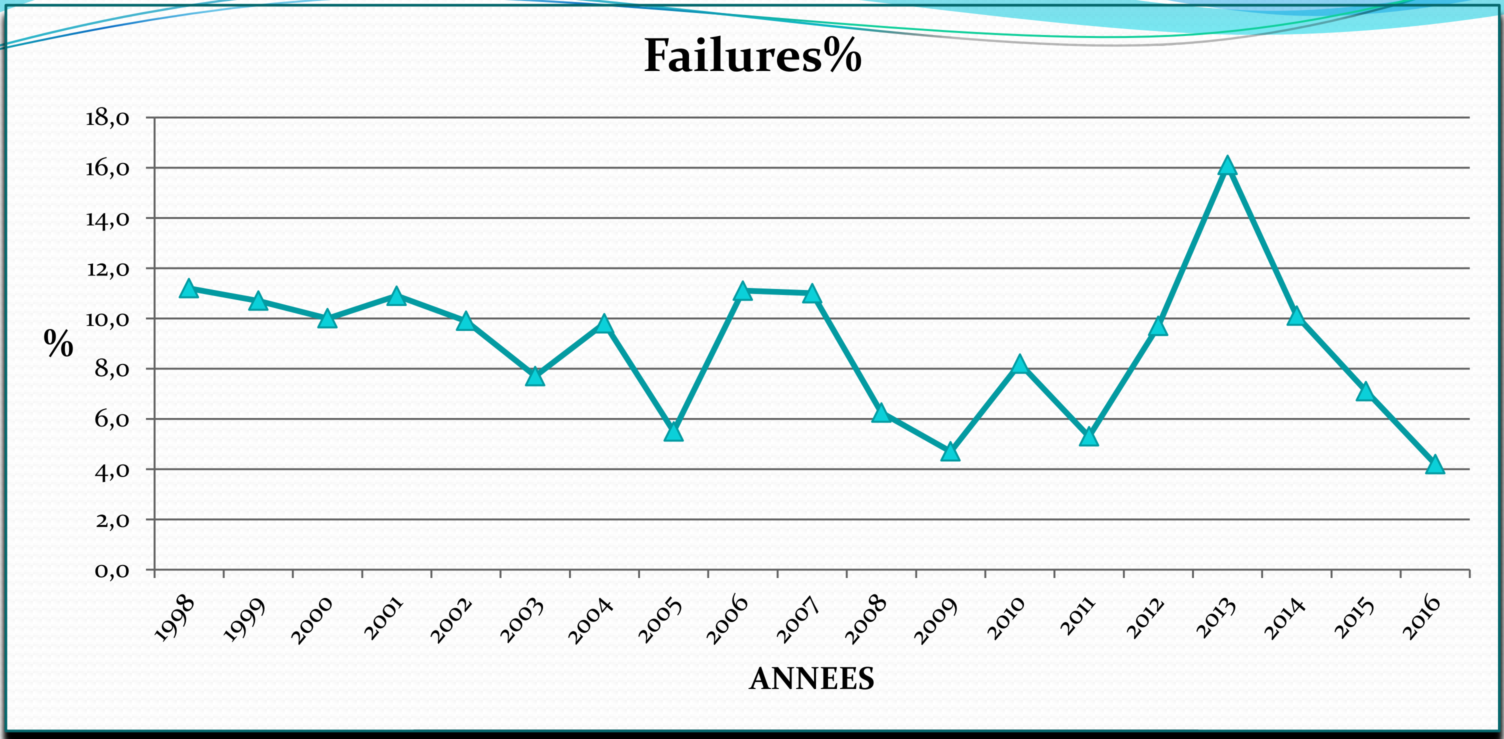
- Running statistic
- Water Leak issues
- Operating modes at GANIL
  - Beam Intensity
  - Spiral 1 (ECR source,...)
- SPIRAL 1 UPGRADE
  - Production Method
  - 1+FEBIAD source
  - Charge breeder
  - Schedule and organization.
- SPIRAL 2 accelerator

Running statistic From 2001 to 2016

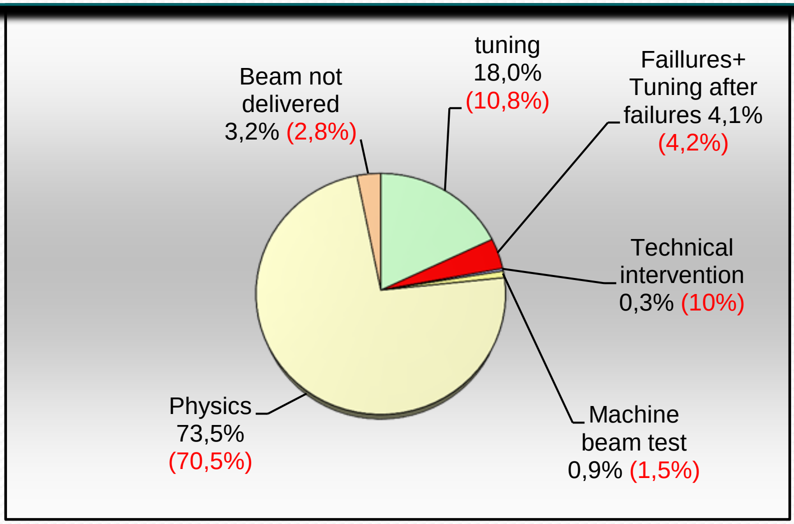




Failures

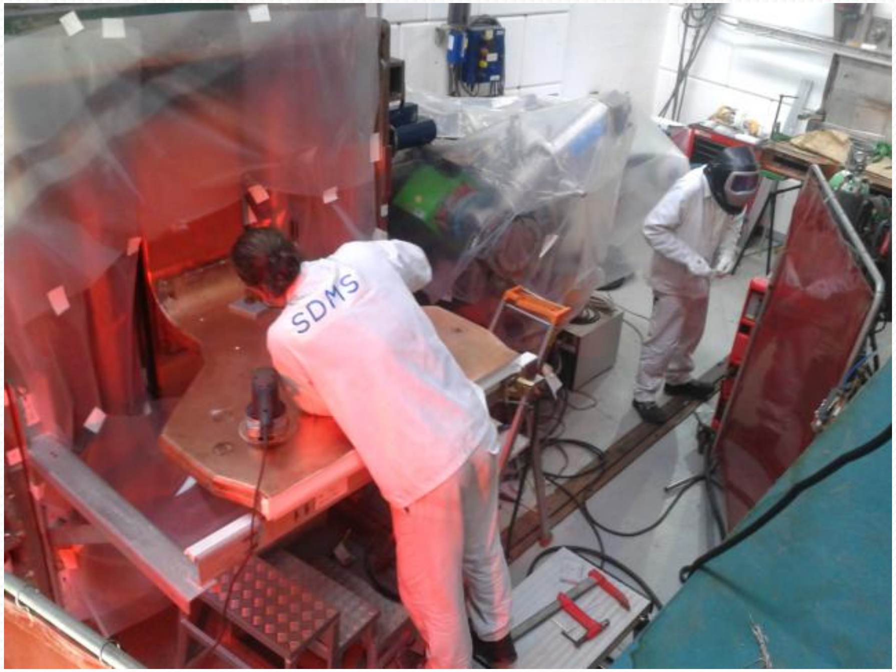


Failures%
18,0
16,0
14,0
12,0
10,0
8,0
6,0
4,0
2,0
0,0
%
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
ANNEES



Beam not delivered 3,2% (2,8%)
tuning 18,0% (10,8%)
Faillures+ Tuning after failures 4,1% (4,2%)
Technical intervention 0,3% (10%)
Machine beam test 0,9% (1,5%)
Physics 73,5% (70,5%)

