STATUS REPORT ON SPIRAL1

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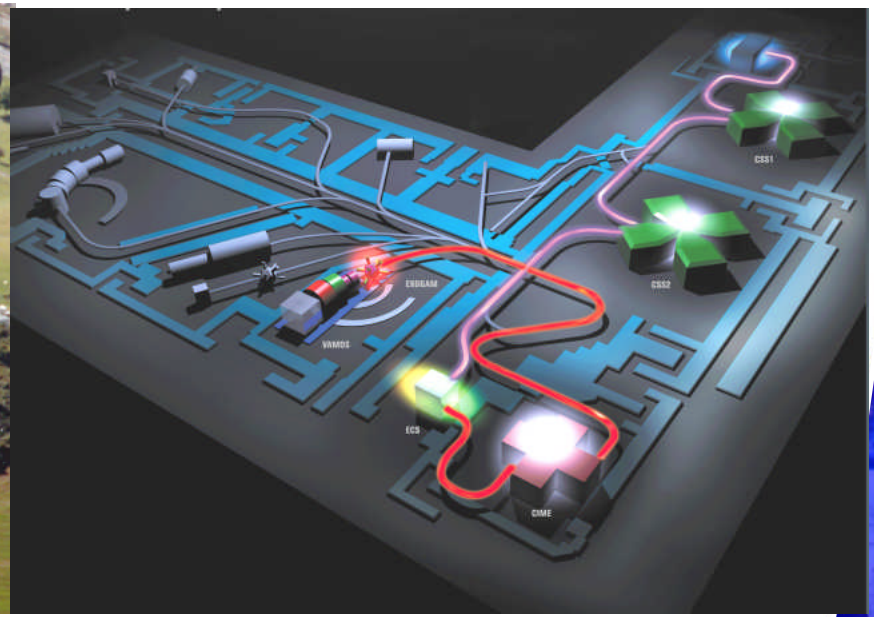
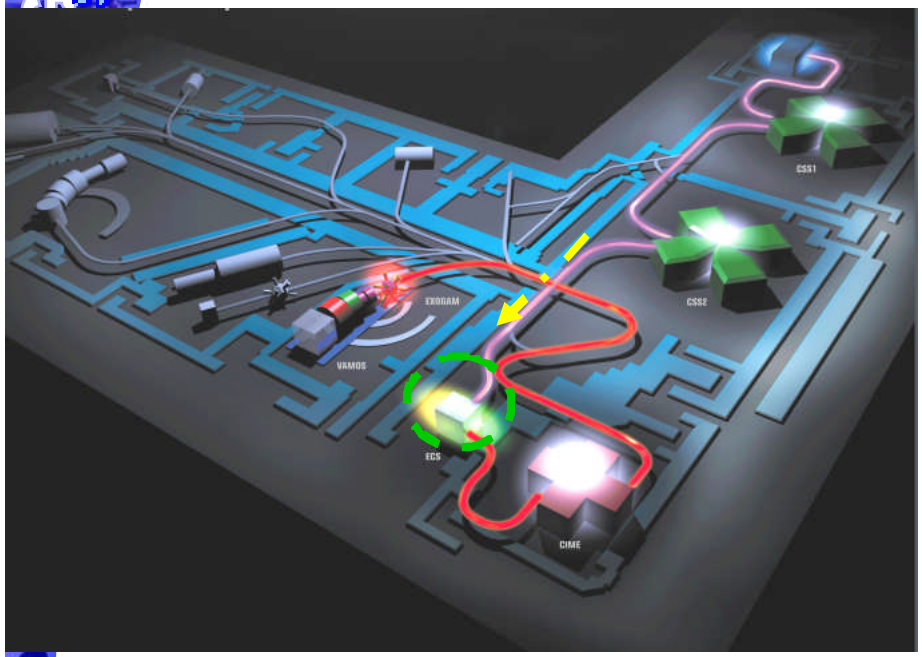
October 2nd, 2007

- **Assessment of GANIL/SPIRAL operation**
- **Technical achievements**
- **Present R&D**
- **Possible developments**



SPIRAL: Radioactive ion beams with «ISOL» method since 2001



Heavy Ion Beams up to 95 MeV/A onto a thick carbon target

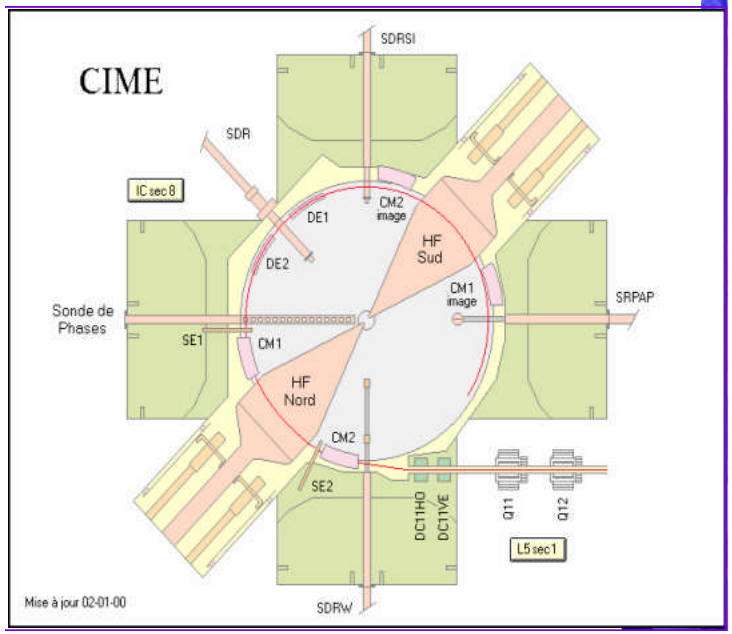
→ **radioactive atoms**

Ionisation by an ECR ion source

Post-acceleration by CIME cyclotro

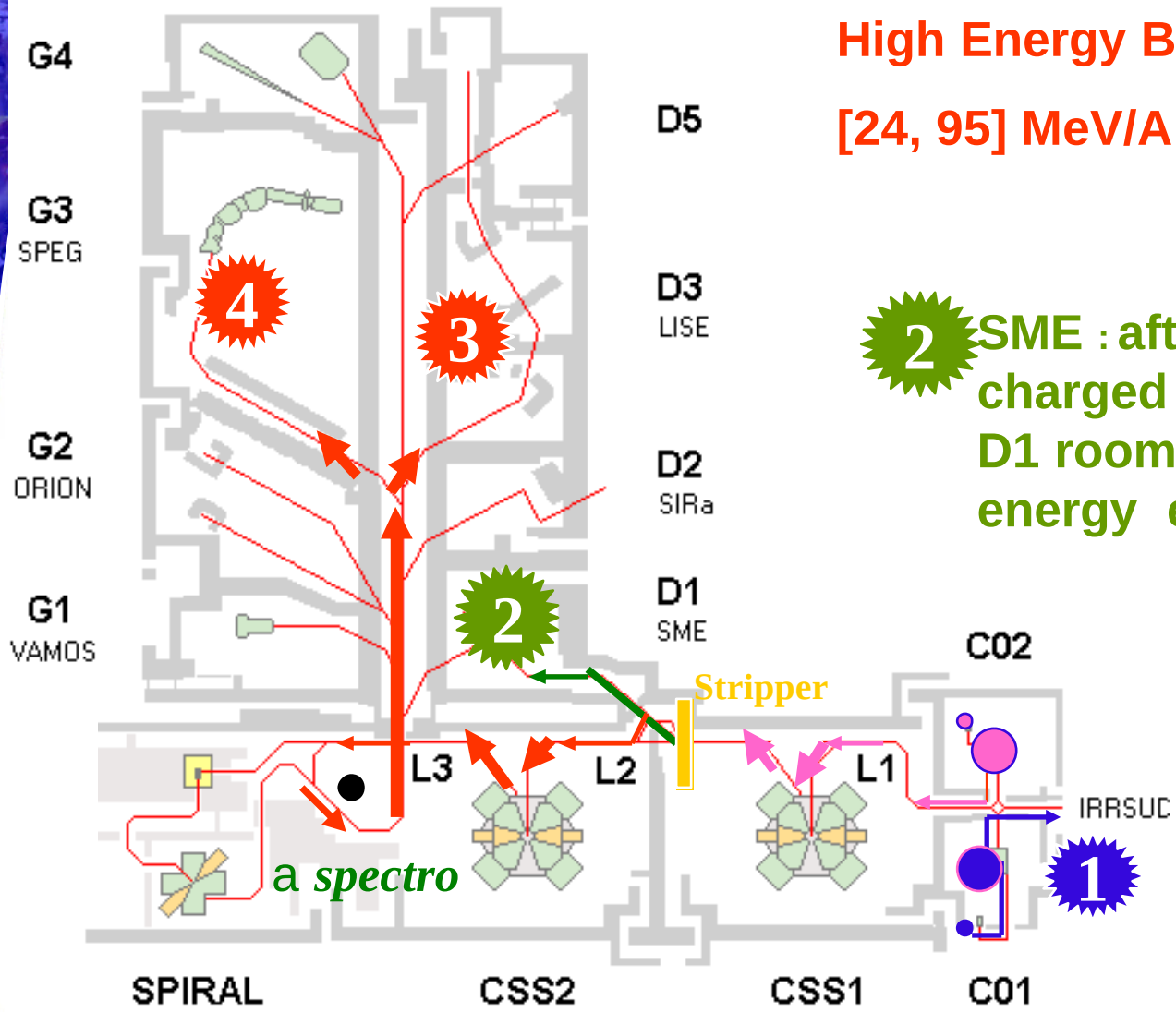
Acceleration and Purification in a compact cyclotron CIME

