GANIL OPERATION STATUS AND DEVELOPMENTS

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Abstract

The GANIL (Grand Accélérateur National d'Ions Lourds) produces and accelerates stable ions beams since 1982. The first radioactive beam post-accelerated with the CIME cyclotron happened in 2001. In 2013, stable beams with higher intensities and new energy range will be available from the new superconducting linear accelerator SPIRAL2. In 2014, new exotic beams will be accelerated with the existing cyclotron CIME. This paper will show how GANIL facility is preparing the arrival of SPIRAL2 accelerator. To achieve this goal two main objectives have to been set:

- Continuing the delivery of high intensity and exotic beams.
- Pursuing the developments of the machine capabilities in a project structure in order to keep equipments running with a high reliability yield and still responding to physics demands.

The progress in ion source production (both beam intensities and new species) will be presented together with the foreseen GANIL beam delivery capabilities when SPIRAL2 will be in operation.

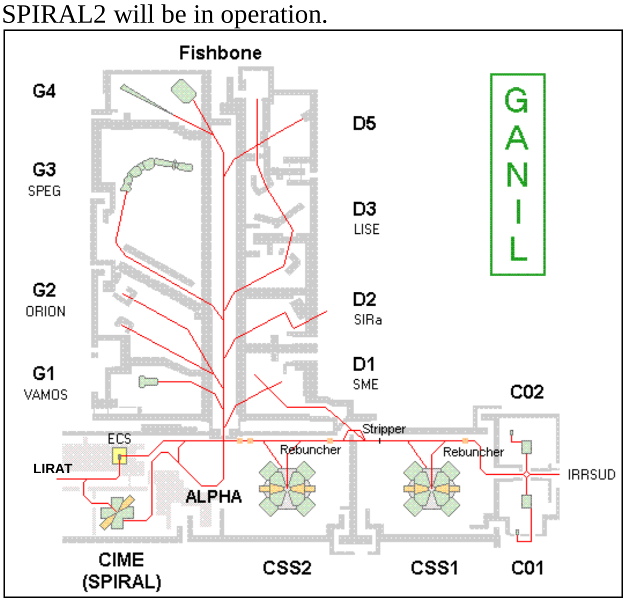

Figure 1: GANIL layout

RUNNING MODES AND BEAM REVIEW

Multi-beam delivery is routinely done at GANIL using its 5 existing cyclotrons. Up to five experiments can be run simultaneously in different rooms with stable beams:

- Beams from C01 or C02 are sent to an irradiation beam line IRRSUD (<1MeV/u).
- A charge state of the ion distribution after the ion stripping downstream CSS1 is sent to atomic physics, biology and solid states physics line D1 (4-13MeV/u).
- A high-energy beam out of CSS2 transported to experimental areas (<95MeV/u).
- An auxiliary experiments shares the previous CSS2 beam (10% of the pilote experiment time)
- Finally, stable beams from SPIRAL1 source can be sent to LIRAT (<34keV/A) or post-accelerated by CIME and given to detector tests for example.

During radioactive beam production with SPIRAL1, the combination are reduced to the four first and with radioactive beam sent to the 2 experimental areas.

Intense Primary Beams

The facility delivers a wide spectrum of high intensity ion beams ranging from ^{12}C to ^{238}U accelerated ranging from 95MeV/u for the lighter ones (12C) to 24MeV/u for Uranium beams. The acceleration scheme lies on the use of three cyclotrons in line. One compact injector cyclotron (C01 or C02, K=30) and two separated sector cyclotrons (CSS1 and CSS2, K=380). Those accelerators and beam lines have been adapted to transport intense ion beams. More than 10 beams are available at a power exceeding 1kW (Table 1) over the 50 stable beams available from the GANIL sources [1]. The beam losses detectors, beam transformers and control system allow the transport of intense stable beams with power exceeding 3kW in routine operation. The main limitations come now from the SPIRAL1 target ability to withstand beam power greater then 3kW and the GANIL safety limitations rules (beam < 2 10^{13}pps or 6kW).