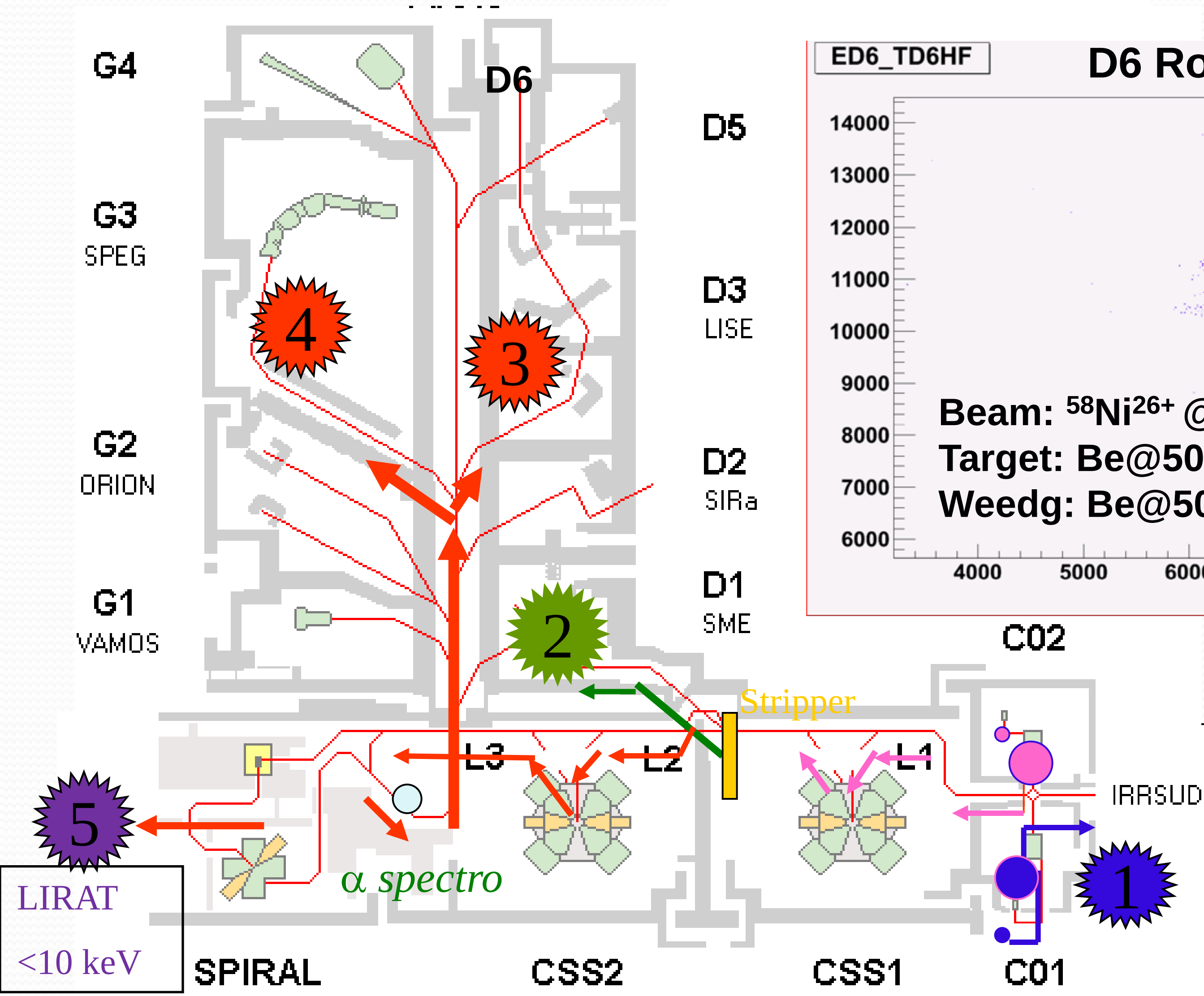
Water leak problems

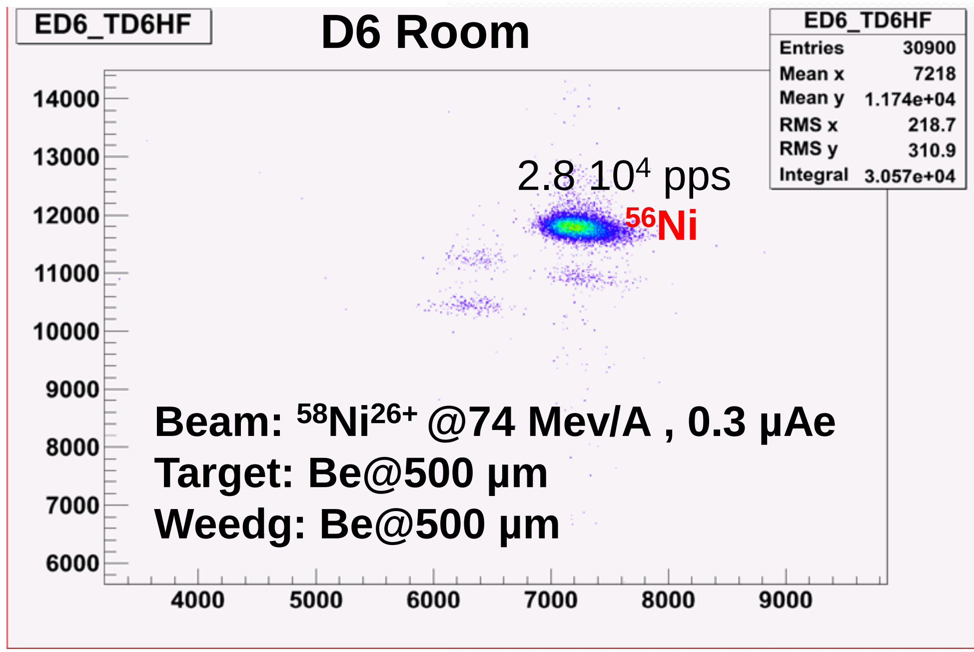


C01 cavity

The C01 cavity is repaired

Operating Mode at GANIL





IRRSUD: low energy beam irradiation line

[0.3, 1.0] MeV/u

1

Intense Primary beams

2.10[13] pps Safety limitation reached

Possible improvement

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	

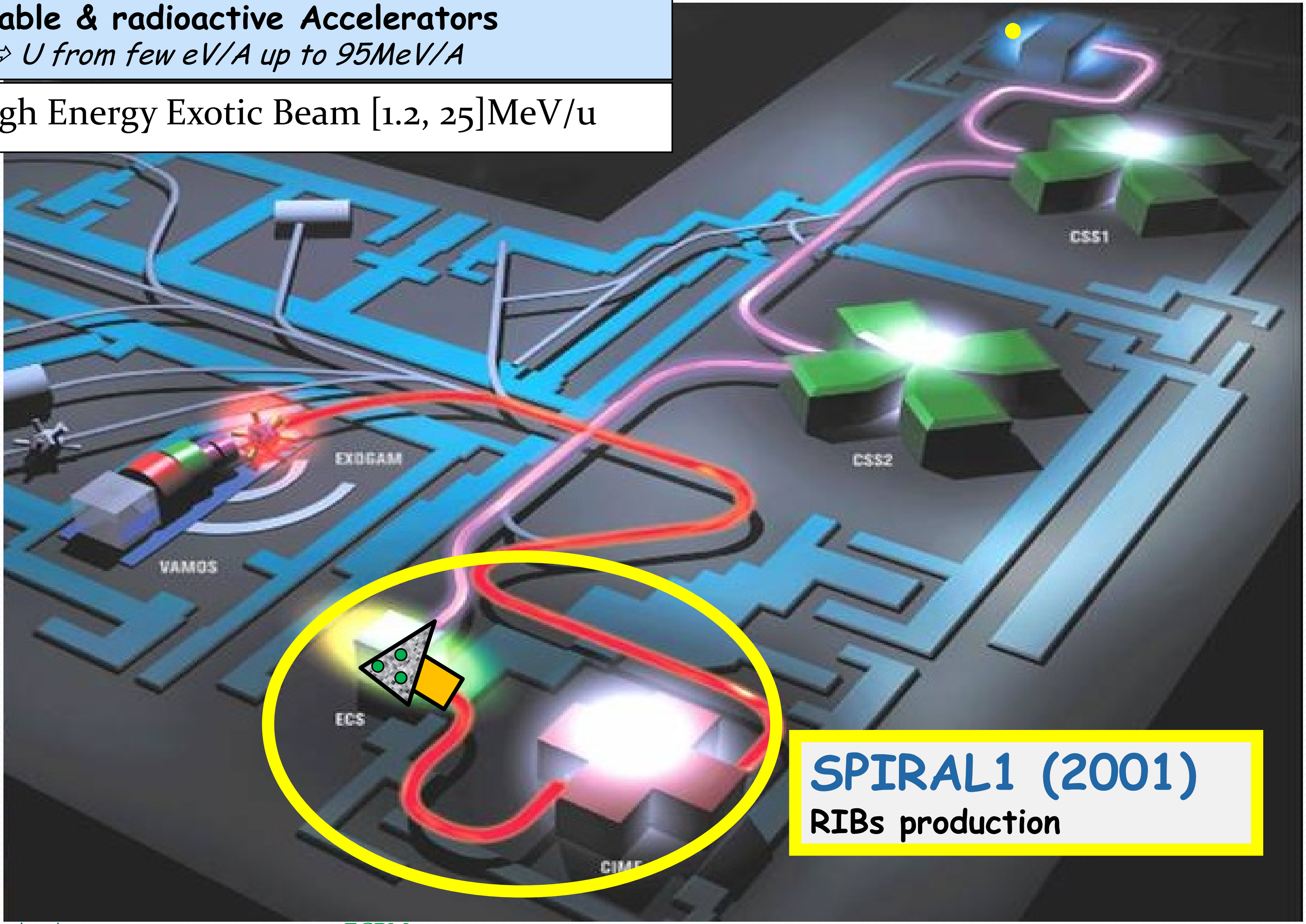
Frequency shift of C01 and CSS1 with BR constant

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}	$<10^{8}$

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

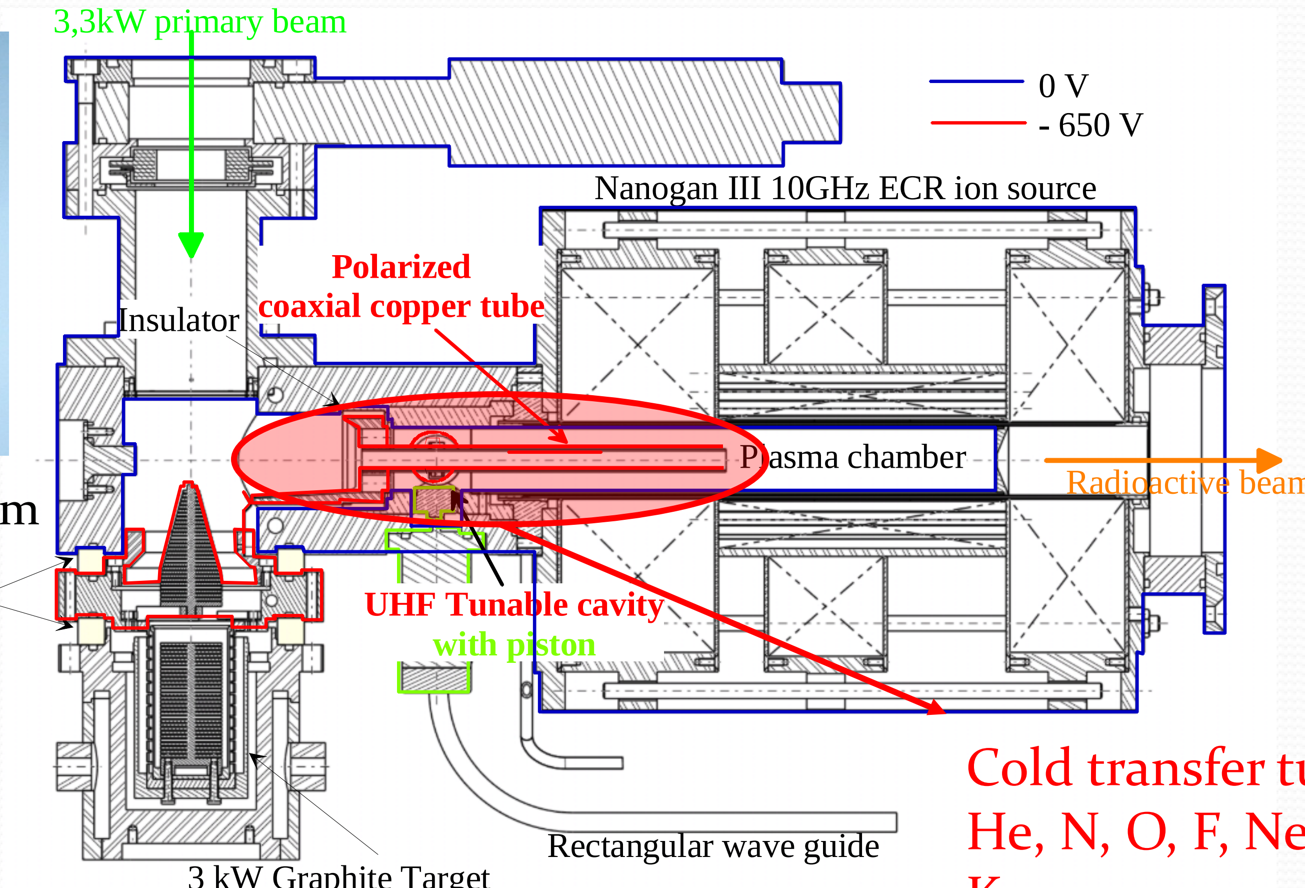


SPIRAL1 (2001)
RIBs production

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

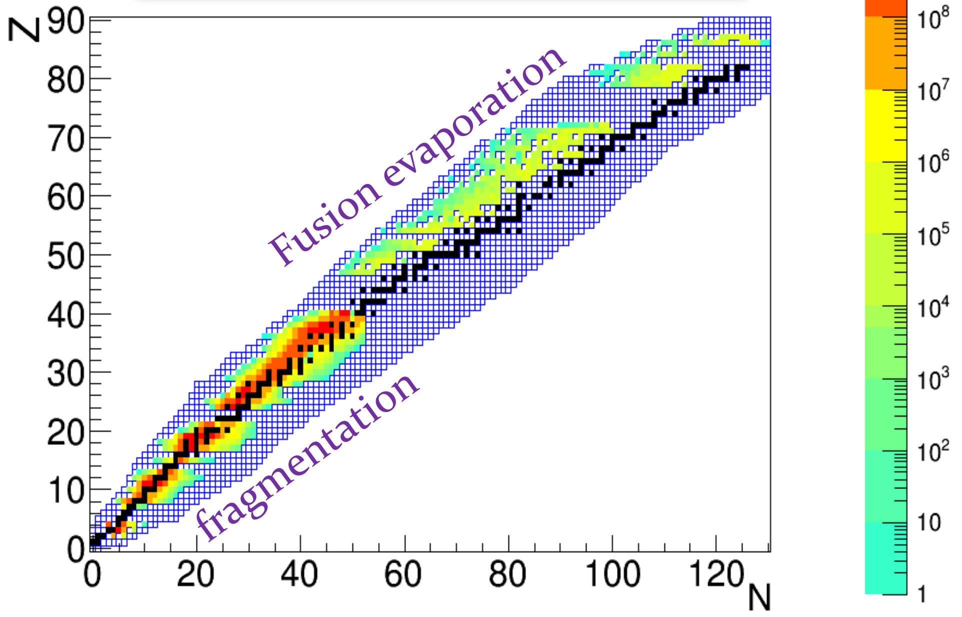
To the cost of universality

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 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