Radioactive Isotopes (He, N, O, Ne, Ar, Kr, F)



Multi-beam operating mode:

4 experiments in parallel



High Energy Beam GANIL

[24, 95] MeV/A 3 4

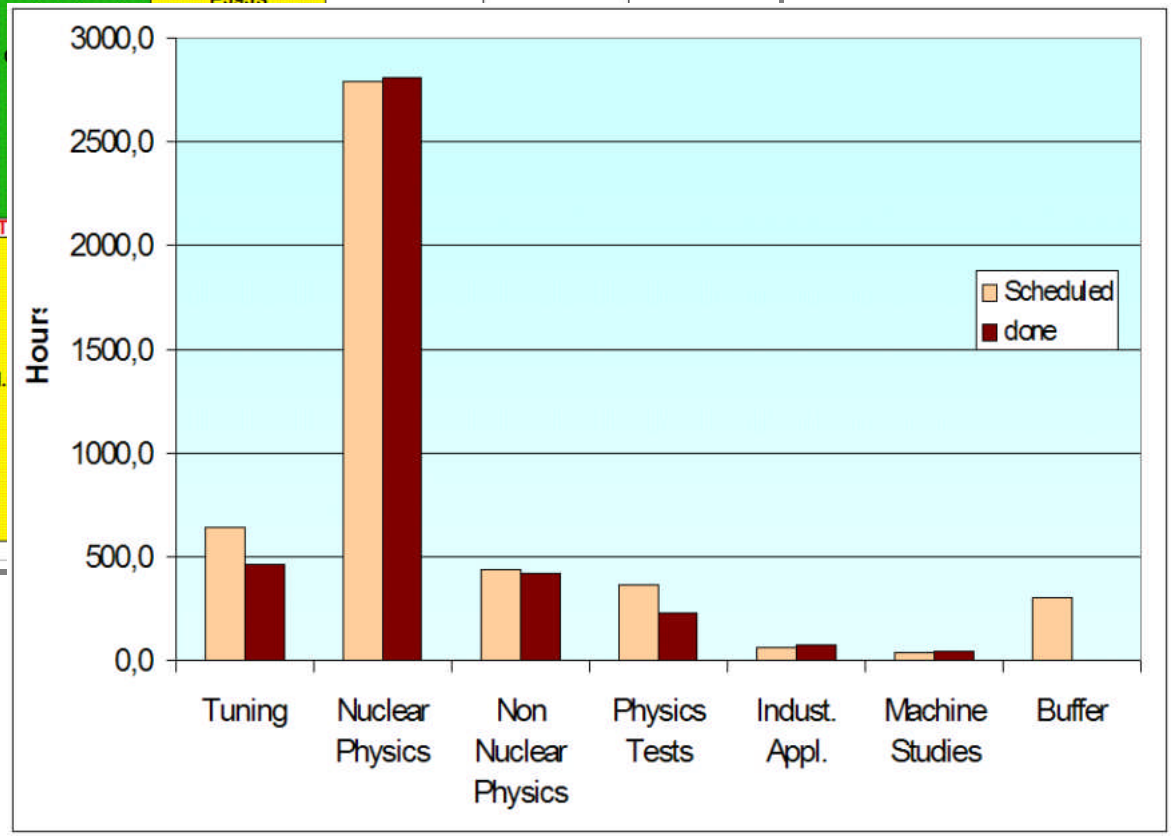
2 **SME : after a stripper, one charged state is sent to the D1 room => the medium energy exit [3.7, 13.7] MeV/A**

IRRSUD : low energy beam irradiation line

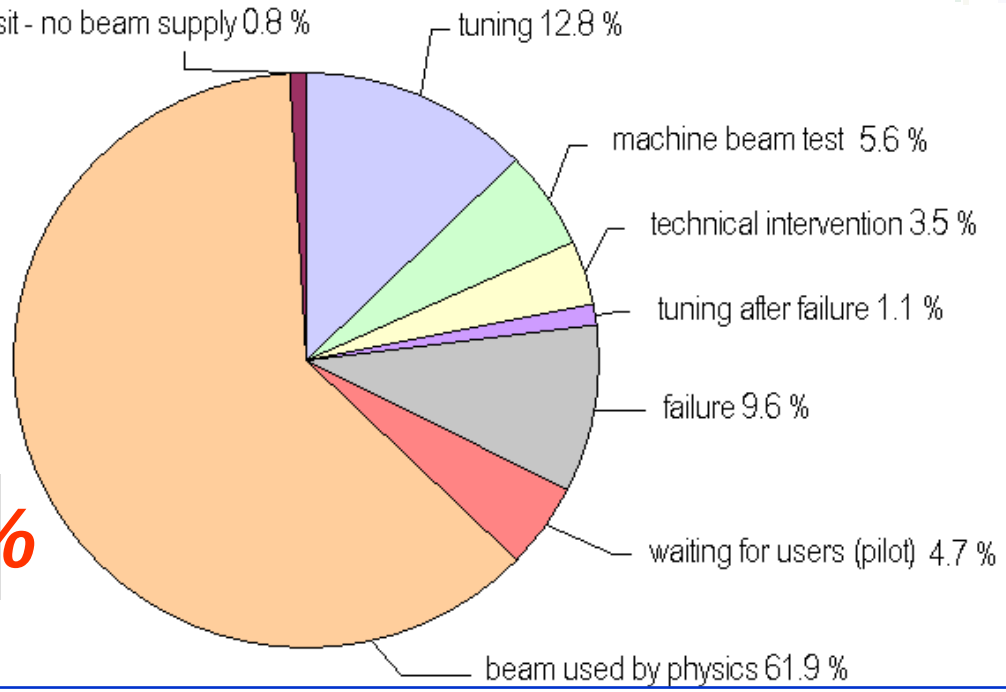
[0.3, 1.0] MeV/A 1

Multi-beam operating mode:
Beam schedule

Date	hour	C01	C02	CSS1, CSS2	CIME	SME	SISSI	Auxiliary beam
Saturday 29-Apr	2h00	ON LINE 48Ca		BEAM ON SPIRAL TARGET	E393S (Gorgen) 1UT 44Ar7+ 2.6 MeV/A H5 R45			
	6h00							
	10h00							
	14h00							
	18h00							
	22h00							
Sunday 30-Apr	2h00				E393S (Gorgen) G2 6 UT			
	6h00							
	10h00							
	14h00							
	18h00							
	22h00							
Monday 1-May	2h00		IRRSUD 208Pb 0.66 MeV/A		E393S			
	6h00							
	10h00							
	14h00							
	18h00							
	22h00		P717-M-S Jurazsek					
Tuesday 2-May	2h00							
	6h00							
	10h00							
	14h00							
	18h00							
	22h00		S26 F. Studer					
Wednesday 3-May	2h00							
	6h00							
	10h00							
	14h00							
	18h00							
	22h00							
Thursday 4-May	2h00							
	6h00							
	10h00							
	14h00							
	18h00		Tuning ECR4M 12C					
	22h00							
Friday 5-May	2h00							
	6h00							
	10h00							
	14h00							
	18h00		Tuning C02 12C					
	22h00							
	2h00							



Running Statistics 2001-2006

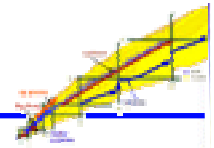


Availability: 90%

GANIL per year: 35 weeks / 4 periods: 5700h of operating time. Leading to 7200h of beam time for users (multi-beam effect)

SPIRAL since 2001: 5000h of exotic beams / 700h of stable beams. More than 30 exotic beams

