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GANIL : A PROPOSAL FOR A NATIONAL HEAVY-ION LABORATORY

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Summary

Under the control of the French Atomic Energy Commission (CEA) and of the National Institute of Nuclear and Particle Physics (I N2 P3) a multi accelerator system for heavy ions is beeing studied.

The heart of this system consists of two identical conventionnal separated-sector cyclotrons K = 400 (SSC 1 and SSC 2) ; at the output of SSC 1 ions are stripped through a foil, high charge is selected and injected into SSC 2.

The injection into SSC 1 will be achieved by a small compact cyclotron or by an 1 MV electrostatic accelerator.

As the required beam must be intense and precise (energy resolution and emittance) special attention has been paid for a careful matching of the three stages of acceleration in transversal and longitudinal planes taking into account space charge forces as well as electric and magnetic defects.

A set of parameters for the two main machines and their injectors is given.

1. Beam requirements

Aiming to be a national heavy ion facility, GANIL has to fulfill the beam requirements expected by the nuclear physicists and chemists on the range of mass and energy, the intensity, the energy spread and emittance. See Table 1 for the main beam characteristics.

2. The accelerator complex

The general disposition of the accelerator complex is shown on Fig. 1.

The low charge state beam coming out of the small injector cyclotron C01 is injected into the separated sector cyclotron SSC1.

As an alternative for the injection of very heavy ions, a 1 MV platform could also be used, but is not yet considered, for the C01 cyclotron seems to have excellent performances in all ranges of ions.

A foil stripper located between the SSC1 and the SSC2 increases the charge state by a factor of 4 approximatively. The beam ejected from the CSS2 is directed toward the experimental area via a beam splitter.

In addition as a possible development of the facility it has been proposed to double the first stage of the accelerator (SSC1) by a 20 MV tandem electrostatic generator.

One interesting feature of this machine is that the two big cyclotrons can be used separately when only medium energy beams are needed in the range of light ions, for instance 50 MeV/A for N^{5+} or 9 MeV/A for Ar^{6+}. This is the reason why each big cyclotron is equiped with a small injector cyclotron.

A description of the main parameters is given in table 2. All the cyclotrons work on the same fundamental radiofrequency.

3. The injector cyclotron

The injection will be achieved by a small compact cyclotron for all particles and energies. As we need only low charge state ions in our design we will use conventional sources of the "cold" or "hot" cathode type. The axial injection of ions from an external source is also under study.

The computations show that the beam extracted from the small cyclotron is suitable for injection into SSC1 : phase width of 15°, energy resolutions 1 per cent, emittance 45 π mm.mrad horizontally, 150 π mm.mrad vertically for the required intensity.

4. Beam matching between the cyclotrons

In order to avoid particle losses when the beam is injected into the SSC1 and the SSC2, and undesirable oscillations when the beam is accelerated, a careful study should be made of the beam transfer system between the cyclotrons. The most difficult case is the beam path between the injector C01 and the SSC1, where ions travel at a slow velocity and with a large emittance.

A convenient system of magnet dipoles and quadrupoles can fulfill the matching of the beam in the "$x, \frac{dx}{ds}, y, \frac{dy}{ds}, t$" space.

The longitudinal debunching of the beam pulse resulting from the chromatic aberration can be corrected almost perfectly by the use of a bunching cavity located midway of the beam path.

5. Beam dynamics for the two SSC

A program has been written and used to simulate the particle motion in the SSC, in order to obtain more information about the parameters of this type of machine. This program is described elswhere [1].

The conclusions are :

The axial stability is good for all cyclotrons.

Flat-topping of the R. F. amplitude is needed for the 2 big cyclotrons to reach the requirements in intensity and energy resolution.

The choice of the harmonic number "k" of the flat-topping frequency depends on a compromise between the following properties : for the same energy resolution, the required voltage is proportionel to $1/k^2$, the phase acceptance is proportional to $1/\sqrt{k}$ and the maximum admissible phase error between the fundamental and the flat-topping R.F. favors the high "k" numbers. For these reasons a harmonic number from 3 to 5 has been chosen.

The amplitude of the flat-topping voltage should be proportional to the amplitude of the fundamental voltage within thin tolerances.

However the thin tolerances bear only on the values averaged over the radius. Locally they may depart significantly from the average value without affecting too much the beam qualities. But if the flat-topping is locally too far from the correct value, energy spread is generated as well as important radial oscillations.