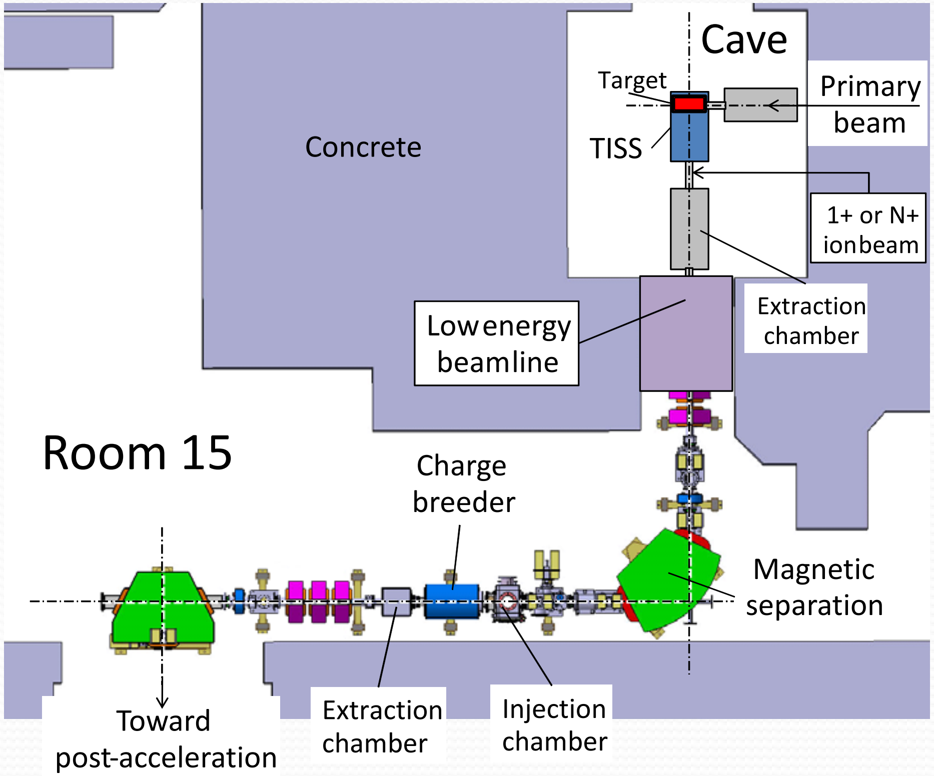
-Developing and operating new targets : shapes and materials

-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

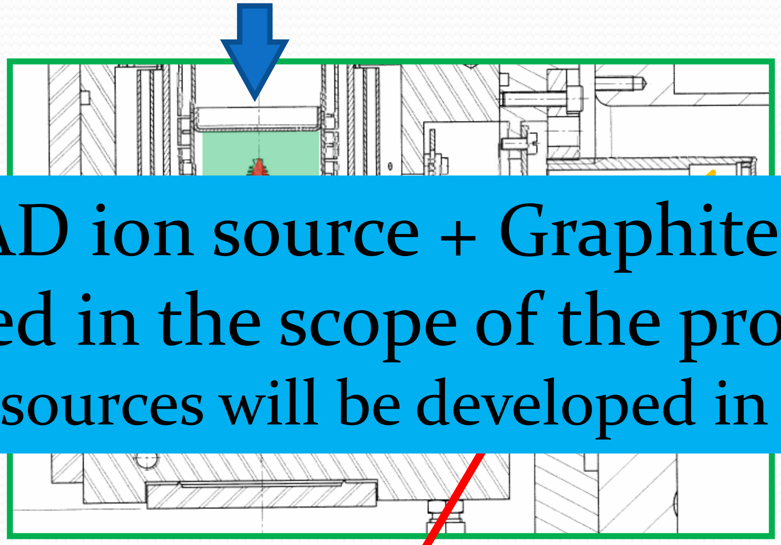


SPIRAL 1 upgrade : Production

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…

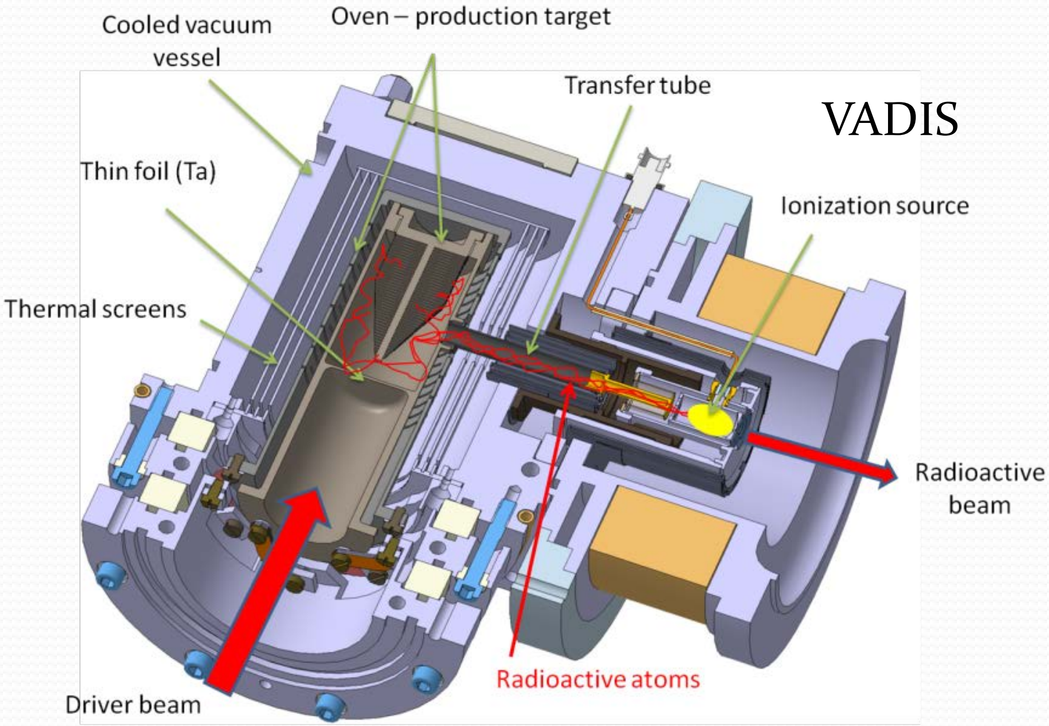
But new ions sources will be developed in the future