Table 1: The GANIL high intensity beams

Beams	Imax [µAe]	10^{13} [pps]	Emax [MeV/u]	Pmax [W]	Used with Spiral
$^{12}C^{6+}$	19	2	95	3 600	planned
$^{13}C^{6+}$	18	2	75	2 900	X
$^{14}N^{7+}$	15	1.6	95	3 400	planned
$^{16}O^{8+}$	16	1	95	3 000	X
$^{18}O^{8+}$	2.3	0.18	75	400	
$^{20}Ne^{10+}$	15.7	1	95	2 400	X
$^{22}Ne^{10+}$	15	1	80	2 600	planned
$^{24}Mg^{12+}$	20	1	95	3 800	planned
$^{36}S^{16+}$	11	0.43	77.5	1 900	X
$^{36}Ar^{18+}$	24	0.8	95	4 600	planned
$^{48}Ca^{19+}$	4.5	0.15	60	700	X
$^{58}Ni^{26+}$	4	0.1	75	700	
$^{76}Ge^{30+}$	3.5	0.07	61	500	
$^{78}Kr^{34+}$	7	0.13	70	1 200	X
$^{124}Xe^{44+}$	2	0.03	50	300	

Exotic Beam Production

Exotic beams are produced with two complementary methods. The ISOL (Isotope Separation On Line) method with SPIRAL1 where the primary heavy ion beam is fragmented into a thick carbon target. The fragments produced are ionized by an ECR source and post-accelerated with the cyclotron CIME (K=265) from 1.2 to 25MeV/u. Table 2 gathered the exotic beam produced by SPIRAL1 and sent to physics. The production of the isotopes is very dependant of the charge state [2]

Table 2: Radioactive beam produced and post-accelerated from 2001 to 2009

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	34 keV/A Lirat	2.10^8	24Ne	7.9	1.4 10^5
6He	20	5.10^6	24Ne	10	2 105
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	2 104			

The production of exotic beam by an In Flight method is also possible with the new rotating , high power target system installed in the LISE beam line, called CLIM (Cible LISE à Intensité Maximale). This devise allows the fragmentation of high energy and intense primary beams onto a rotating target. The equipment is located in the LISE experimental room (Figure 3). The exotic cocktail beam after the target is purified with the following fragment separator spectrometer. A 2kW beam can be sent to the 2000rpm target with a maximum of 800W beam power deposited. This is an alternative to the device SISSI (Superconducting Intense Source for Secondary Ions) [3] which operation had been stopped in 2007. The energy beam produced is comparable to the primary beam (max 95MeV/u)

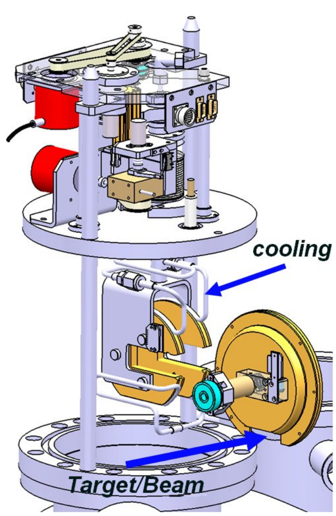

Figure 2: Schematic view of rotating target CLIM before insertion in the module for irradiation.

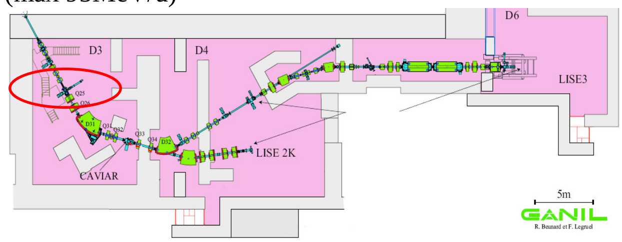

Figure 3: LISE experimental room (D3, D4 and D6) where In Flight exotic beams are produced

2001-2009 GANIL OPERATION STATUS

Since 2001, (Figure 4) more than 26400 hours of beam time was delivered by GANIL to physics. 16700 hours of beam time have been delivered to physics from the CSS cyclotrons and 9700 hours from SPIRAL1. The total beam time for physics (tuning and maintenance excluded) is on the average around 3000 hours a year.