Primary beams



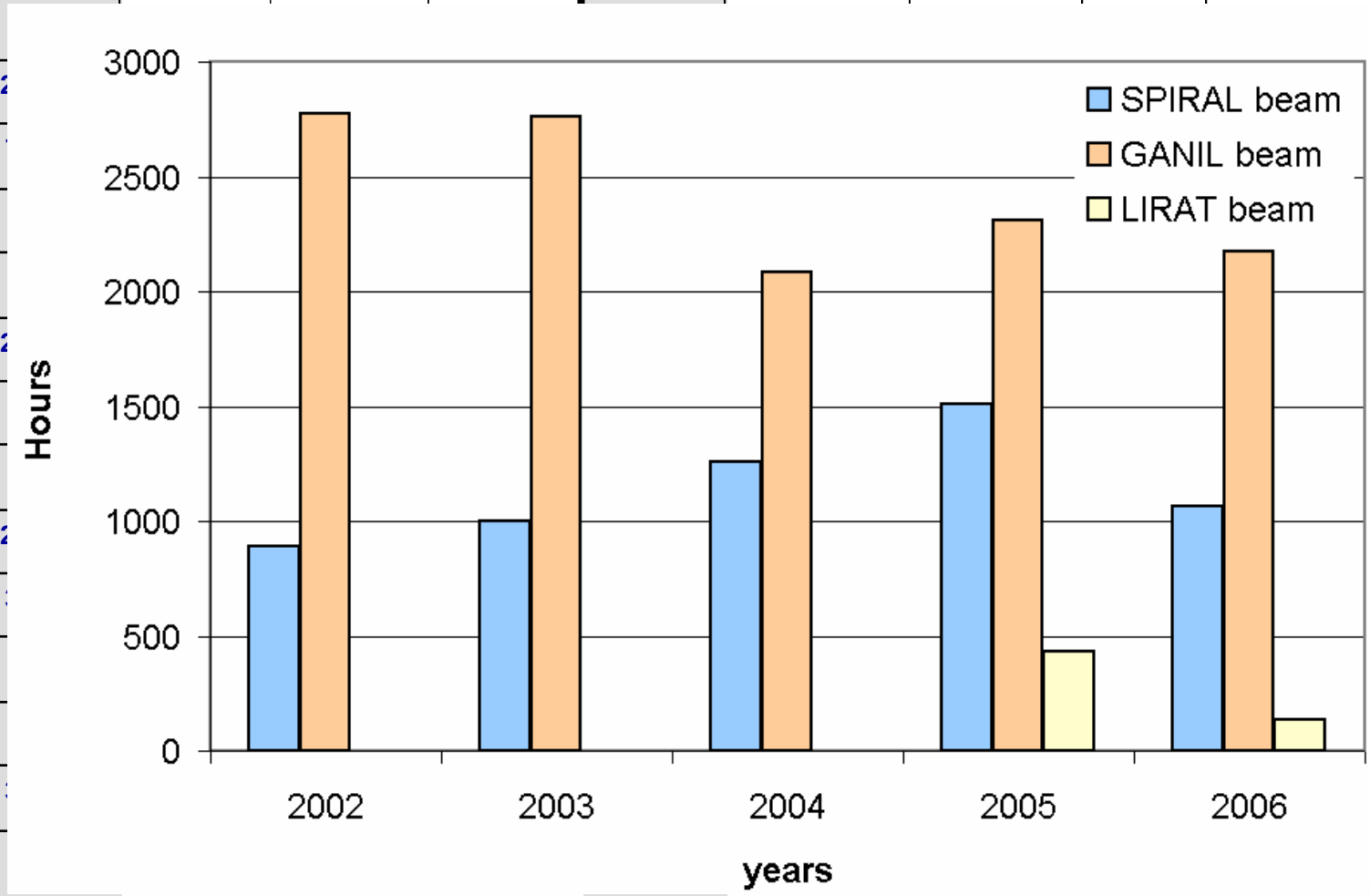
(http://www.ganil.fr/operation/available_beams/available_beams_tabular.htm).

Beam	Imax [mAe]	[pps]	Emax [MeV/A]	Pmax [W]	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	
$^{36}S^{16+}$	6.4	$2.5\ 10^{12}$	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	
$^{78\text{-}86}Kr^{34+}$	7.5	$1.4\ 10^{12}$	70	1200	X
$^{124}Xe^{46+}$	2	$2.7\ 10^{11}$	53	300	

SPIRAL operation

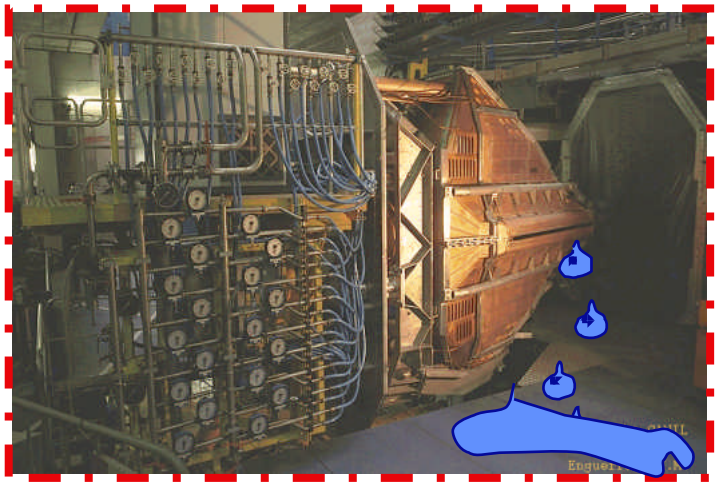
(http://www.ganil.fr/operation/available_beams/radioactive_beams.htm)

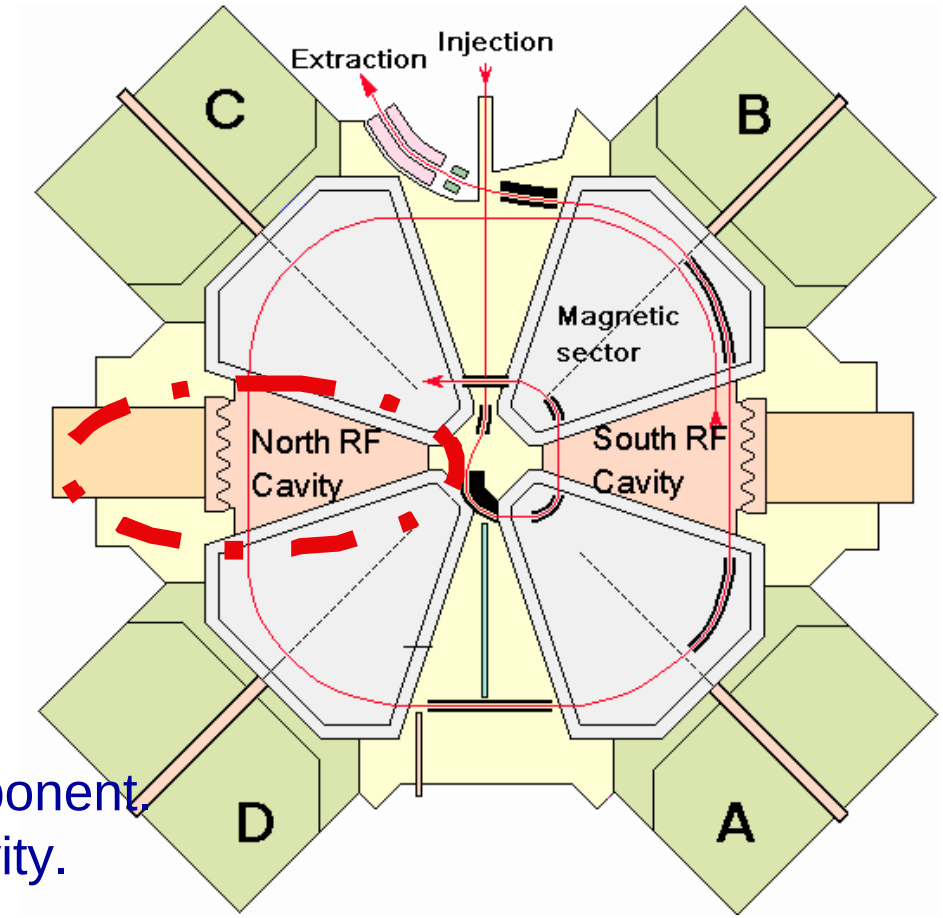
ion	W [MeV/A]	[pps]	Year	ion	W [MeV/A]	[pps]	Year
^{18}Ne	7	10^6	2001	^{31}Ar	1.45	1.5	2004
^{8}He	15.5	10^4	2001	^{6}He	3.2, 5	3.10^7	2004



Ageing Problems and Maintenance

- Since few years, the accelerating cavities of the SSC's encountered water leaks due to 25 years of functioning.
- Interventions require to remove the whole cavity.
- Inducing one week delay to physics experiment.





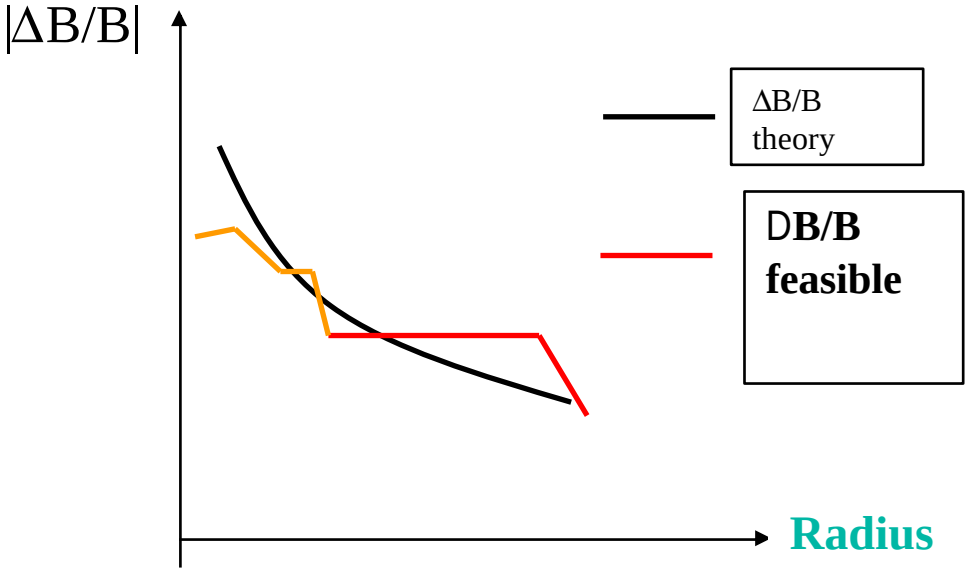
Corrective actions:

- Replacement of defective component.
- Tuning of SSC with one RF cavity.

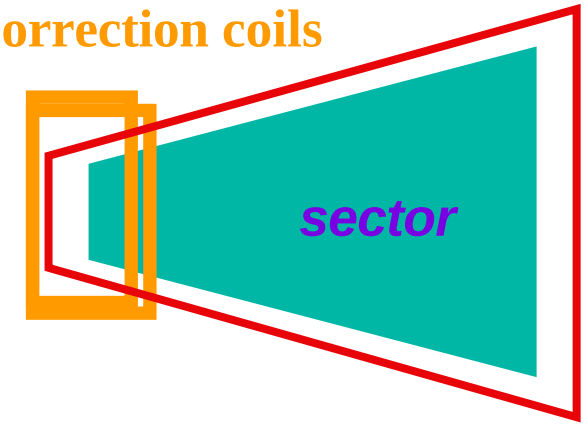
Ageing Problems and Maintenance

•Simulations and analytical calculations show that compensation of a RF acceleration can be done by modifying the magnetic field law.