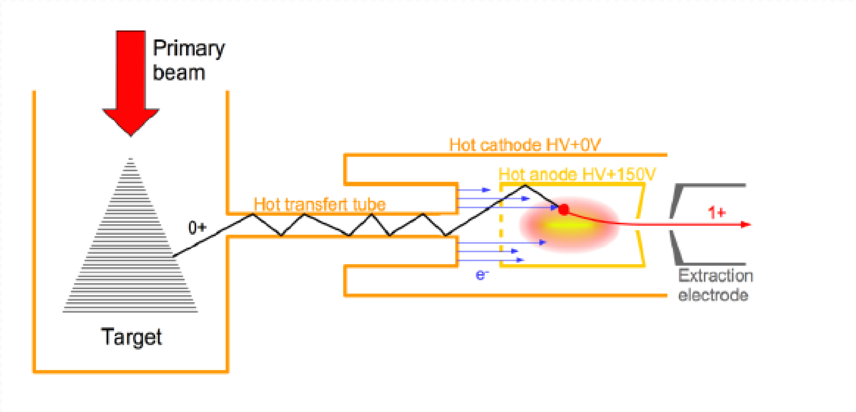
Ion sources

- 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

^{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

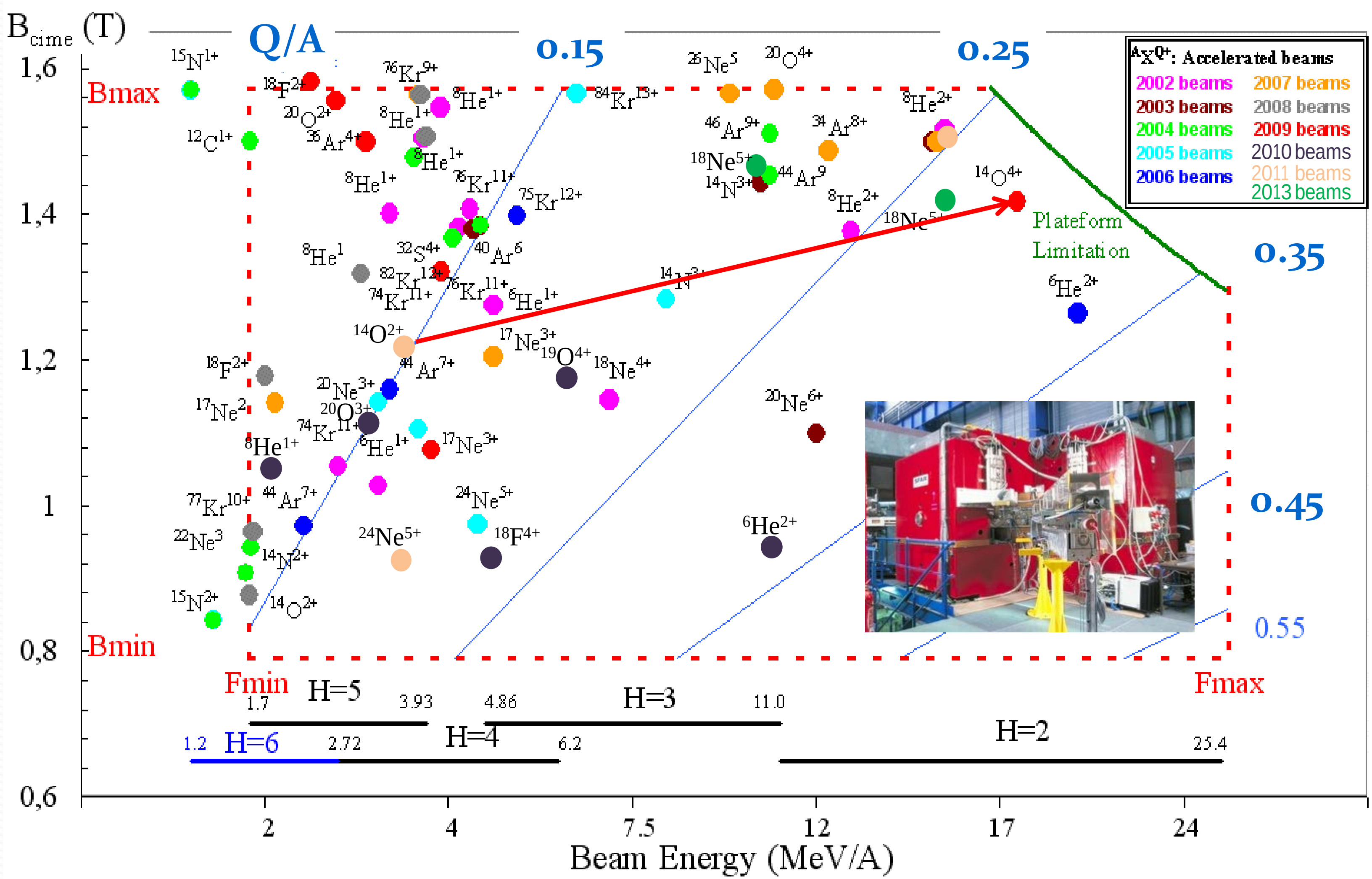
Molecules

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

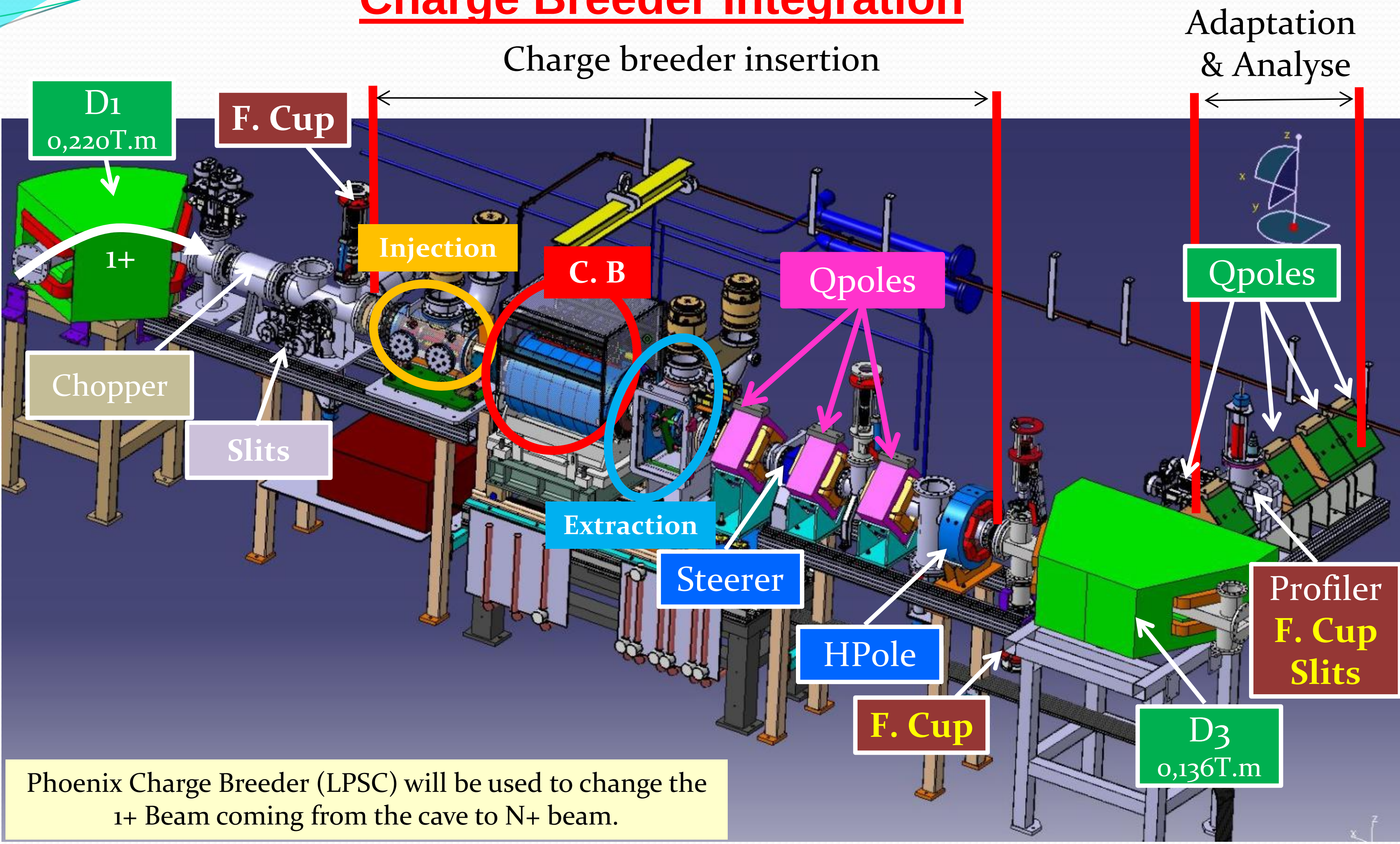
Mostly >10^5 pps!

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

CIME : Post-accelerator requirements



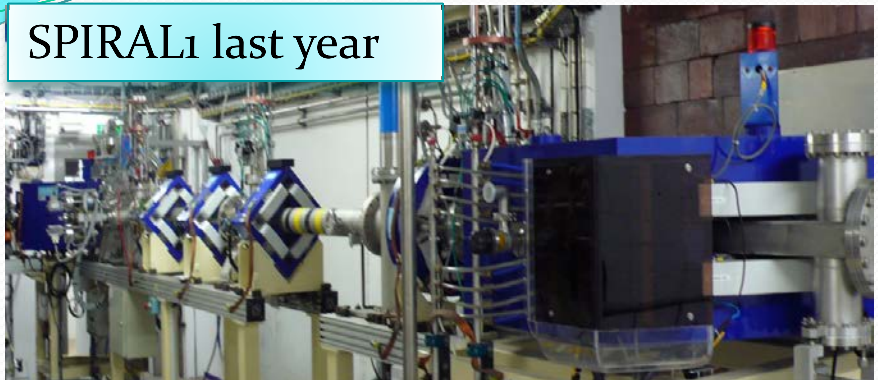
Charge Breeder Integration



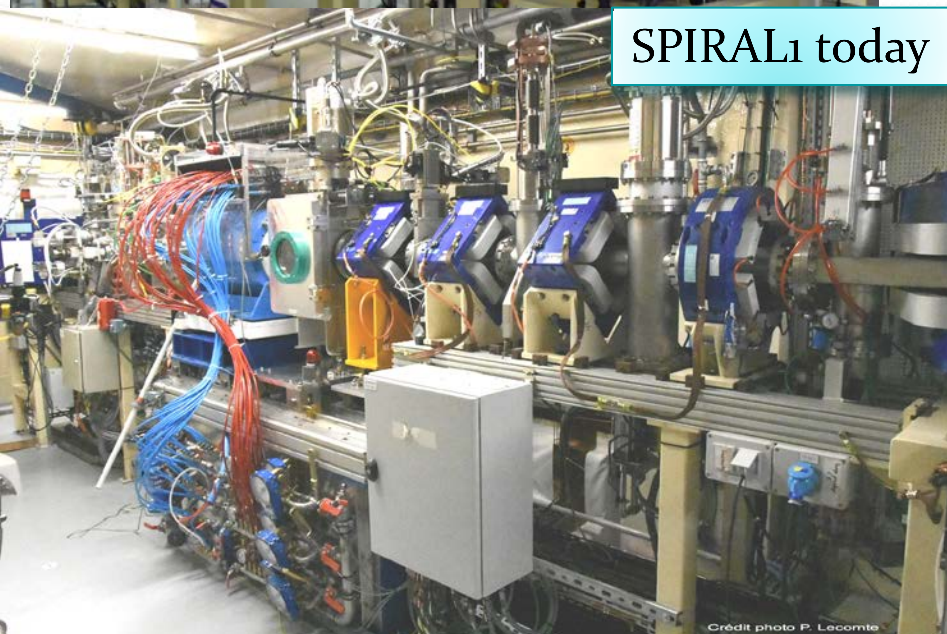
Phoenix Charge Breeder (LPSC) will be used to change the 1+ Beam coming from the cave to N+ beam.

Status and commissionning

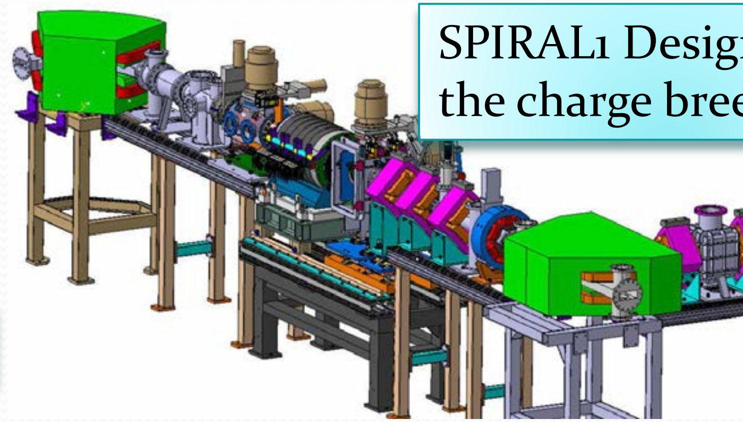
SPIRAL1 last year



SPIRAL1 today



SPIRAL1 Design with the charge breeder



Upgrade SPIRAL 1 : start of commissionning with stable
1/06/2017 :first beam from the charge breeder ($^{40}Ar^{9+}$)

