STATUS REPORT ON GANIL

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ABSTRACT

The first beam (Ar^{+4}) from SSC1 was obtained in June 82. A full energy Ar^{+16} beam at ∿ 44 MeV/A was accelerated in SSC2 in November and delivered to physicists in January 83. Till now, nine experiments have been performed.

I. INTRODUCTION

GANIL was already described in many conferences[1,2,3,4,5] so we just briefly recall the general lay-out (fig. 1) and the main characteristics of expected beams (fig. 2). This paper deals with the main results obtained on beam operation with SSC1 (from June 82), SSC2 (from Nov. 82). A short description of physics experiments already made with a 44 MeV/A - Ar^{+16} ion beam is also given.

II. OPERATION ON THE PRESTRIPPER LINE

1. I_1 injector

The beam characteristics from the injector cyclotron are in good agreement with computations. They are summarized in Table 1.

Table 1

RF harmonic number	: 4
RF frequency	: 9.52 MHz
RF voltage	: 56.8 kV
Pressure	: 1 - 1.5 10^{-6} Torr
Number of accelerated turns	: 14
Ion source duty cycle	: .25 - .50
Extracted beam (Ar^{+4})	: 1 - 1.5 10^{12} pps (1 eμA)
Longitudinal emittance	: $\lvert\Delta\phi\rvert \; \lvert\frac{\Delta W}{W}\rvert \sim 6° \times 3\ 10^{-3}$
Radial emittance (full beam)	: Er ∿ 50 πmmrad
Vertical " " "	: Ez ∿ 30 πmmrad
Energy stability	: $\frac{\delta W}{W} \sim 10^{-4}$

For the moment, physicists do not require high intensities.

2. Transfer line L_1 (fig. 2)

According to theory L_1 was tuned so as to provide achromatism but correlations and matching are not yet fully controlled. Slits are limiting the emittance given by I_1 to the acceptance of SSC1, i.e. 40 πmmrad, so that the overall transparency of L_1 is usually 80 % for such an emittance. Rebuncher R_1 is working as expected without any problem.

3. SSC1

Acceleration began on June 1982 without phase compression [6], and some weeks later with phase compression, which is the normal procedure.

3.1. Injection

The injection + acceleration efficiency is routinely ∿ 75 % and tuning is very easy. However, a coherent vertical oscillation was observed ; repositionning of the magnetic septum SMi3 reduced the amplitude to ∿ 5 mm.

3.2. Acceleration

The adequate value of the main field in sectors is achieved by the means of the ISOGRO code which uses the beam phase values given by 15 radial phase probes to compute the extra main coil current needed to get a global isochronism. Distorsions of the curve due to local anisochronism are also analyzed and trim coil currents are computed.
The RF phase at injection is optimized looking at the position of the last 2 or 3 accelerated turns by means of radial probes. The optimum phase is obtained when the radius of the last orbit is maximum.

The RF voltage (∿ 140 kV) has been chosen so as to get the 68th orbit ejected. A fine tuning of this voltage is needed to get this last orbit precisely positionned at the entrance of the ejection septum.
Bad injection conditions (R_i, R'_i) are easily detected by ISOGRO : the phase curve exhibits oscillations which can be then minimized.

Beam off-centering is computed by TROPIC a code computing the radial beam position at the center of the hills from the signal of 4 yoke probes moving from the inner to the outer radius. The first harmonic of the magnetic defects as well as the residual betatron oscillation are calculated (see appendix) ; the corresponding field corrections are then applied, acting on the respective auxiliary coil current of each sector.

The minimum radial betatron amplitude is ∿ 5 mm. The first and last 10 turns are perturbed by magnetic injection and extraction elements ; amplitude and phase of these defects are so quickly varying with radius that corrections by trim coils is not easy.

Recently, the power supply for the main magnetic field has been locked so as to maintain a constant difference between the phase of the ejected and injected beam. A considerable improvement of the beam stability has resulted from the application of this technique.

Introduction of phase compression was successful : a factor 2 ($\Delta\phi_{inj} \sim 10° \rightarrow \Delta\phi_{ej} \sim 5°$) leads to a rather small energy dispersion for the extracted beam ($\Delta W/W \sim 10^{-3}$) as expected.

3.3. Extraction

If the above mentioned procedure is carefully followed, the single turn extraction is straight forward with ∿ 90 % efficiency.

Table 2 gives some data about SSC1 and characteristics of the accelerated beam.