For the SSC1, the ratio of the fundamental radio frequency to the particle frequency should not be too high, also the energy gain per turn to the energy of the particle should be not too large. Otherwise the isochronism will be impaired.

The space charge does not affect much the beam dynamics in the SSC. Its main effect is a slight increase of the energy resolution.

6. Injection and extraction

Injection and extraction are made in the median plane for both SSC, using the space available in the two "empty" valleys. Computations have shown that conventional electrostatic and magnetic deflectors can be used for that purpose.

One of the main advantages of the SSC complex is to allow single turn extraction, due to the separated orbit pattern of the beam. In fact 100 percent injection and extraction could be achieved without difficulty, except for the extraction from the SSC2 of particles having the highest velocity.

In that case the turn spacing is about 2.5 mm, somewhat lower than the beam width. A first harmonic defect in the magnetic field will be used to increase the turn spacing. This harmonic should have a strong radial gradient, for the radial wave number $\nu_r \simeq 1.2$ does not allow a true resonnant extraction. For a gradient of 70 gauss per cm, the turn spacing can be increased by a factor of 4 over a few revolutions. Consequently, single turn extraction can be achieved.

7. R.F. system

Conceptually, the R.F. system for SSC1 and SSC2 will be similar to the R.F. system of the Indiana University Cyclotron.

However because of a much larger frequency range requirement (3 to 14 MHz) we will probably have to use both a moving short circuit and a moving pannel.

The flat-topping dees will be located within the fundamental dees.

High gain low-level servo controls will be relied on to achieve the necessary regulation of voltage and phase between the 4 independant fundamental dees and the 4 independant flat-topping dees.

Present status and conclusion

The theoritical studies of the GANIL project will be completed this year. A model of a sector magnet will be built and experimented next year. Different models of R.F. cavity are under construction. More knowledge of the stripping process and the heavy ion sources behavior will be gathered from the experiments which are under way in other french laboratories.

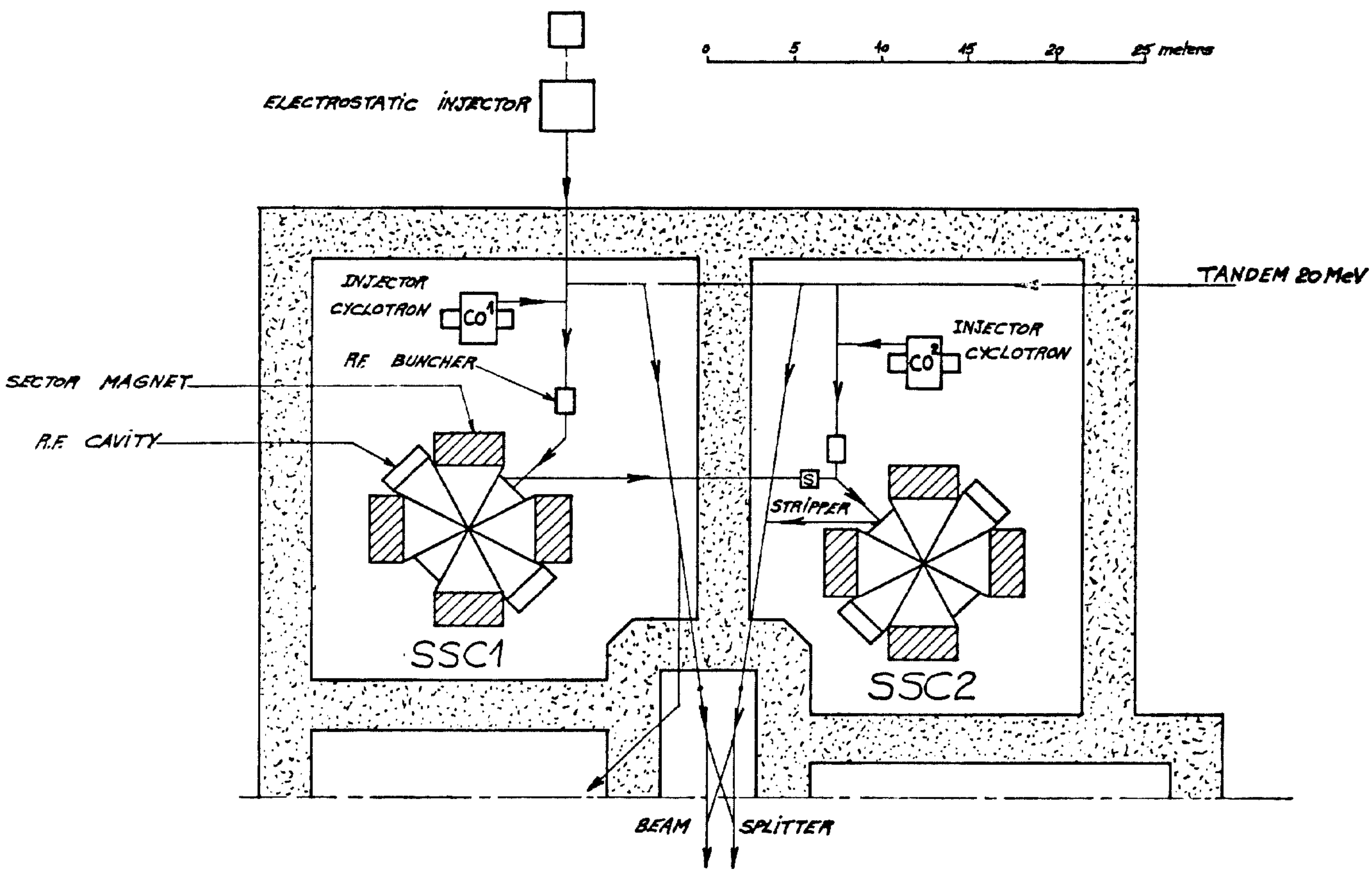
Comparative studies of other accelerator systems, like a H.I. LINAC or a synchrotron prove that the GANIL project is the most economical system for the planned beam requirements. Morever, the GANIL project is flexible enough to be accommodated in the future to the use of higher charge state ions sources.