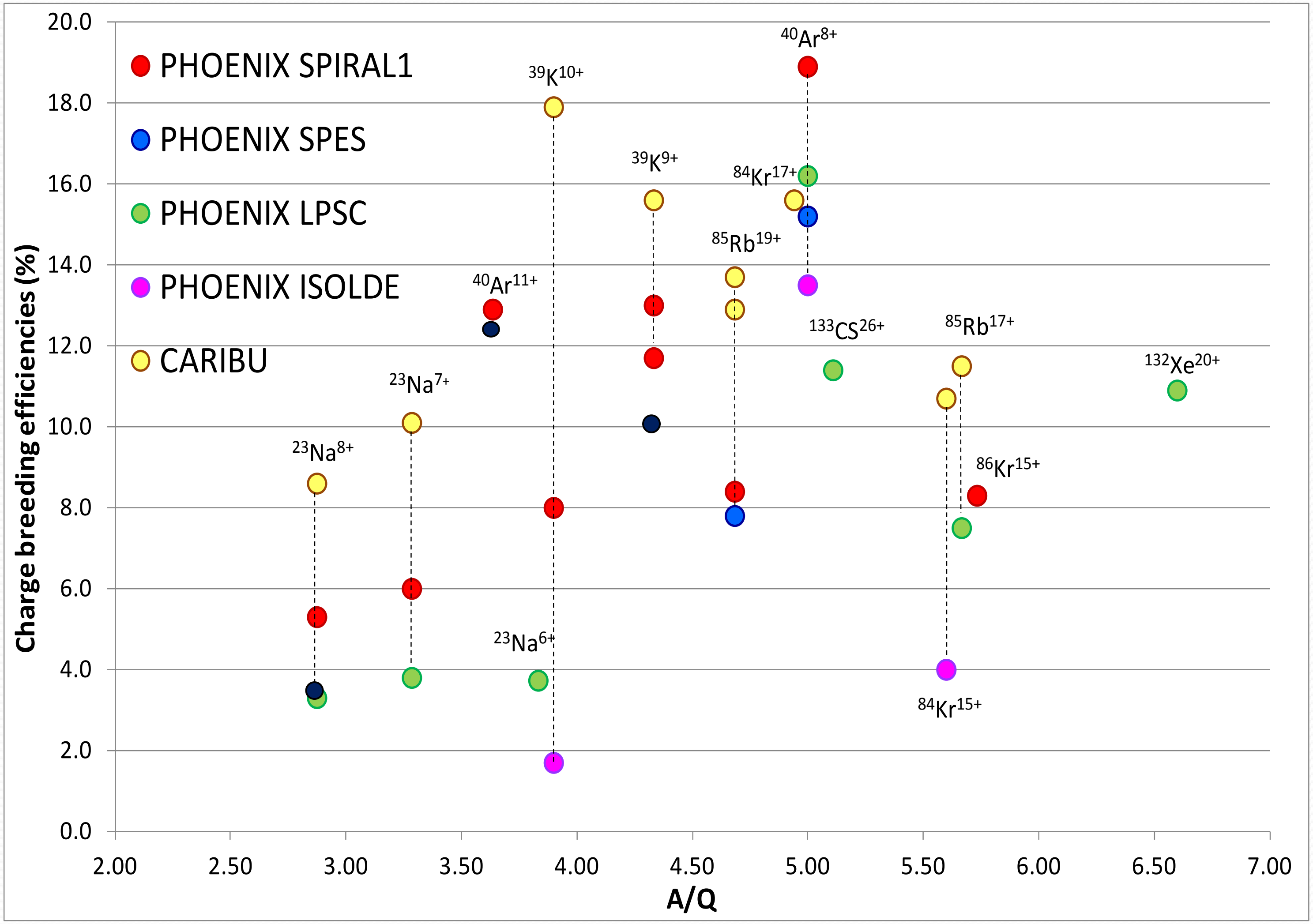
Day 1 RIB

Post-accelerated beams

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

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

Charge breeding efficiencies (%)

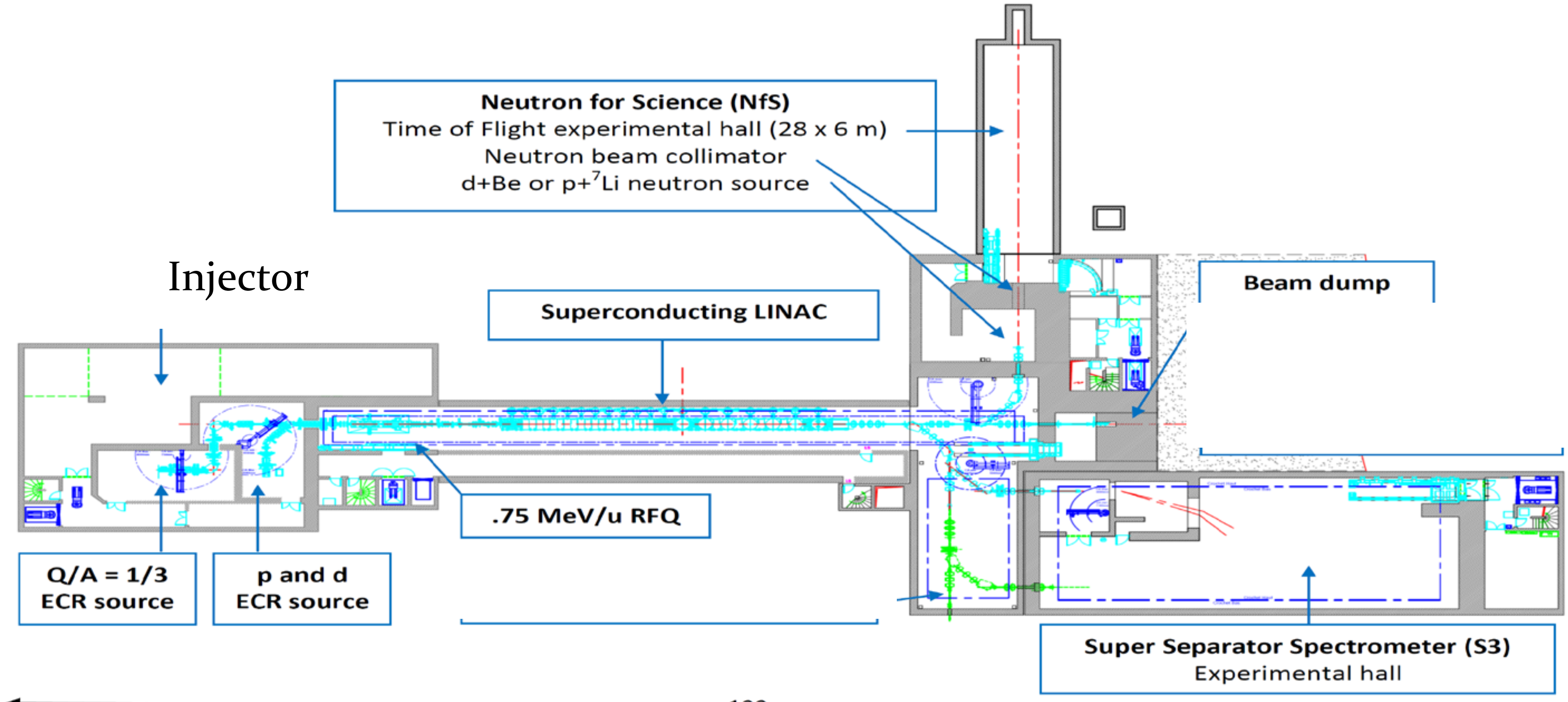


Schedule and organization

Obtention autorisation SSR

Tests avec faisceaux

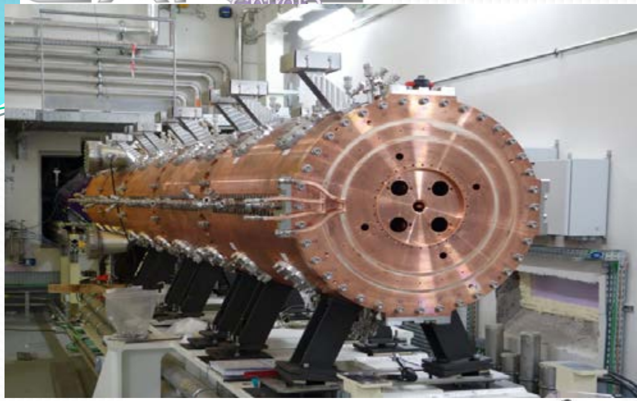
SPIRAL2

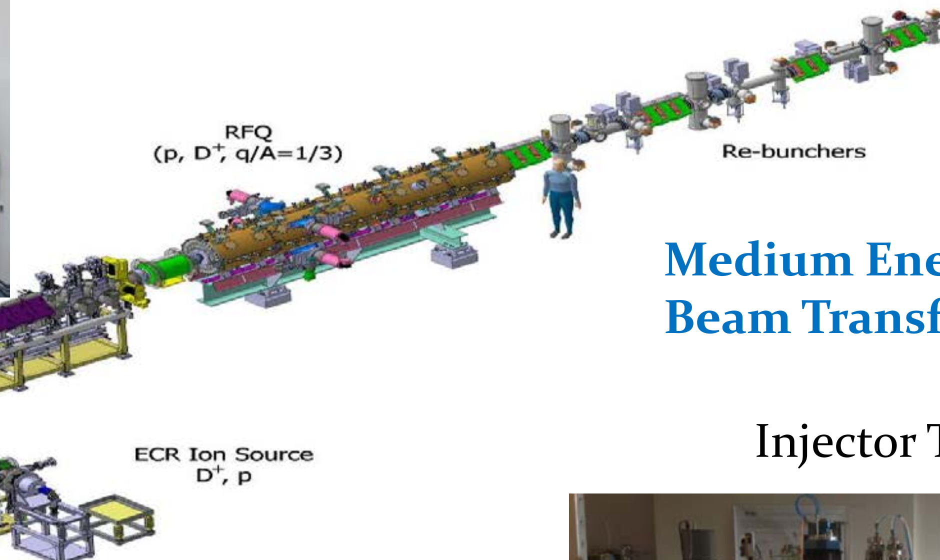
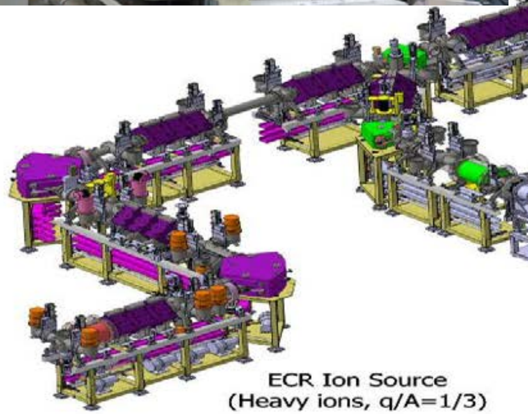


	Q/A	I max (mA)	Energy (MeV/n)	CW max beam power (kW)
P	1/1	5	2 - 33	165
He	*2/3*	*1*	*2-2 4*	*36*
D	1/2	5	2 - 20	200
Ions	1/3	1	2 - 14.5	45

JM Lagniel et al, proceedings of the 13th Heavy Ion Accelerator Technology Conference, Yokohama, September 7-11, 2015