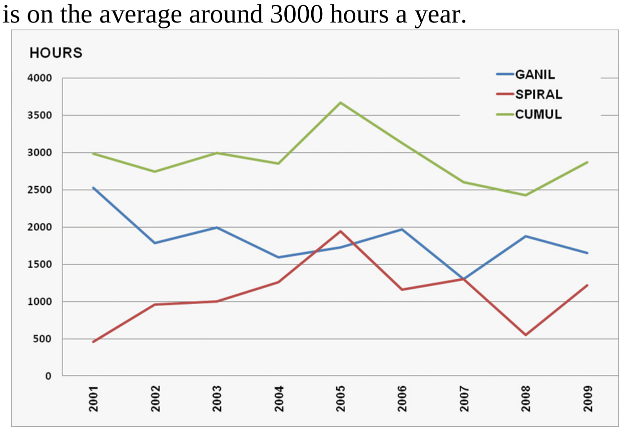

Figure 4: Beam time repartition between SPIRAL and GANIL beams over 9 years.

The number of beam delivered per year (Figure 5) has increased but the tuning time requiered impacts on the time dedicated to physics. Campagne of physics with similar ion beam is tempted to reduce tunings.

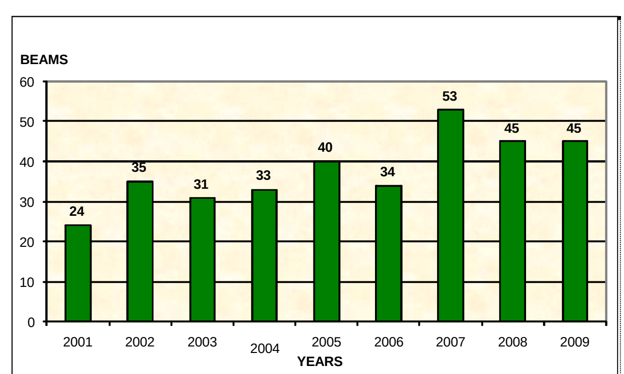

Figure 5: Number of beams tuned between 2001 and 2008

Finally, maintenance on a 27 year old accelerator is a main concern. Recently:

- 36 power supplies of the fishbone and entrance of few experimental rooms have been changed. This allows us to test also in operation the future equipment and command-control system for the SPIRAL2 project.
- All of the flexible cooling water pipes (600) of the magnets and RF systems (except experimental area) have been replaced.

Those actions are manpower consuming but the Figure 6 shows such maintenance actions have given rise to a higher availability time.

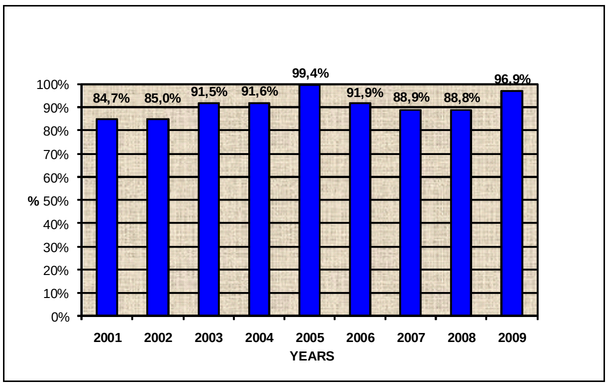

Figure 6: Ratio between the beam time available to the physics to the scheduled beam time online.

STABLE BEAM DEVELOPMENTS

The GANIL source activity [4] is focused to improve the reliability of the actual beams delivered (~30 chemical species + isotopes) as well as the intensities within the safety range limitations (2.10^{13}pps or 6kW beam out of CSS2). It goes with an improvement of the oven for the metallic ion production. Two different steps are under study. First, a modified version of the existing micro-oven at high temperature (1700°C max) to a higher capacity oven (Figure 7) but at a lower average temperature (1100°C max). In a second step build a large capacity and high temperature oven. Above the 1700°C temperature limit, development with induction oven is foreseen. Those developments are coherent with the beam needs expressed by the SPIRAL2 project for the production of $48Ca^{16+}$ and $58Ni^{19+}$.