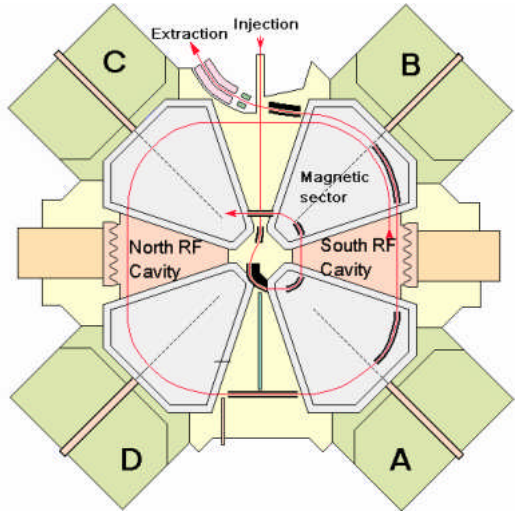
$$\frac{\Delta B_{sector}}{B}(r) = \pm 0.5 \cos(45°)\, s_{injection}\, r_{injection} / r$$



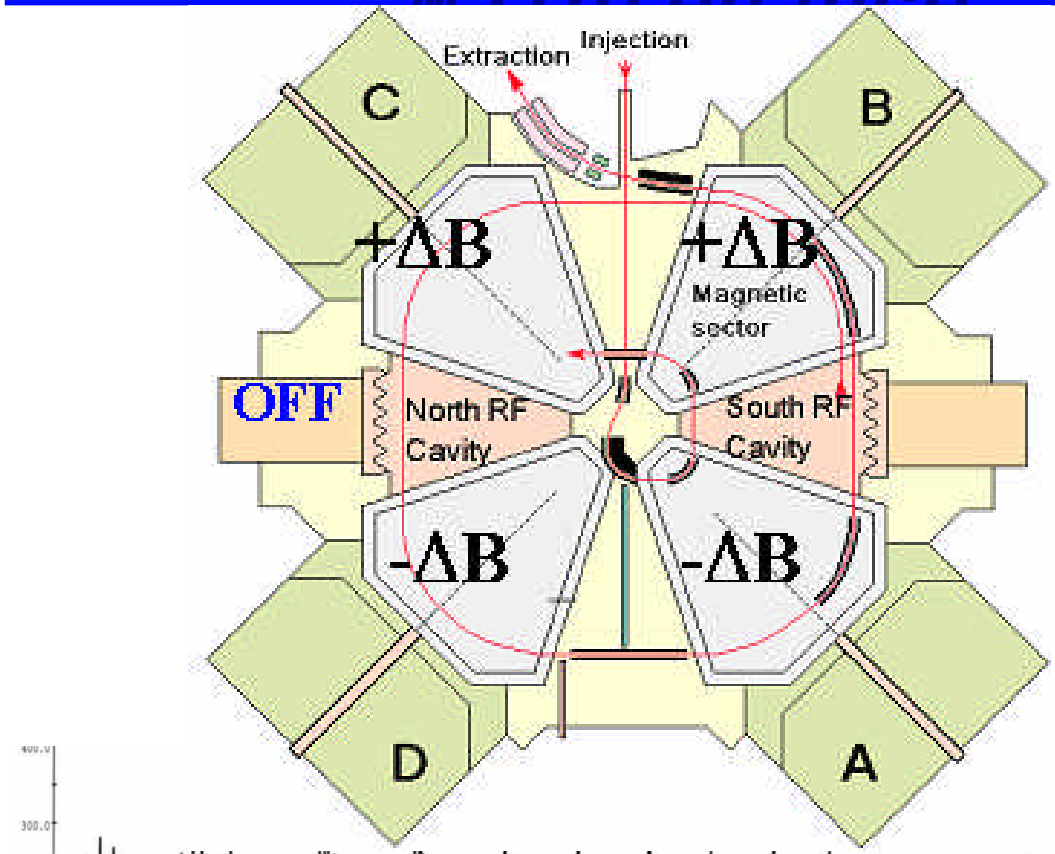
Correction coils

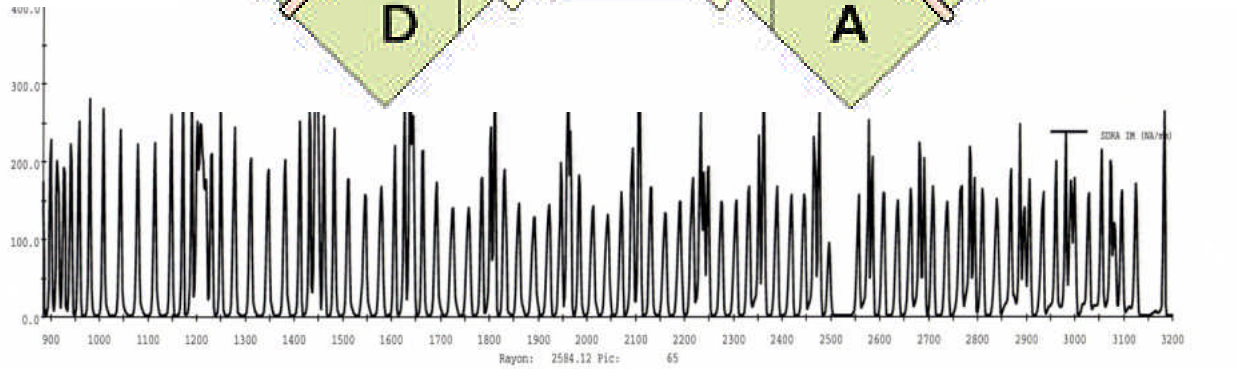


Sector coil



Ageing Problems and Maintenance

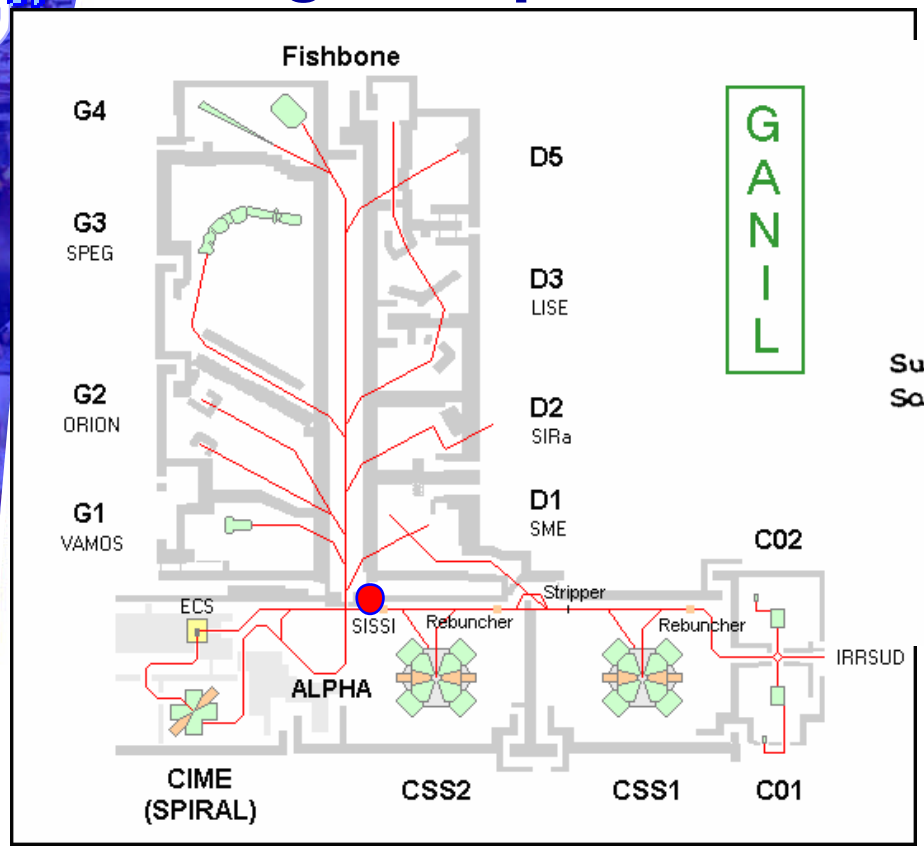


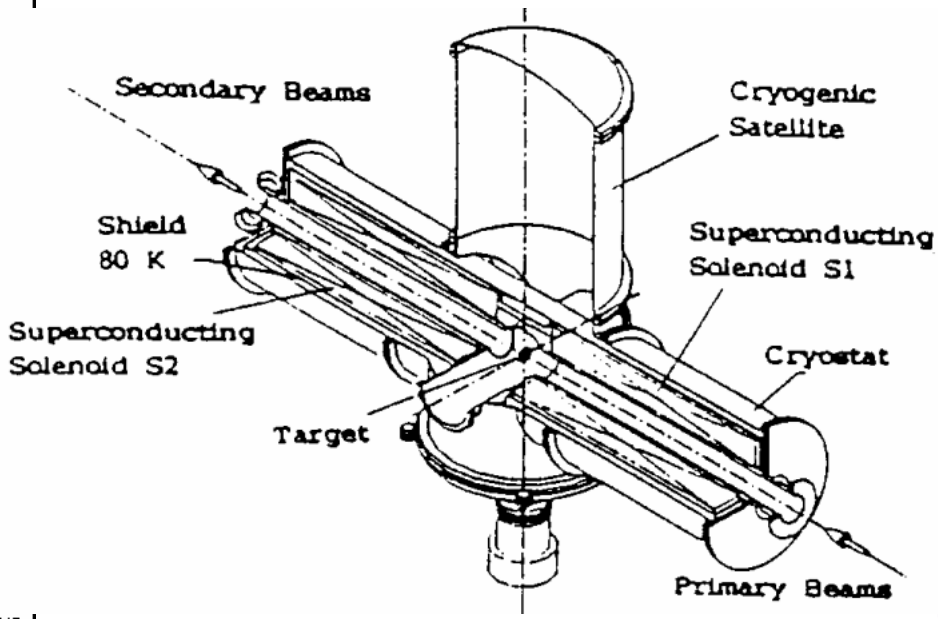


On a Radial probe: Still precession, but 90% transmission

Ageing Problems and Maintenance

In-Flight Separation techniques (SISSI)