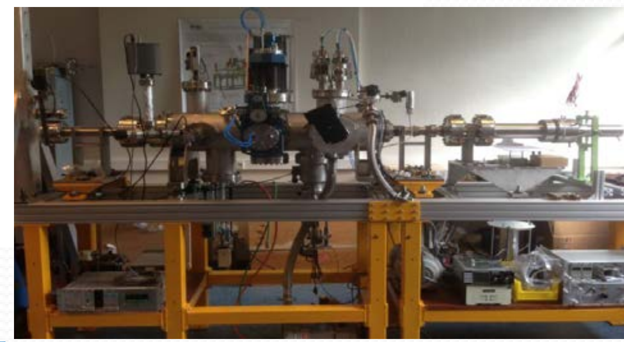
Injector



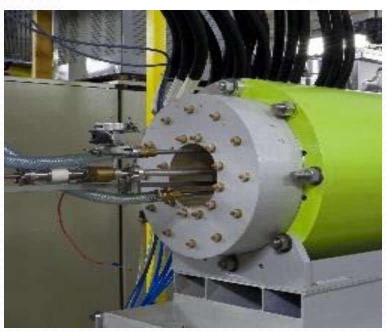



Medium Energy Beam Transfer Line

Injector Test Bench



2.45 GHz 40 kV IRFU Saclay



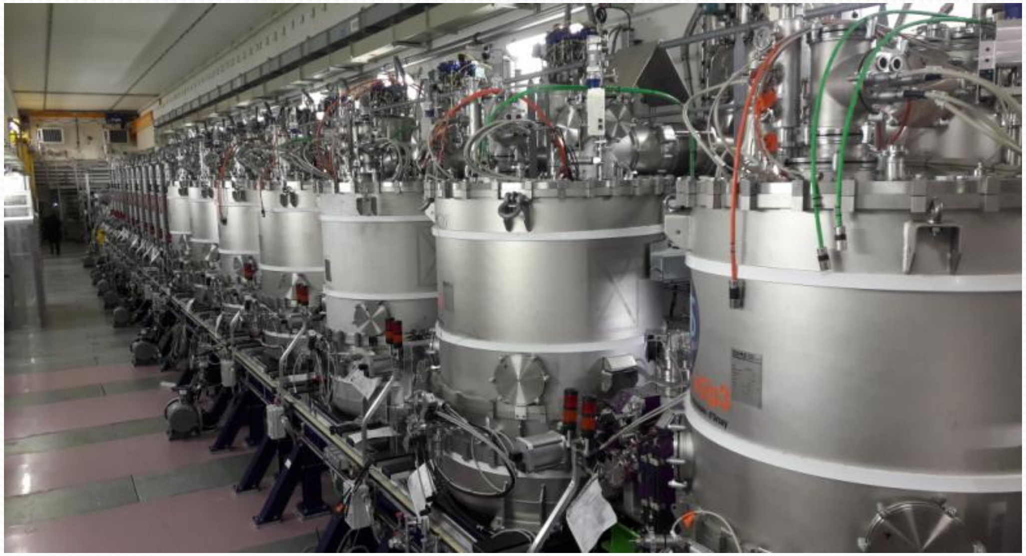
18 GHz 60 kV
LPSC Grenoble

SPIRAL 2 accelerator

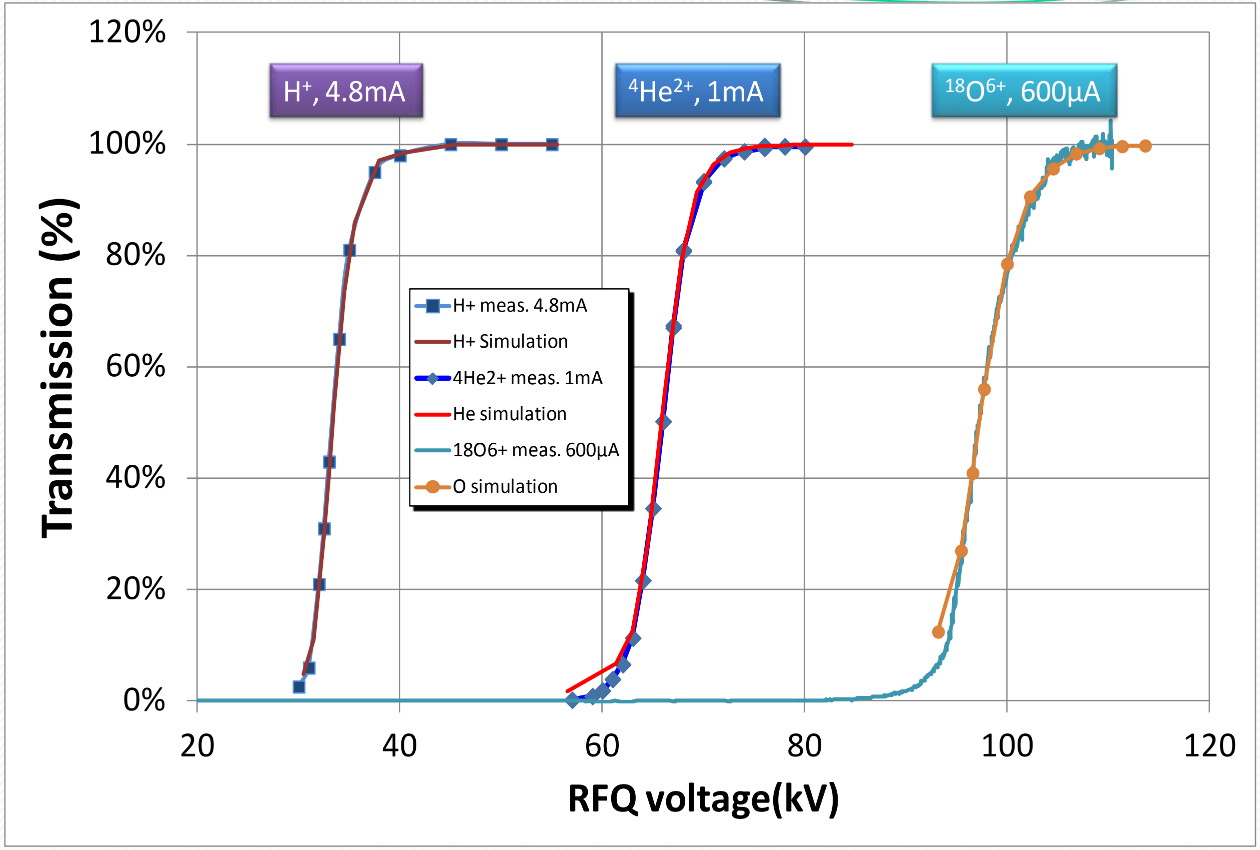
Cryomodules in the linac tunnel

= > all elements of LINAC accelerator are installed (janvier 2017)

• 19 cryomodules
• 20 haute sections



RFQ beam commissioning

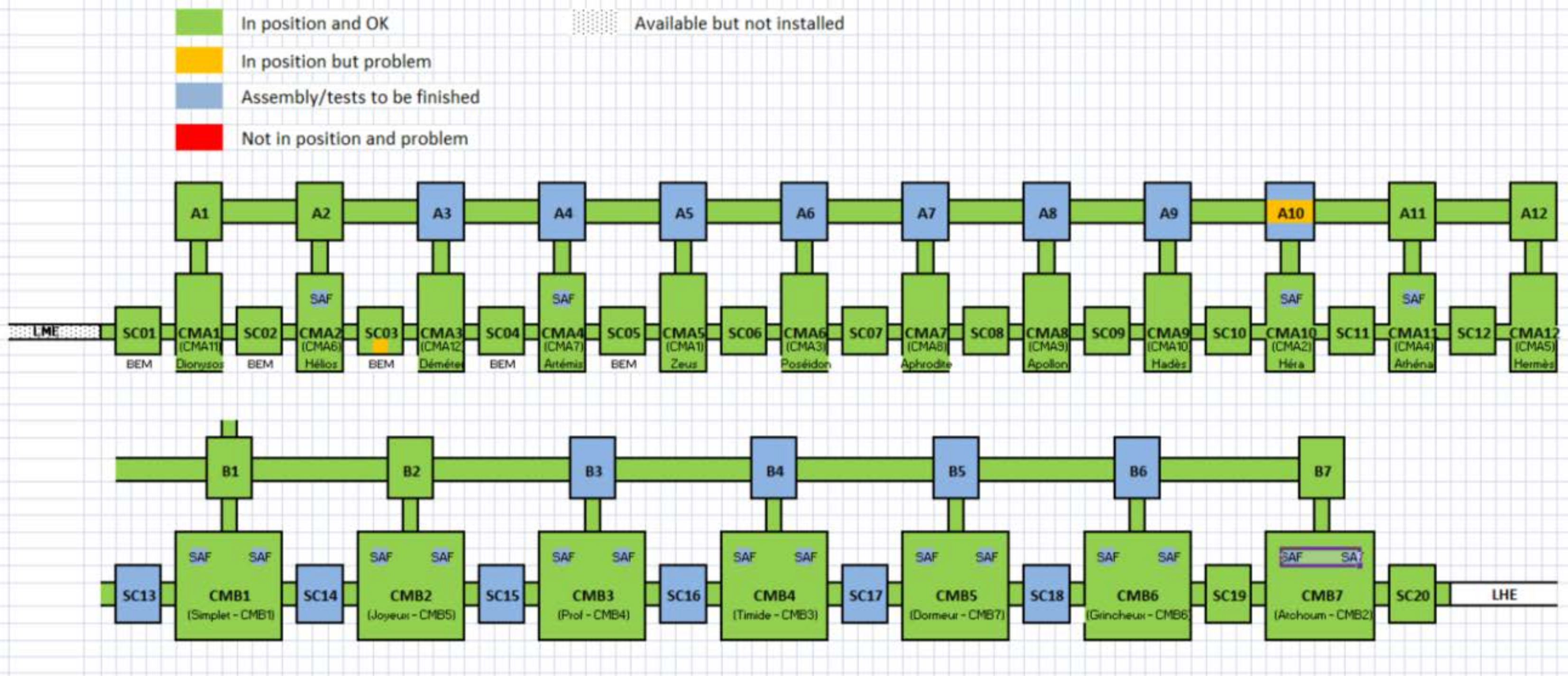


The RFQ injector is ready to accelerate the deuterium beam (**waiting for safety autorisation ASN)**