Table 3: GANIL recent stable beam developments

Beams	Imax [µAe]	10^{13} [pps]	Emax [MeV/u]
$^{64}Zn^{28+}$	1.2	0.03	74
$^{127}I^{45+}$	0.23	0.03	49.5
$^{133}Cs^{47+}$	0.08	0.01	49.3
$^{238}U^{34+}$	0.04	0.01	7.8

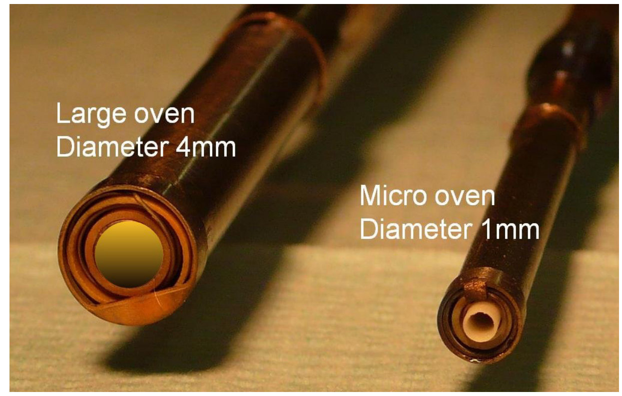

Figure 7: Example of large and micro oven developments

EXOTIC BEAM DEVELOPMENTS

The recommendations of "GANIL 2015", a prospective study on the possible evolution of the SPIRAL1 facility driven by letters of intent from the physicist community have emphasized the importance of broadening the range of the exotic and stable ion beams from the SPIRAL1 target ion-source system. Today, only gaseous elements can be produced (see Tableau 2) due to the use of a cold transfer tube installed between the production target and the ECR source. To overcome this limitation a new project is launched to modify the SPIRAL1 cave in term of power and connectors. No modification on the remote system is foreseen as well as the modification of the storage of used target-ion sources. But it is showed that solutions for remotely install new types of ion sources to permit the production of other elements are possible. It is then expected to have by the end of 2013 the first new 1+ exotic beams produced out of the actual SPIRAL1 thick carbon target. These 1+ beams are further stripped by a charge breeder downstream before the post-acceleration by the CIME cyclotron.

Charge Breeder

Because of strong constraints on the SPIRAL1 Target and Ion Source units (TIS) dimensions, the choice was made to start with compact 1+ sources such as FEBIAD (Forced Electron Beam Induced Arc Discharge) source producing various 1+ metallic ions.

This new 1+ beam could be sent to LIRAT line but a charge breeder has to be inserted between the TIS unit and CIME to reach the N+ charge of the ion required for acceleration with the CIME cyclotron. A collaboration with ISOLDE (CERN) has been set up to install their phoenix 1+N+ test bench at GANIL[5]. It will be mechanically adapted to be inserted in the actual low energy line (fig 3). It is foreseen that by the end of 2013 the first new SPIRAL1 exotic beam is produced.

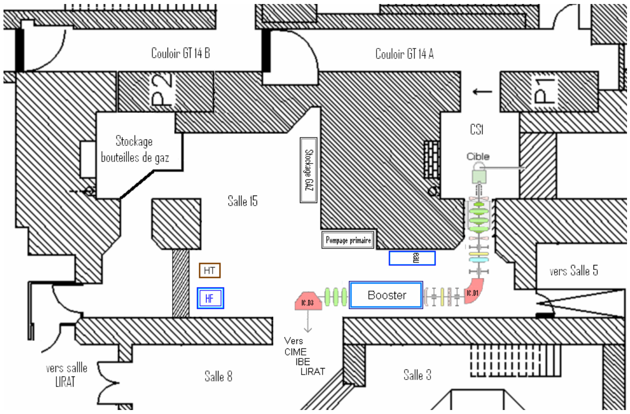

Figure 8: SPIRAL1 low energy beam modifications to insert a new charge-breeder.

Intense R&D activities are being pursued in the framework of this new project to define other possible source types such as surface ionization source, EBIS source or advanced N+ source with high density plasma.