Table 2

RF harmonic number	: 7
RF frequency	: 9.52 MHz
RF voltage	: ∿ 141 kV
Mean vacuum pressure	: 5.10^{-8} Torr
Number of accelerated turns	: 68
Turn separation	: { 1st turn ∿ 38 mm
(with compression)	: at extraction ∿ 25 mm
Extracted beam (usual)	: ∿ 5 10^{11} pps (300 enA)
Overall efficiency	: ∿ 70 %
Bunch length at injection	: ∿ 10°
" " at extraction	: ∿ 5°
Energy of the extracted beam	: 3.42 MeV/A
Energy resolution	: < 10^{-3}

III. OPERATION ON THE POST-STRIPPER LINE

1°) Transfer line L2

No time was alloted for fine tuning of L2 line so that theoretical conditions (achromatism, correlations, matching) are not controlled.
The 20 μg/cm² carbon foil stripper has a life-time of one week. The Ar^{+16} ion beam selected for acceleration in SSC2 corresponds to 35-40 % of the particles crossing the stripper, so the transparency of the whole line measured in number of particles is 25-30 %.

2°) SSC2

The first beam of Ar^{+16} accelerated at 44 MeV/A was

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obtained in November 1982 and delivered to physicists mid-January 83. Consequently, the time alloted for CSS2 beam studies was very short. The phase compression procedure is not yet used. Injection + acceleration efficiency is usually 65 % with a turn separation of 12 mm at injection. The yoke probe signal shows oscillations of the beam (off-centering + betatron oscillations) which make separation of turns not satisfactory for beam studies. Optimization of parameters is not yet done. Ejection is easily achieved using a magnetic field bump and some uncontrolled precession ; the overall efficiency is $\sim$ 50 %.

Table 3 gives some characteristics of SSC2.

Table 3

RF harmonic number	: 2
RF frequency	: 9.52 MHz
RF voltage (at R = 1 m)	: 129 kV
Mean vacuum pressure	: 1.5 - 2 10^{-7} Torr
Number of accelerated turns (without compression)	: $\sim$ 380
Turn separation (without compression)	: at injection $\sim$ 12 mm : at ejection (with bump) $\sim$ 24 mm
Extracted beam (usual)	: $\sim$ 5 10^{10} pps (120 enA)
Overall efficiency	: 50 %
Bunch length	: not yet measured
Energy of the extracted beam	: $\sim$ 44 MeV/A
Energy resolution	: $\sim$ 10^{-3}

3°) Transfer line L3

The beam is going through with the theoretical values in the quadrupoles but they are not yet matched to the SSC2 emerging beam so as to fit predicted conditions (achromatism...). The efficiency at the image point of the spectrometer is $\sim$ 90 %. The maximum current measured on the target was 150 enA ($\sim$ 6 10^{10} pps) with a beam size of $\sim$ 2 mm and an energy resolution of $\sim$ 10^{-3}.

IV. BEAM TIME DISTRIBUTION

Fig. 4 shows how the beam is distributed in time within one period of 35 days.

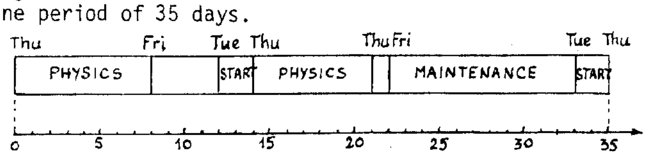

Fig. 4

V. PHYSICS EXPERIMENTS

Physics experiments have been performed at GANIL since January 1983. The first experiments essentially aim at obtaining an overview of the nuclear reaction mechanisms occuring at the incident energy of 44 MeV/A, with an ^{40}Ar beam. Especially, the transition between the strongly collective behaviour observed below 10 MeV/A and more individual one, expected from the data collected at the Bevelac, will have to be traced.

The first data show up the importance of the fragmentation phenomenon in the reaction ^{40}Ar + ^{197}Au and ^{40}Ar + ^{58}Ni, as deduced from the energy spectra and angular distribution. However, rather broad patterns are found for nuclides far below the projectile. The linear momentum transfer to the target has also been studied. It appears that in the Ar + U system, no complete fusion is observed, and the momentum transfer appears to be much more uncomplete than it was with lighter projectiles. Currently, further studies of the fragmentation mechanism, elastic scattering and isotope production from the target residues are underway.

APPENDIX

DETERMINATION OF MAGNETIC DEFECTS FROM THE YOKE PROBES.