Installation / commissioning of linac

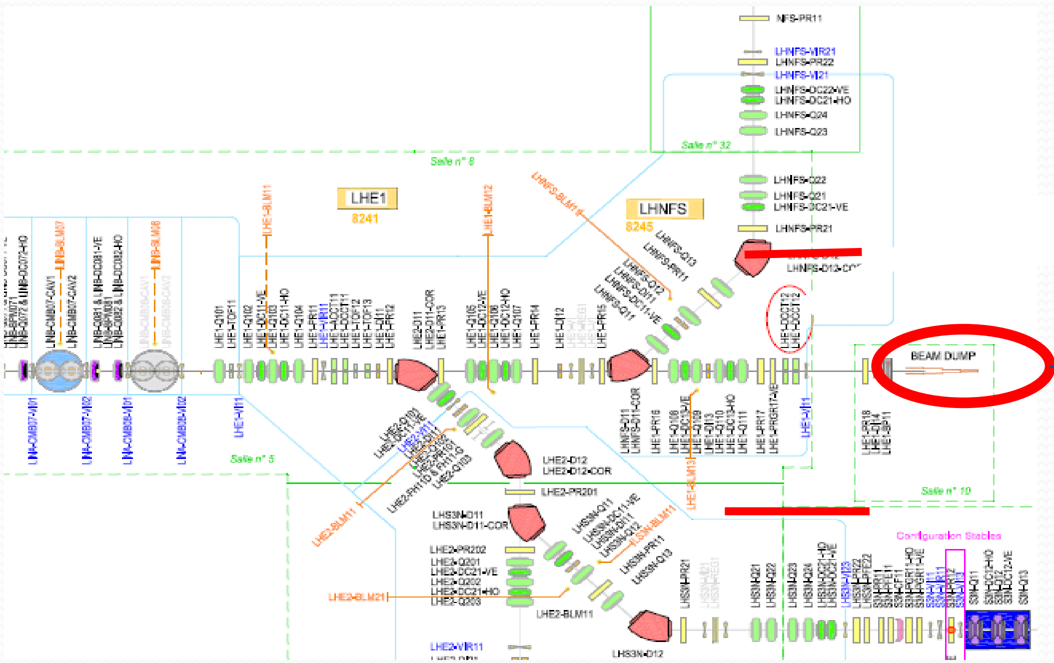
Rest:

- tunnig of cryogenic valves .
- vaccum control system test.
- cryomodules control system test (cryogenics and frequency tuning system of the cavities)



High Energy beam Lines LHE

The Line is partially installed and tested



Will be installed:

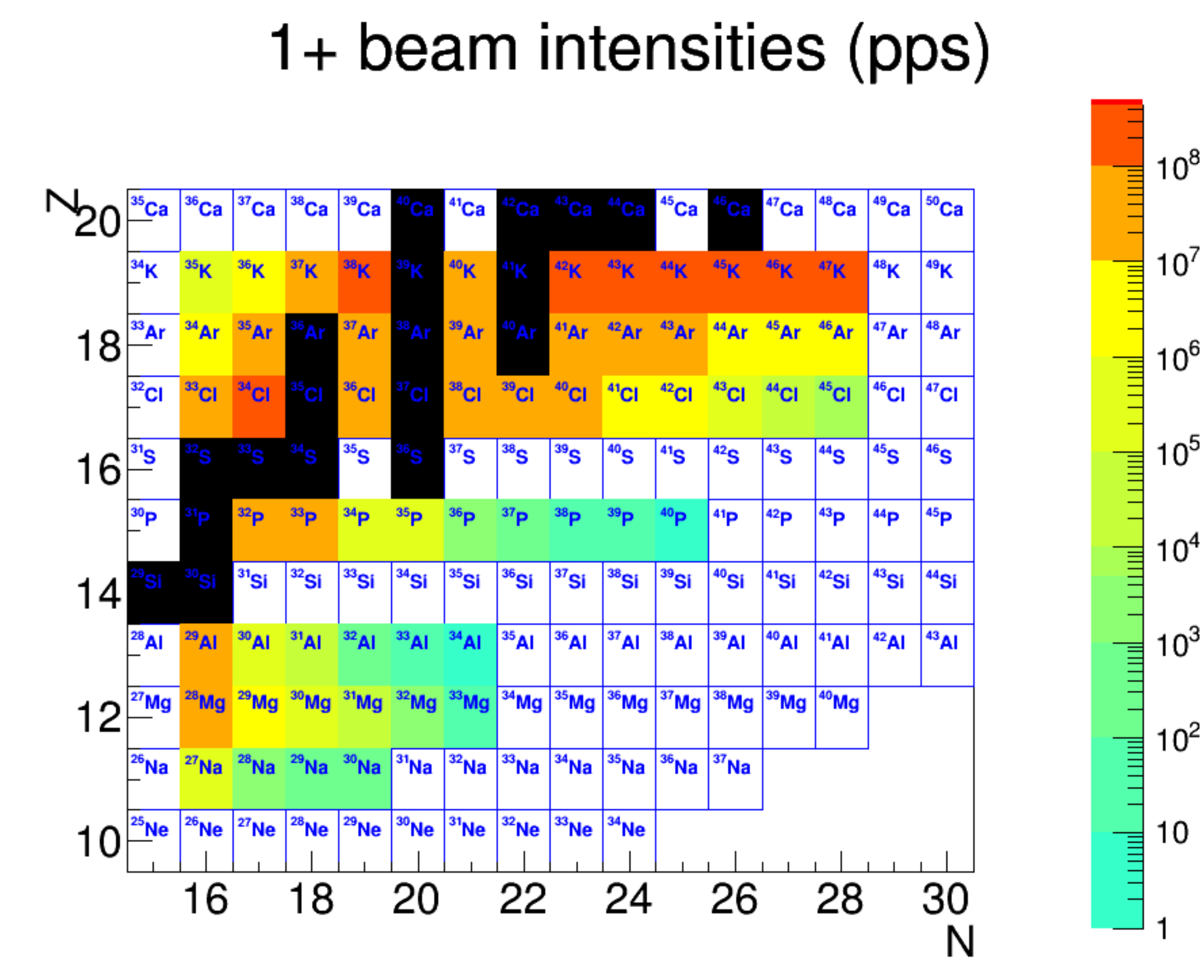
- the beam dump(BD)
- profilers and beam alignment
- beam line junctions BD et S3
- control system for vacum

- ..

Tests vide arrêt faisceau principal avant installation (4/2017)

Thank you for your attention

Status and commissionning



Post-accelerated beams

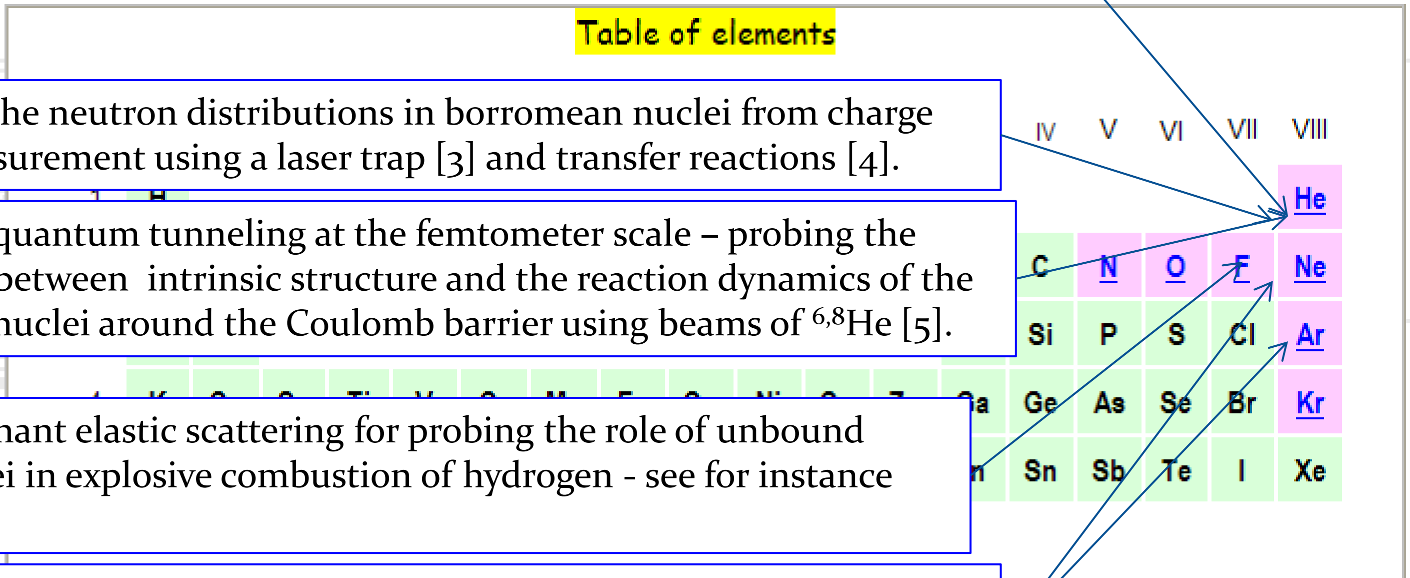
^{38m}K 9 A.MeV Coulomb excitation experiment

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

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].

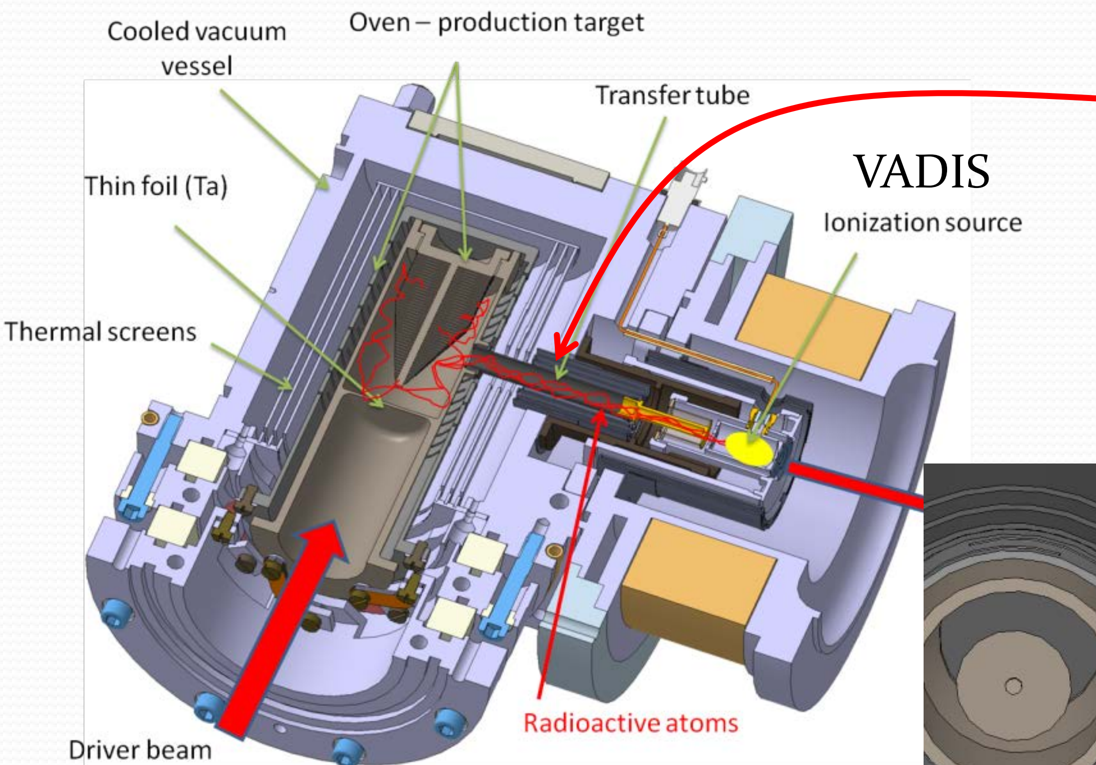
Evolution of N=20 and 28 shell closures far from stability and the emergence of new shell gap at N=16, using neutron rich beams of Ne [7] and Ar[8].