SPIRAL1 Beam Purification System

Even if the present ion source of SPIRAL1 is too selective from the physicist point of view, the exotic beam is nevertheless sometimes accelerated with CIME polluted by ions with a ratio mass over charge (M_2/Q_2) close to the ion of interest (M_1/Q_1) and then be extracted and sent to the physics. The condition to eliminate an undesired ion corresponds at first order to:

$$\left[\frac{M_2}{Q_2}-\frac{M_1}{Q_1}\right]\Big/\frac{M_1}{Q_1} > \frac{1}{2\pi\ H\ N_{turn}} \qquad (1)$$

Where N_{turn} and H are respectively the number of turns and the harmonic in the cyclotron. Hence the mass resolution of a cyclotron is defined as $R = 1/2\pi\ H\ N_{turn}$. The mass resolution of CIME can reach 2 10^{-4}. But even with this resolution beam tail may exit. For example, isobars are of main concern because purification around 10^{-4} or 10^{-5} would be needed and is out of reach of the cyclotron. Similarly, in a close future, SPIRAL2 beams will also be affected by the same problem more dramatically mainly due to the production mode. Thus, an upgrade of the diagnostics station for beam detection and purification will be installed at the exit of CIME in the fall of this year (Figure 9). Composed of remotely controlled silicon detectors for identification and 7 thin targets for purification by stripping or by energy loss in a degrader. The drawback can be an important intensity loss for beam energies below 3MeV/u.

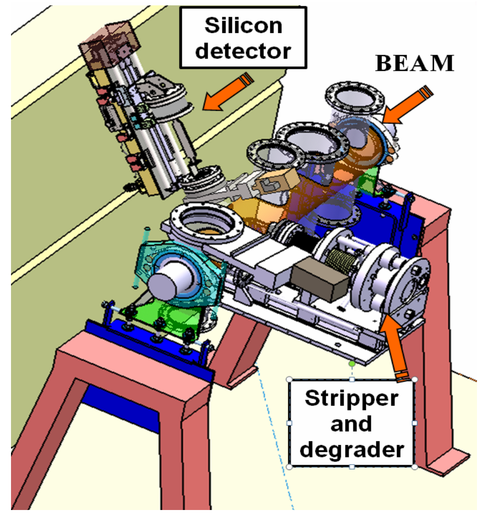

Figure 9: New diagnostics vessel at the extraction of CIME to improve the identification of post accelerated exotic beams and their purification by stripping and energy degrader remotely inserted.

Another way explored since few years, is the development of an electrostatic vertical deflector (Figure 10). An elegant solution is to insert an electrostatic vertical deflector around the 10 last trajectory paths of the beam in the cyclotron. The amplitude of the sinusoidal electric wave between the deflector plates will be zero for the beam of interest (isochronous) and increase with the mass/charge ratio difference. The efficiency of such a device is measured and is able to reduce by a factor 10 beams which have difference of M/Q as low as 310^{-4}. It is expected to test this device in 2011.

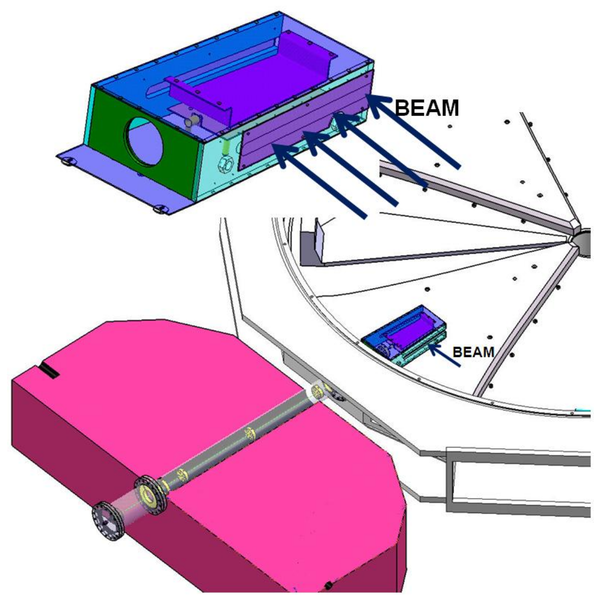

Figure 10: Electrostatic vertical deflector used to purify exotic beam from polluant beam.