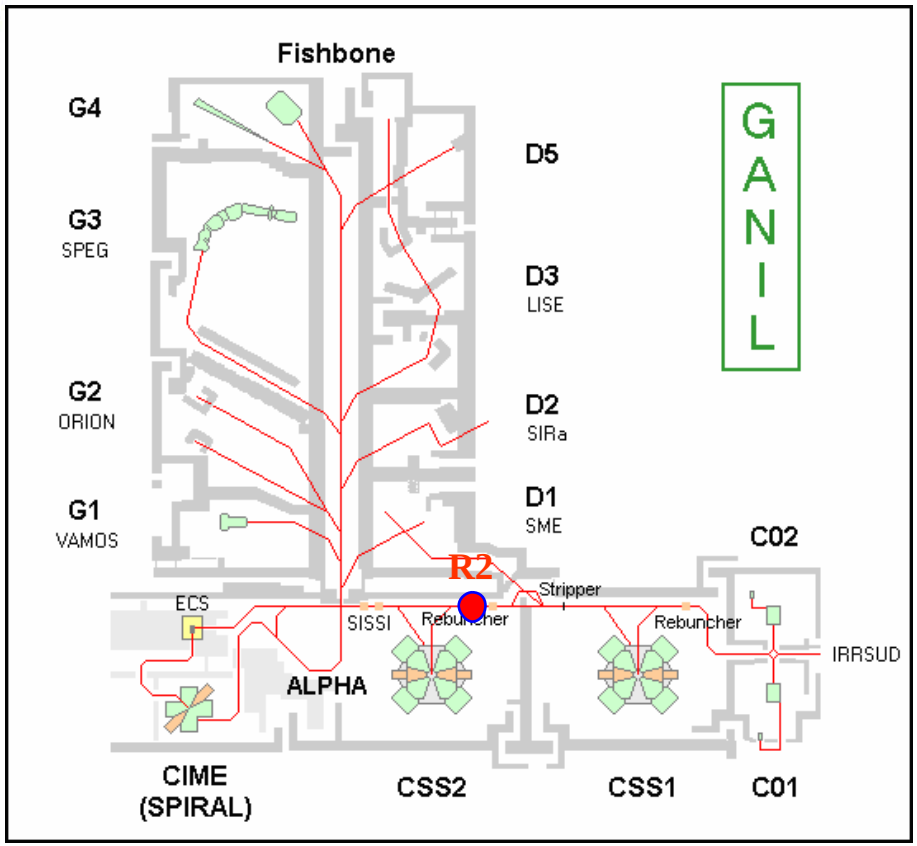
In June 2007, the second solenoid S2 of the SISSI device quenched during current rising and cannot be used since. The reasons of the repetitive quenches are still unknown (ageing, device weakness, neutron effects …) : Short term alternative solutions are studied.

Ageing Problems and Maintenance

R2 Rebuncher

The clear interest of such a rebuncher is to reduce the beam losses in CSS2 deflector improving the beam stability, (especially heavy ions such as krypton).

- **Unavailable since 2002 because of defective RF contactors.**
- **The cavity is repaired and has been put back in line in 2007.**



The SPIRAL strengths can be resumed by:

- Large Energy range of post-accelerator : from 1.2 MeV/A to 16 MeV/A (for Q/A=0.25)
- Mass purification of the cyclotron R= few 10^{-4}.
- Good energy definition of the CIME beams $\Delta E/E < 5\ 10^{-3}$
- Good transmission for such an accelerator technology 20%-40%.
- Great target-source selectivity + cyclotron purification giving a pure beam of most of available ion beams.
- 40 isotopes available.
- Possibility to run detectors developments with stable beam of CIME in a stand alone operation.

But SPIRAL has also its limitations:

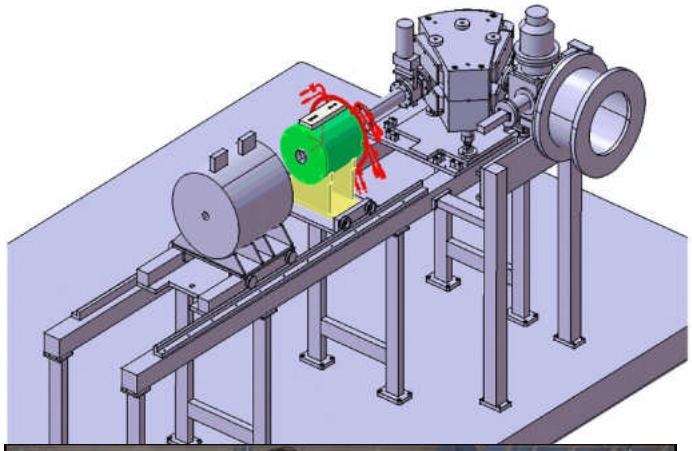
- Still, too few radioactive ion species are available (He, O, N, Ne, Ar, Kr, F).

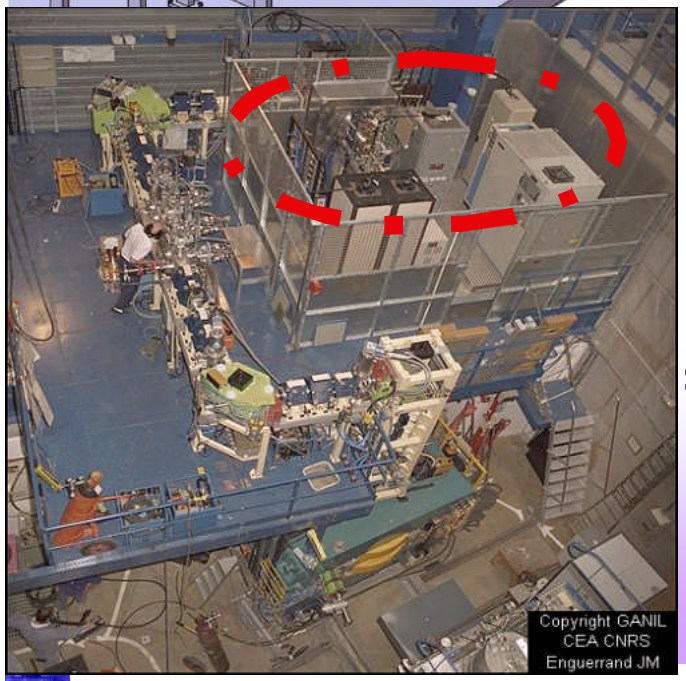
- Intensity is a parameter of utmost importance; It is the main limitation for most of experiments.

- The large turn number in CIME impacts the beam emittance: ΔTFWHM < 2ns and emittance ~ 16π.mm.mrd imply multi-turn extraction.

What about improvements since 2001?

2004 Modification of the high voltage platform C01 (100 kVolts)





Goal: Increase the beam intensity of the source

Limitation: space–charge

Solution: Increase the extraction voltage from 25 kV to 100 kV in two stages.