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.

1+ FEBIAD source (type VADIS ISOLDE)

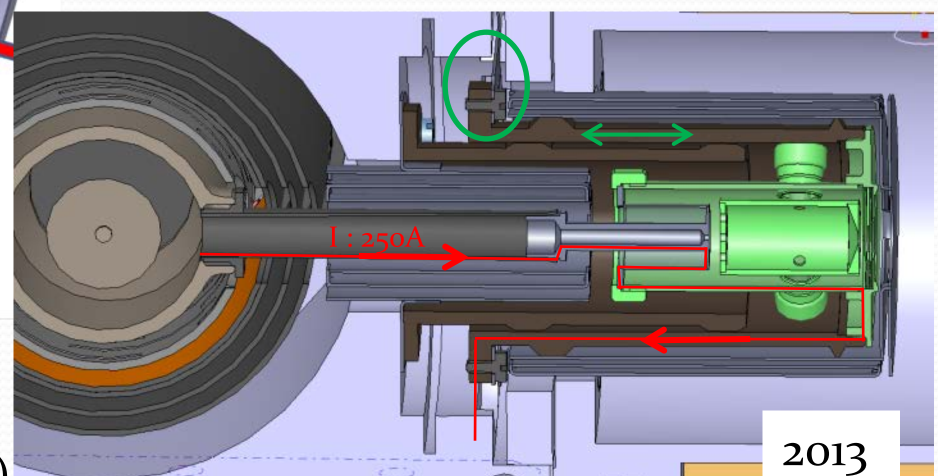
FEBIAD ion source development since 2011



Main difficulty to overcome :
Thermal expansion of the transfer tube

<u>Transfer tube length</u> :
- 20° : 62.5mm
- 2000° : 62,5 + ***1.5mm***

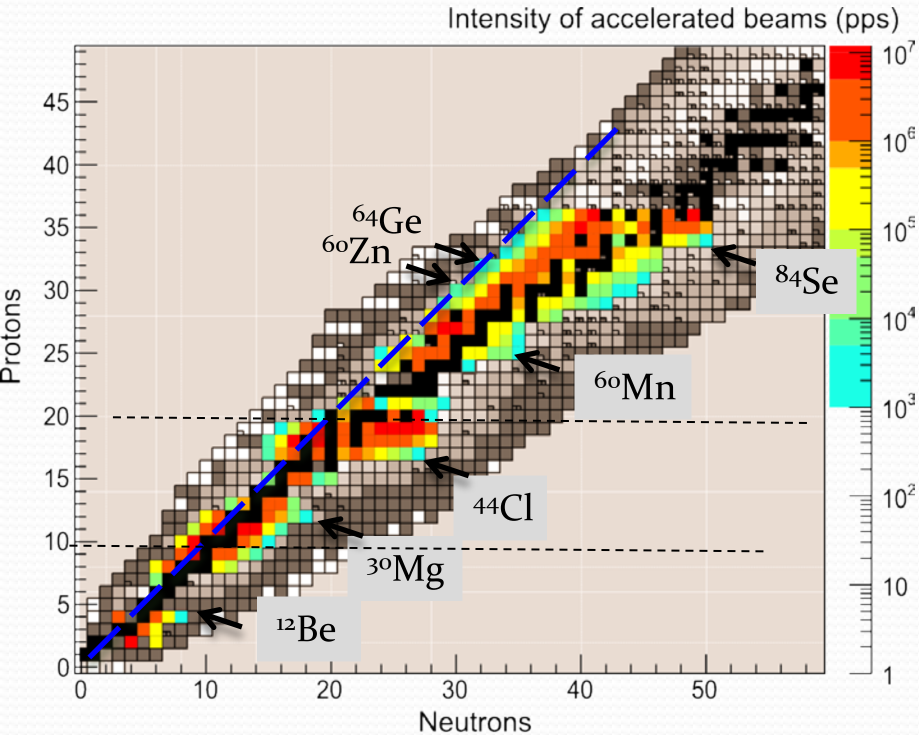
Need to develop a system having a translation movement while conserving a good electrical contact (~250A)



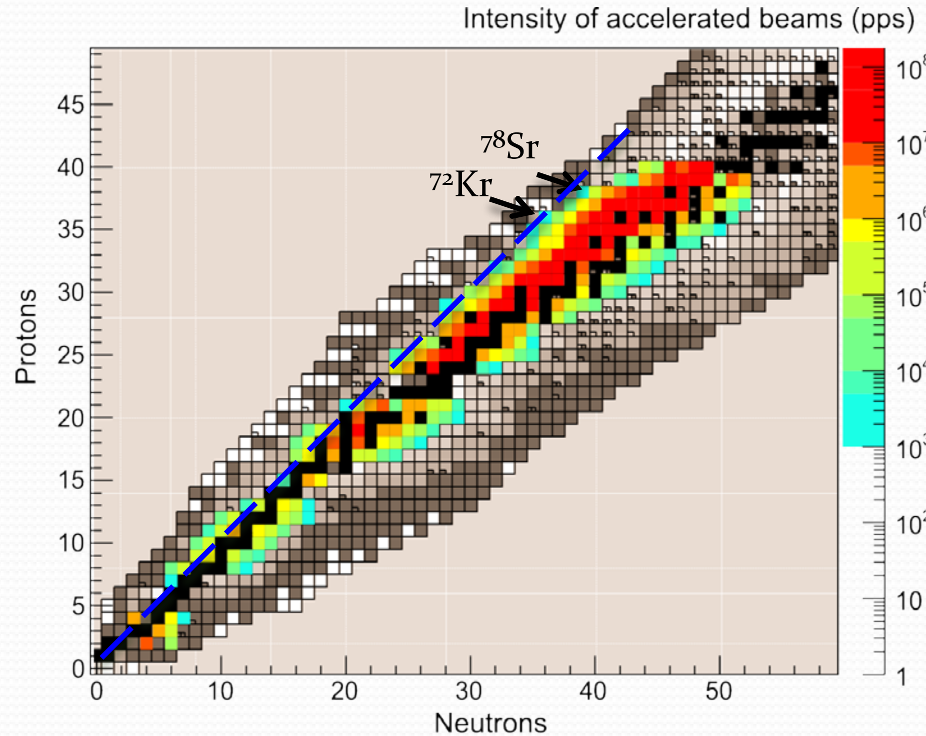
2012

- 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



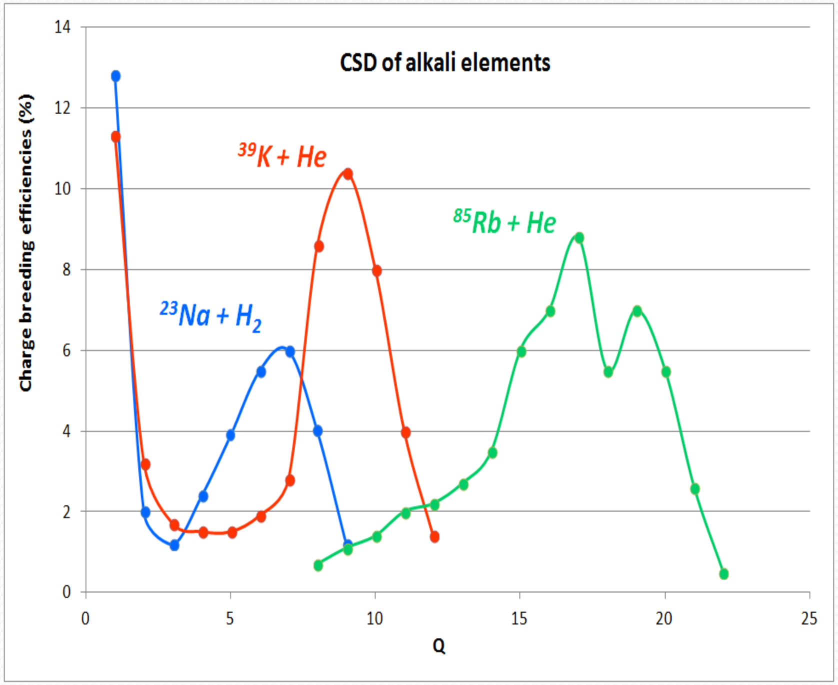
SPIRAL: Expected production from Nb target

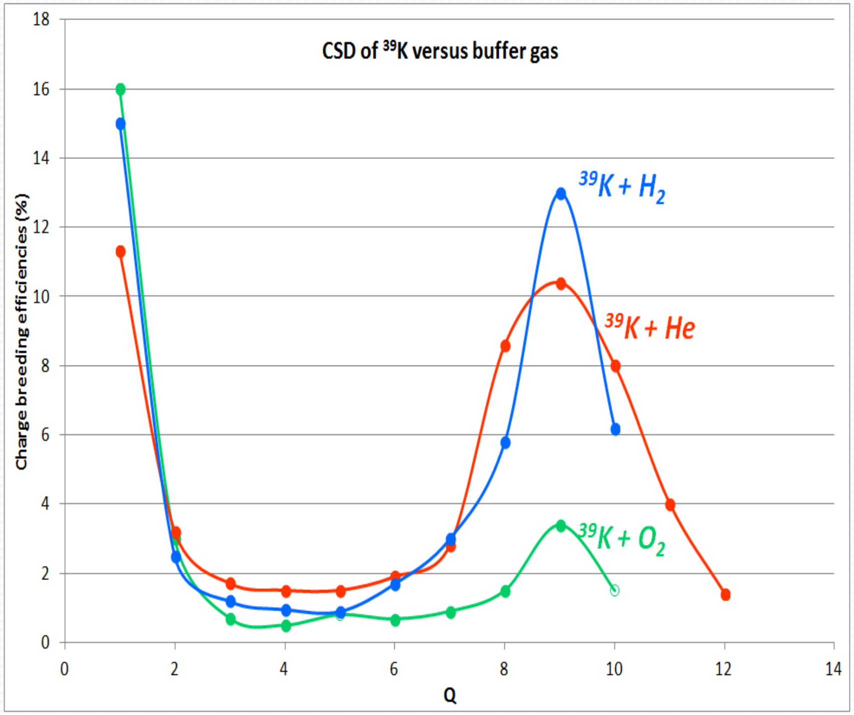
Best accelerated intensities from fragmentation of 1.2kW when available of ^{13}C, ^{16}O, ^{18}O, ^{20}Ne, ^{22}Ne, ^{24}Mg, ^{26}Mg, ^{36}Ar, ^{36}S, ^{40}Ca (800W), ^{48}Ca (700W), ^{58}Ni (700W), ^{78}Kr, ^{86}Kr (800W) at maximum energy. A threshold has been set at 10^3 pps. 3kW targets could be 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.

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

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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

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		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*								

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