FORSEEN OPERATION

The SPIRAL2 machine [6] will increase the capability of GANIL in term of beam time. It is possible to use at the same time the new SPIRAL2 beams and the existing ones (Figure 11). 44 weeks for SPIRAL2 and 36 weeks for GANIL a year are foreseen. The Figure 11 shows the possible sequences between accelerators:

- Stable beams :
  - LINAG
  - CSS1 and 2
  - CSS1 solo
  - SME
  - IRRSUD
- Exotic beams :
  - SPIRAL1
  - SPIRAL2
    - UCx target
    - Other targets

Again along with GANIL 2015 conclusions [7], one of the main recommendation was to ask for detailed studies to allow the high intensity beams of SPIRAL2 into specifically identified caves have to be carried out with very specific constraints from the radioactive beams.

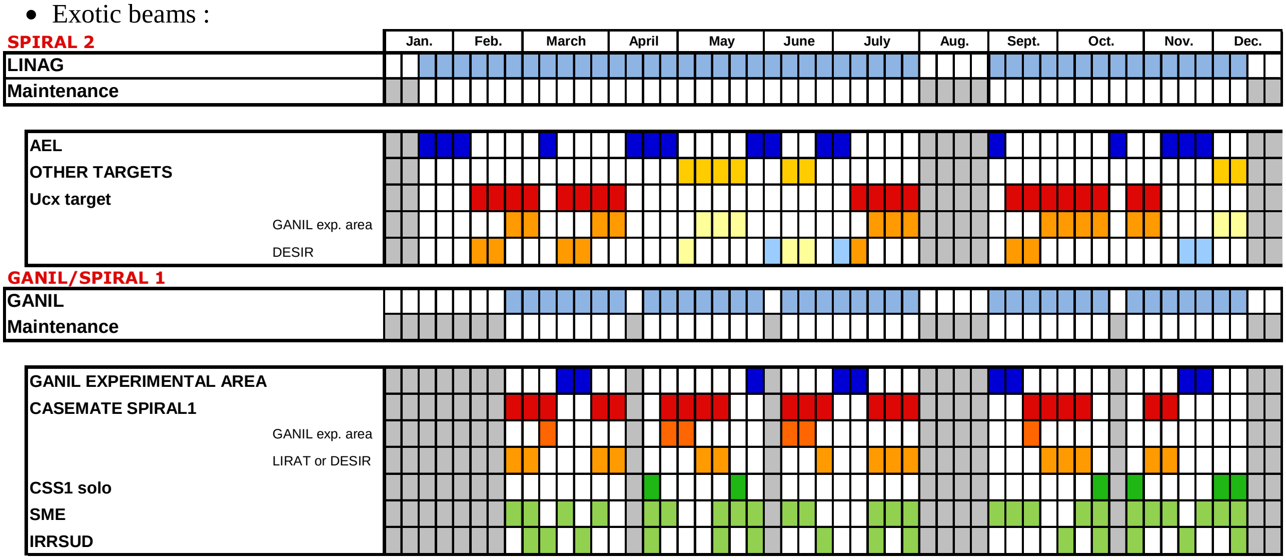

Figure 11: GANIL operation potential with the SPIRAL1, SPIRAL2 and CSS

CONCLUSIONS

The first beam of GANIL was sent to an experimental room in 1983. Since then, the variety and intensity of the ion beams available has continuously evolved. Progresses in the ion source domain make possible to potentially the transport of kW beams. The cyclotrons and the beam lines had to be upgraded to handle such a new constraint. In 2001, the first exotic beam of SPIRAL1 was produced with the existing cyclotron used as a driver. The exotic ion production was then strongly dependant of the target power capabilities and of the increase of the primary beam power. The developments made led to the production of 3kW target for SPIRAL1 and meanwhile increase the primary beam power within the safety limits (<6kW).

The diversity of the ion species (stable and exotic) is now the main concern at GANIL. The present selective ECR ion source should be replaced by alternative ion sources in order to access to metallic beams.

The great care given to the maintenance of the 27 years old allows us to still expect to increase its performances and be competitive until the completion of the SPIRAL2 facility.

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