First stage: extraction at 25 kV and selection to remove unwanted intense beams

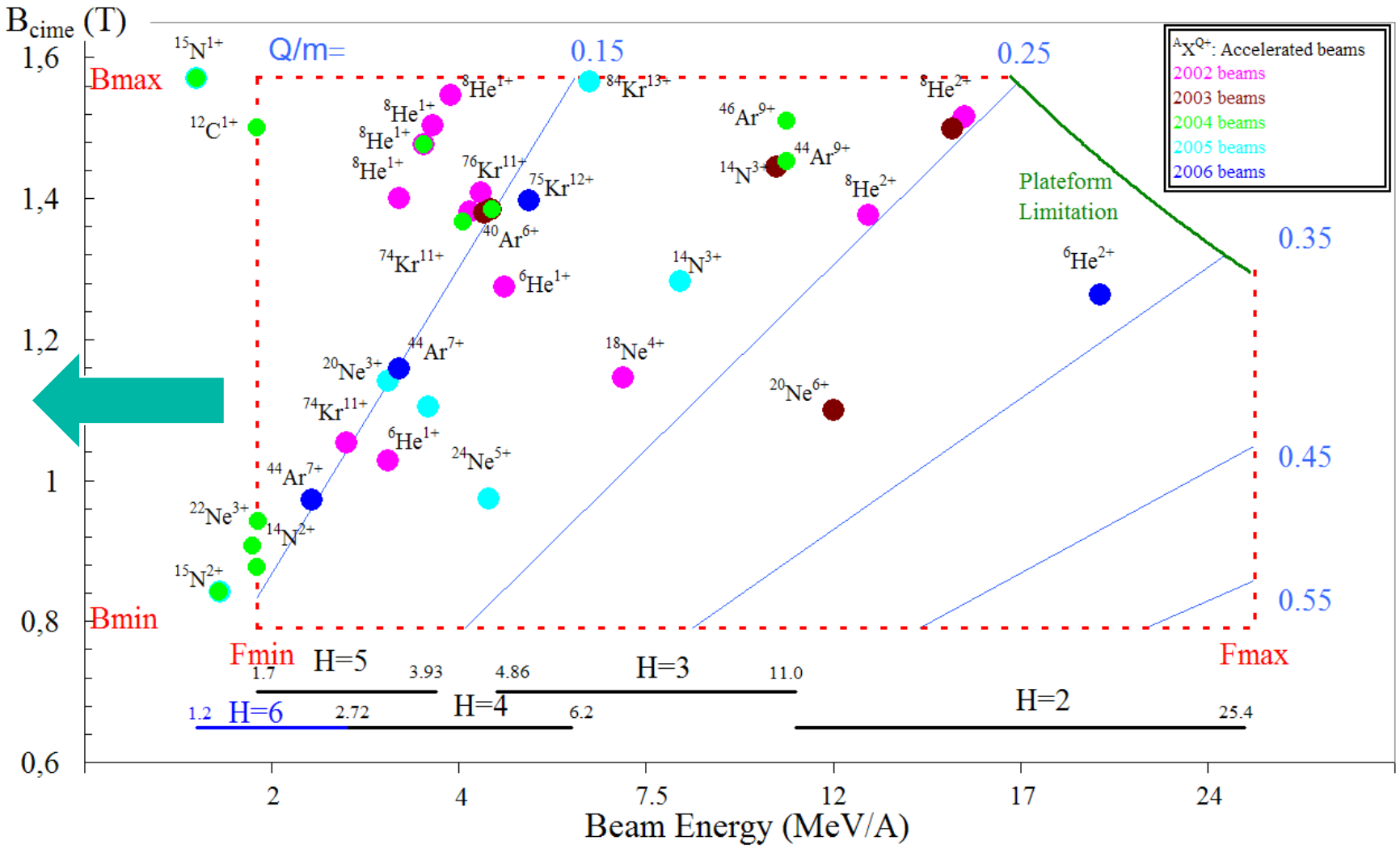
Second stage: acceleration to the wanted energy for injection into the C0

=> Beam more stable, gain of a factor 1.5 - 2 in intensity (S, Kr, Mg, Ar)

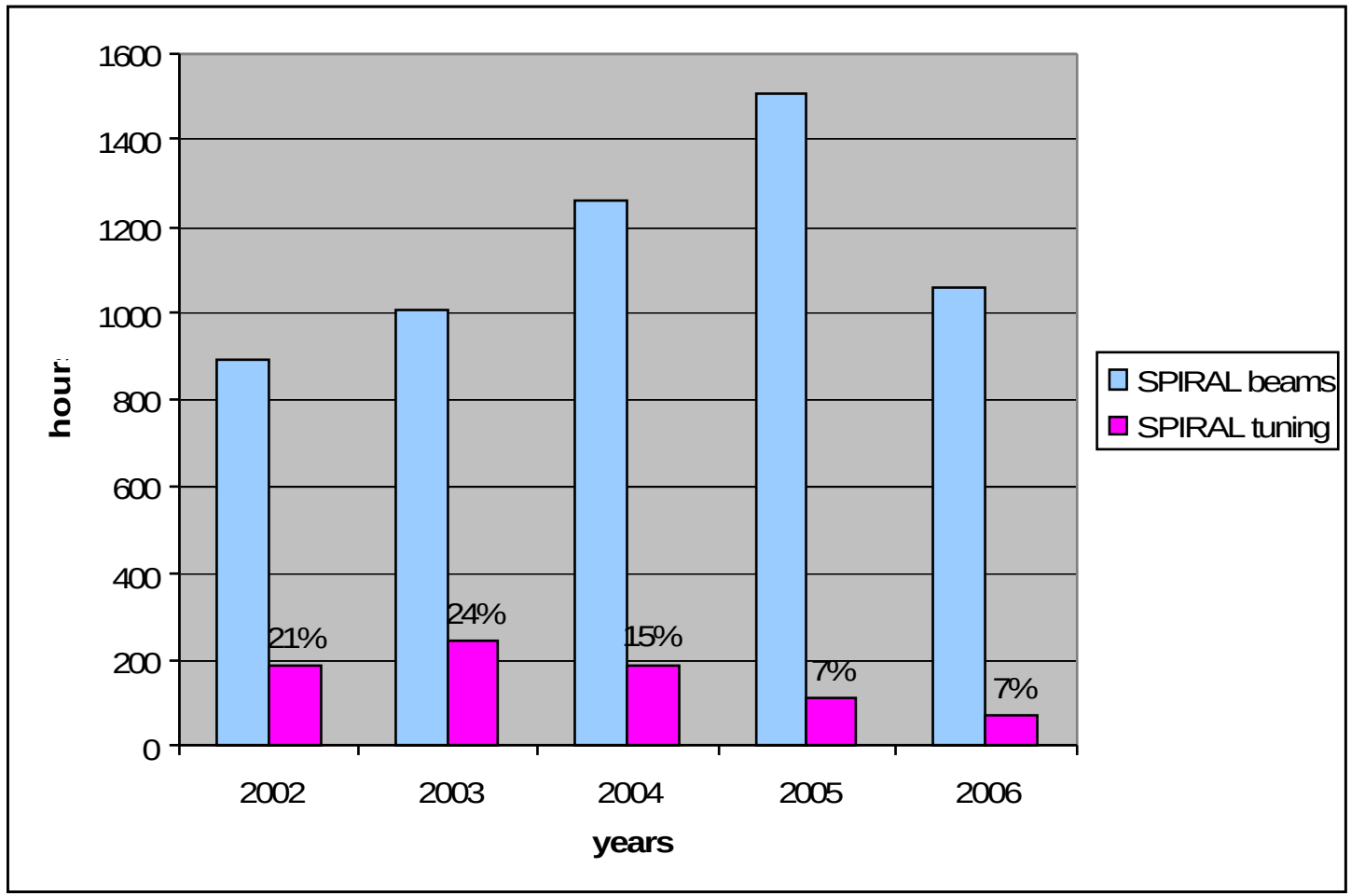
$^{36}S^{8+}$ 38 mAe

$^{78}Kr^{15+}$ 30 mAe

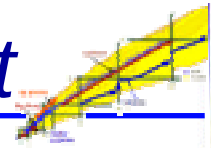
SPIRAL working diagram extension



Tuning optimization



Irradiation control of Spiral Target



Until few days ago the irradiation time was **limited** to 15 days due to safety regulation (worst computed figure for target activation).

The goal is to be more precise in the criteria of limitation: ion species, intensity, energies.

This will be achieved by controlling the ion integrated flow over the lifetime of the target.
Solution: use of a Current Transformer coupled to an automatic beam stop and data storage.

GAIN:
- Decreases the volume of the nuclear waste.
- Optimises the device availability.
- Decreases the frequency of the handling operations and manpower.

And from now ?

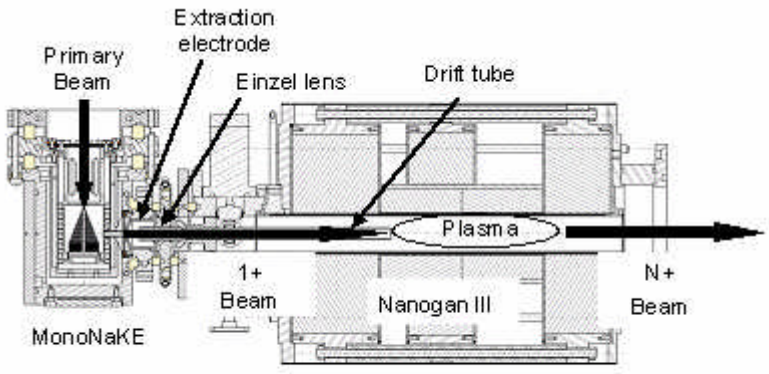
Development of a 1+/N+ radioactive alkali ion source

Isotopes →

Krypton	69	70	71	72	73	74	75	76	77	**78**	79	**80**	81	82	**83**	**84**	85	**86**	…
Argon	30	31	32	33	34	35	**36**	37	38	39	**40**	41	42	43	44	45	46	47	…
Neon	16	17	18	19	**20**	21	**22**	23	24	25	26	27	28	29	30	31	32		
Fluorine	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29			
Oxygen	12	13	14	15	**16**	17	**18**	19	20	21	22	23	24	25	26				
Nitrogen	10	11	12	13	**14**	**15**	16	17	18	19	20	21	22	23	24				
Helium	***3***	***4***	5	6	7	8	9	10											