Reference

1. A. Chabert, T.T. Luong, M. Promé
Separate Sector Cyclotron Beam Dynamics
(to be given at this conference)

TABLE 1 - GENERAL BEAM CHARACTERISTICS

MASS NUMBER A	MAXIMUM ENERGY (MeV per nucleon)	FLUX (PARTICLES PER SECOND)	ENERGY RESOLUTION $\Delta W/W$	EMITTANCE (mm.mrad at 10 MeV/A)		DUTY FACTOR %	
				HORIZONTAL	VERTICAL	MACRO (PIG source)	MICRO
< 60	from 100 for Carbon to 8 for Uranium	2.10^{11}	4.10^{-4}	5	50	25	4
		10^{12}	4.10^{-4}	50	50	25	4
		10^{13}	10^{-3}	100	100	25	4
> 60		10^{11}	10^{-3}	100	100	25	4



GENERAL LAYOUT OF THE GANIL ACCELERATOR COMPLEX

FIGURE 1

TABLE 2 - GANIL MAIN PARAMETERS

	C_o	SSC 1	SSC 2
1 - Orbit parameters			
Energy constant K	25	400	400
Number of sectors N	1	4	4
Sector angle 2α		52°	52°
Injection mean radius R_i		0.75 m	0.75 m
Extraction mean radius R_e	0.375 m	3 m	3 m
Energy ratio W_e/W_i		16	16
Betatron wave numbers		$\nu_x \sim 1.07-1.20$	$\nu_x \sim 1.07-1.20$
		$\nu_z \sim 0.86-0.73$	$\nu_z \sim 0.86-0.73$
Beam envelope modulation m_e		$m_{ex} \sim 1.4-1.5$	$m_{ex} \sim 1.4-1.5$
		$m_{ez} \lesssim 1.1$	$m_{ez} \lesssim 1.1$
RF phase acceptance	15°	15°	15°
2 - Magnets			
Magnet gap	20 cm	10 cm	10 cm
Maximum field	1.91 T	1.6 T	1.6 T
Main coil power	150 kW	600 kW	600 kW
Iron weight	$\sim$ 54 t	1600 t	1600 t
Main coil copper weight	4 t	16 t	16 t
Number of trimming coils		> 30	> 30
3 - RF cavities			
Dee number	2	2	2
Dee angle	60°	28°	28°
Peak RF working voltage	110 kV	250 kV	250 kV
RF power (per dee)	25 kW	100 kW	100 kW
Fundamental resonator tuning range	3-14 MHz	3-14 MHz	3-14 MHz
Harmonic (RF/orbit frequency)			
C_o + SSC1 + SSC2 case	4	8	2
C_o + SSC	1	2	2
Flat-topping harmonic		3-5	3-5
4 - Vacuum			
Operating pressure	10^{-6} Torr	5.10^{-8} Torr	3.10^{-7} Torr