Stable

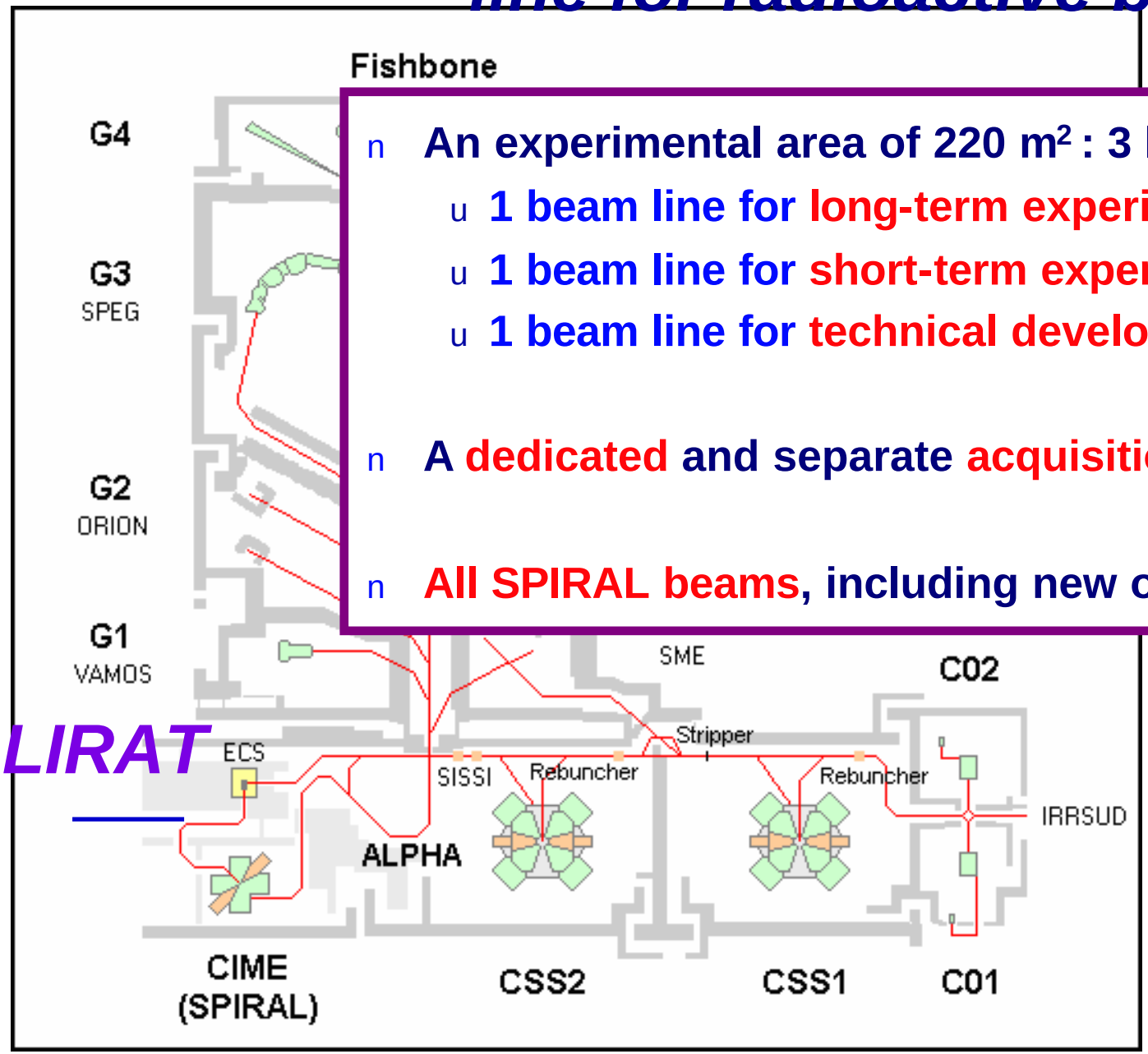
Exotic



- Physicists demands
- Radioactive 1+ alkali production tests with IS source (in 2006)
- Radioactive n+ alkali production tests coupling IS and ECR source (may 2007, very low efficiency 0,04%)
- Constraints of the production cave (compact solution)

Extension for a Low Energy beam line for radioactive beam

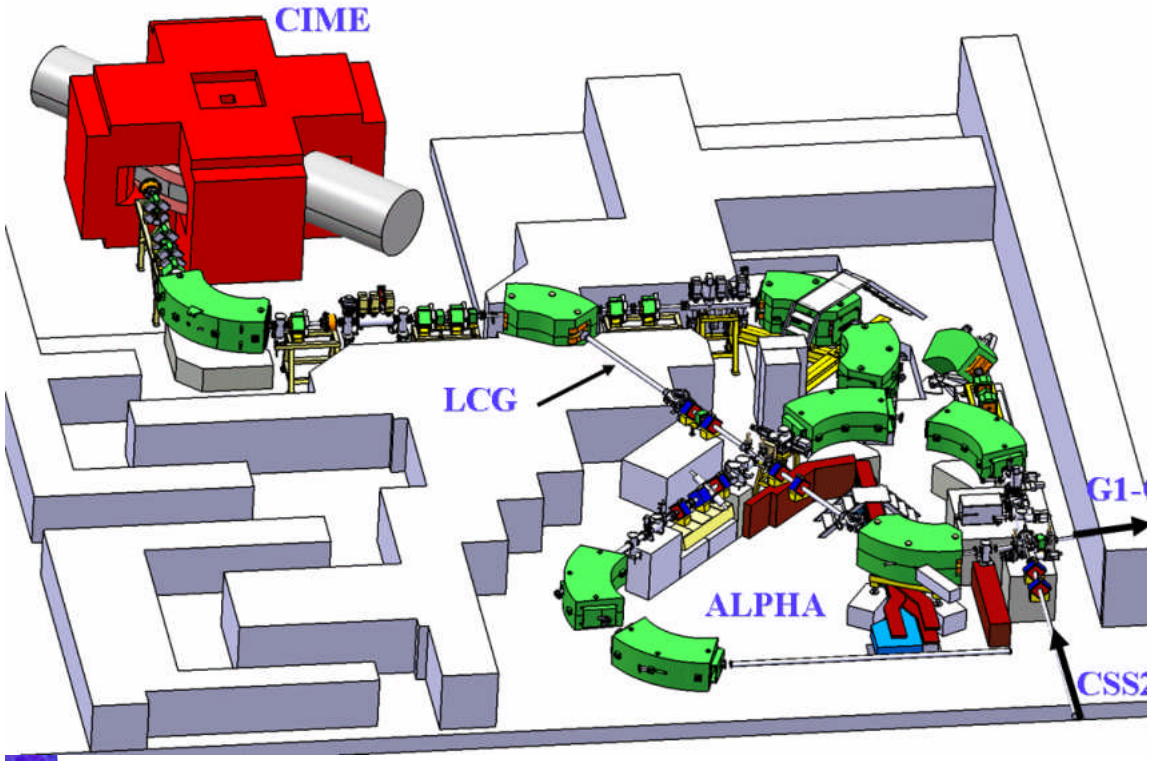
- An experimental area of 220 m² : 3 lines
  - 1 beam line for long-term experiments
  - 1 beam line for short-term experiments
  - 1 beam line for technical developments
- A dedicated and separate acquisition room
- All SPIRAL beams, including new ones

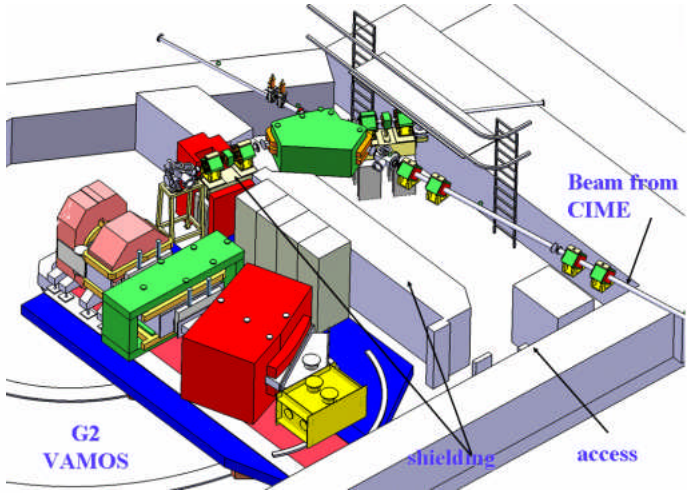


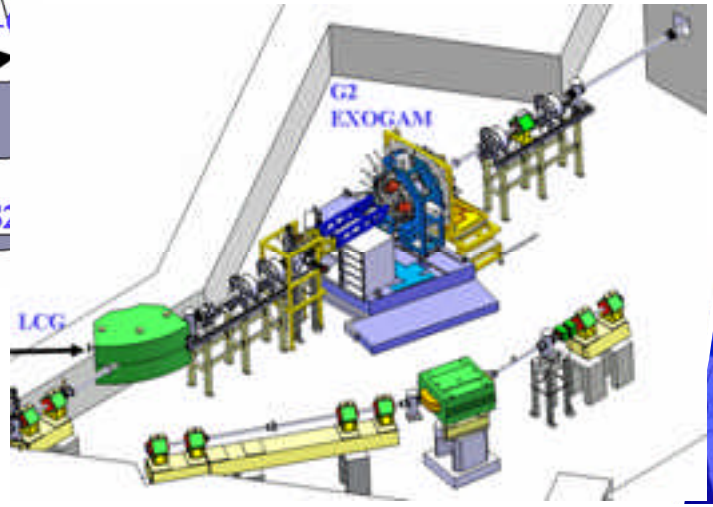
Direct line CIME-experimental caves:

Since 2004

Direct beam line between CIME and G1/G2 allowing the transport of ions into experimental rooms in parallel to SSC2 beams.







Status Summary

- **SPIRALTarget-Source developments:**
  - Alkali ions: compact solution to be validated in April 2008 for stable ions
  - Metallic ions: stand by

- **Low energy line extension:**
  - Predesign study achieved
  - Project under discussion

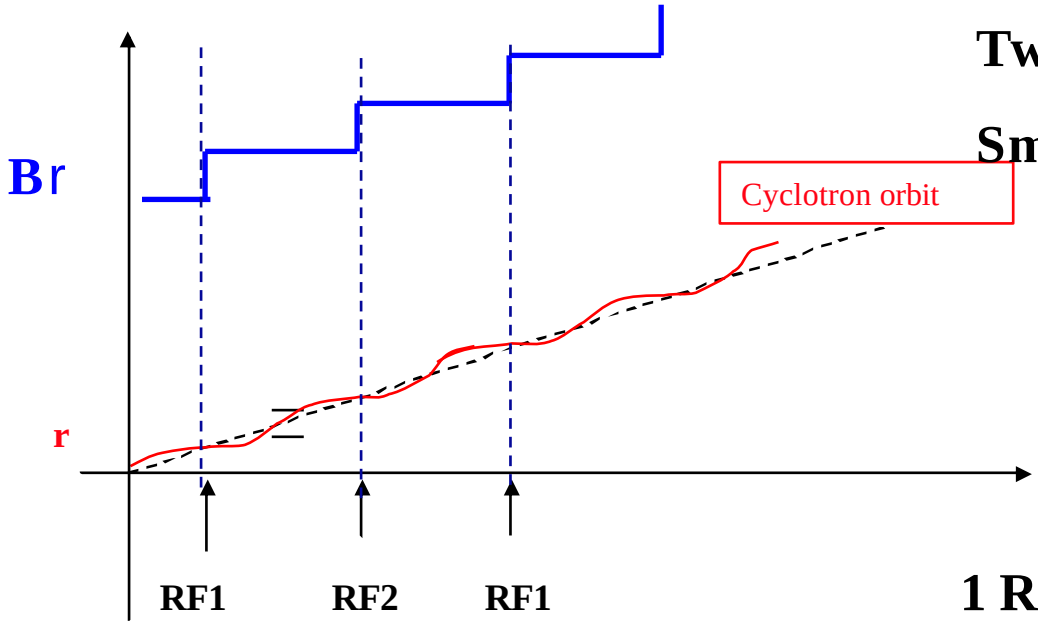
- **Direct line CIME-experimental caves:**
  - Predesign study achieved
  - Under discussion in the frame of the SPIRAL2 project

GANIL-SPIRAL Looking Toward the Futur

- A new machine, SPIRAL2, is about to be constructed on the GANIL site (talk TUZCR04 by P. Bertrand).
- The post-acceleration of the exotic beams produced will be done by the actual cyclotron CIME from SPIRAL1.
- Therefore, new safety requirements have to be applied and constraints taken into account for those exotic beams accelerated. In this frame, projects were launched such as access control upgrade, improvement of the SPIRAL1 equipment reliability, new transfer line, …
- Internal report compiles about 15 potential SPIRAL improvements identified before SPIRAL2 coming

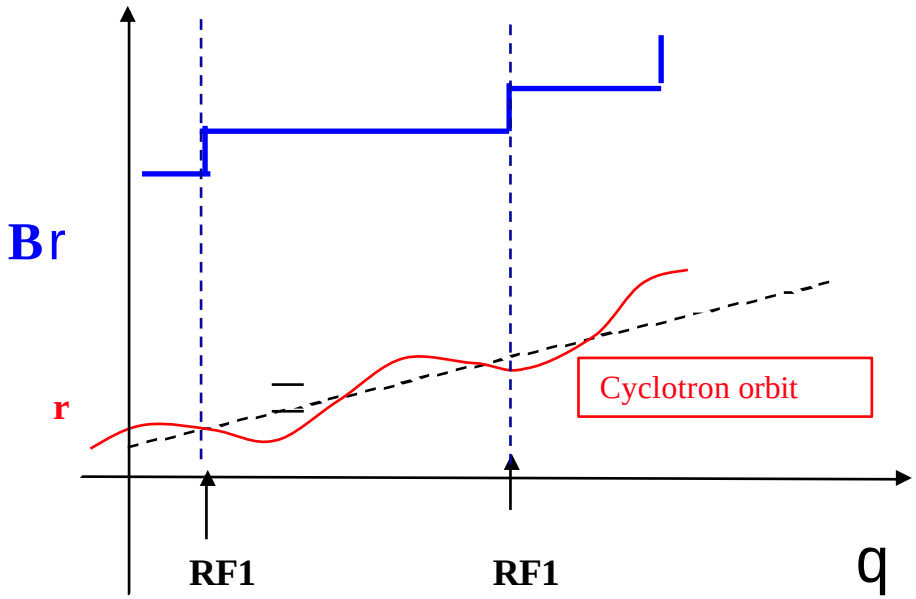
Thank you for your attentio

Beam dynamics in cyclotron



Two RF cavities :

Smooth H=2 oscillations



1 RF cavity (1 OFF) :

STRONG H=1 oscillations

<u>Simulation in CSS1</u>

radial oscillation : up to 7cm

<u>Experimentally</u>

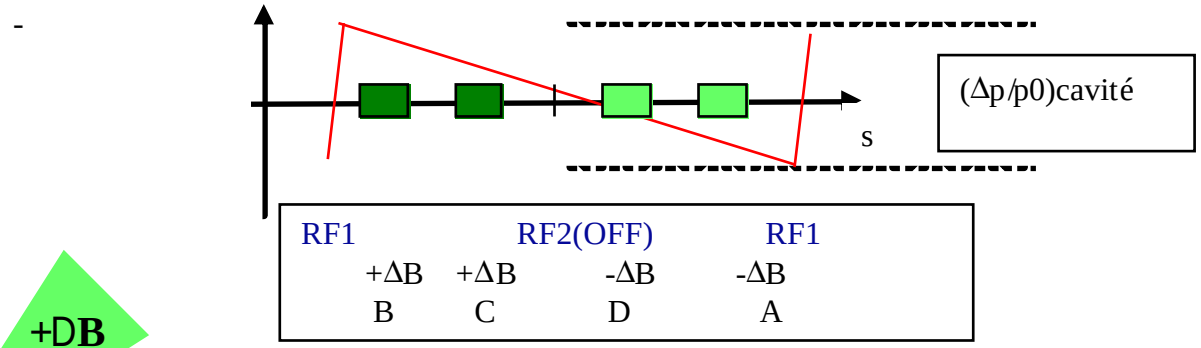
Impossibility to extract the beam

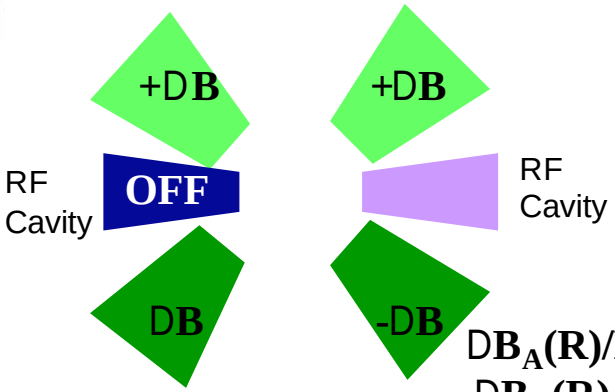
0% transmission ! !!!!

Field Corrections

Pref=Pinj+ q/2p * (DP)$_{RF}$

(P-Pref)/Pref



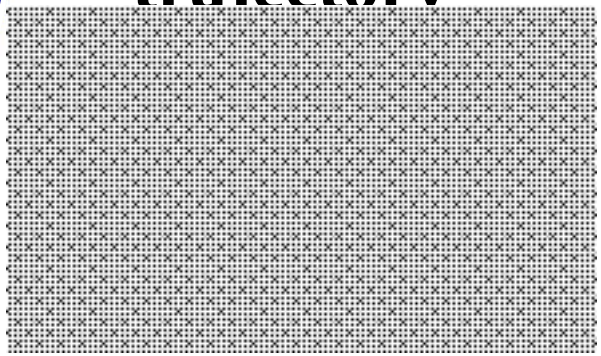


DB$_A$(R)/B= - 0.5 cos(45°) s injection R injection / R^2
DB$_B$(R)/B=+ 0.5 cos(45°) s injection R injection / R^2
DB$_C$(R)/B=+ 0.5 cos(45°) s injection R injection / R^2
DB$_D$(R)/B=- 0.5 s cos(**45°**) σ injection R injection / R^2

s injection=turn separation At injection

Beam dynamics :

Hill equation over 1 turn for the central trajectory



$$\left[\frac{\Delta p}{p}\right]_{1\ cavity} = \frac{\Delta B\,r}{B\,r} = \frac{\Delta r}{r} = \frac{s}{r}$$

With 1 cavity => 1 defect per turn

$$x'' + \left(\frac{1}{r^2(s)} - k\right)x \approx \frac{1}{r(s)}\frac{s}{2r(s)}\cos\left(\frac{s}{r}\right) + \frac{1}{r(s)}\frac{\Delta Bz(s)}{B} = 0$$

With 1 cavity + field correction

Reduction of the h=1 oscillation :

=> $|\Delta B(R)|/B = -0.5\,\sigma\cos(s/R)/R$

Correction of the sectors

$\Delta B_A(R)/B = -0.5\cos(45°)\,s_{injection}\,R_{injection}/R^2$
$\Delta B_B(R)/B = +0.5\cos(45°)\,s_{injection}\,R_{injection}/R^2$
$\Delta B_C(R)/B = +0.5\cos(45°)\,s_{injection}\,R_{injection}/R^2$
$\Delta B_D(R)/B = -0.5\,s\cos(45°)\,\sigma_{injection}\,R_{injection}/R^2$

* $s_{injection}$=turn separation at injection