The beam position observed in the middle of sectors (where $\beta = \beta_{max}$) at azimuth θ_i is given by :

$$R(\theta_i) = \tilde{R}(\theta_i) + a_1 \sin(\theta_i + \phi_1) + a_2 \sin(2\theta_i + \phi_2) + a_2' \sin 2\theta_i + b \sin(\nu\theta_i + \psi) \qquad (1)$$

where : $\tilde{R}(\theta_i)$ = reference orbit in $\theta = \theta_i + 2\pi N$

a_1 , a_2 = closed orbit amplitudes due to the 1st and 2nd harmonic of the magnetic perturbation

a'_2 = closed orbit amplitude due to the RF accelerating field (2 cavities at 180°) $\sim \frac{1}{2\pi} \frac{1}{4-\nu^2} \bar{\sigma}_{\theta_2,\theta_3}$

b = amplitude of the betatron oscillations (ν=frequency)

The turn separation $\sigma(\theta_i, N)$ at the N^{th} turn is :

$$\sigma(\theta_i,N) \sim \frac{1}{2}\Big[R(\theta_i, N+1) - R(\theta_i,N) + R(\theta_{i+2}, N+1) - R(\theta_{i+2},N)\Big] \qquad (2)$$

if $b \sin \pi\nu \cos \frac{\pi\nu}{2} \ll 1$ mm which is usually the case.

Using equation (1) for $\theta = \theta_i, \theta_{i+1}, \theta_{i+2}, \theta_{i+3}$ and turns N,N+1, we can derive quantities $\delta R_i(N)$ defined by :

$$\delta R_i(N) = a_1 \sin(\theta_i + \phi_1) - b \sin\frac{\pi\nu}{2} \cos\left(\nu\theta_i + \psi + 2\pi\nu N + \frac{\pi\nu}{2}\right) \qquad (3)$$

$$\delta R_i(N) \sim \frac{1}{2}\Big[R(\theta_i,N) - R(\theta_{i+2},N)\Big] + \frac{1}{8}\Big[R(\theta_{i+1}, N+1) - R(\theta_{i+1},N) + R(\theta_{i+3},N+1) - R(\theta_{i+3},N)\Big] \qquad (4)$$

This calculation assumes that amplitudes a_1 and b are nearly constant over 3 turns. Equation (3) shows that :

$$\overline{\delta R}_i(N) = a_1 \sin(\theta_i + \phi_1) \qquad (5)$$

$$\left|\delta R_i(N) - \overline{\delta R}_i(N)\right|_{max} = b \sin\frac{\pi\nu}{2} \sim b \qquad (6)$$

mean values being calculated within $\Delta N \sim \frac{1}{\nu - 1}$ turns

From (5) :

$$\begin{cases} a_1 \sin\phi_1 = \frac{\sqrt{2}}{4}\left[\overline{\delta R}_1 + \overline{\delta R}_4 - (\overline{\delta R}_2 + \overline{\delta R}_3)\right] \\ a_1 \cos\phi_1 = \frac{\sqrt{2}}{4}\left[\overline{\delta R}_1 + \overline{\delta R}_2 - (\overline{\delta R}_3 + \overline{\delta R}_4)\right] \end{cases} \qquad (7)$$

If we fourier analyze the magnetic defects $\frac{\Delta B_i}{B}(\theta_i, N)$ in sectors 1,..4 and calculate the amplitude a_1 of the corresponding closed orbit (smooth approximation) it is then easy to obtain the field corrections to apply in sectors :

$$\frac{\Delta B_1}{B} = -\frac{\Delta B_3}{B} = \frac{\sqrt{2}}{8\lambda}\left(\overline{\delta R}_1 - \overline{\delta R}_3\right)$$

$$\frac{\Delta B_2}{B} = -\frac{\Delta B_2}{B} = \frac{\sqrt{2}}{8\lambda}\left(\overline{\delta R}_2 - \overline{\delta R}_4\right) \qquad (8)$$

with

$$\lambda = \frac{\sqrt{2}R}{\pi\rho}\sqrt{\frac{\beta_{hill}}{\bar{\beta}}}\ \frac{R}{\nu^2 - 1}\ \sin\alpha .\ k$$

2α = magnetic angle of sectors

$\frac{R}{\rho}$ = circumferential factor

R = physical radius(N^{th} turn)

$\}$ k = 1.3 for GANIL due to the smooth approximation

To-day, $R(\theta_i, N)$ is computed on line by TROPIC and $\frac{\Delta B_i}{B}$ off-line. In the future, $\frac{\Delta B_i}{B}$ will be included in TROPIC.

BIBLIOGRAPHY

1 7th International Conference on Cyclotrons and their Applications. Zürich 1975.

2 8th Int. Conf. on Cyclotrons and their Applications Bloomington 1978.

3 9th Int. Conf. on Cyclotrons and their Applications Caen 1981.

4 1979 Particle Accelerator Conference. San Francisco IEEE Trans. NS 26, April 1979.

5 All Union Particle Accelerator Conference. Protvino, October 1982. To be published.

6 A. Chabert et al "Bunch length compression inside an SSC and related problems". 1981 Particle Accelerator Conference, Washington. IEEE Trans. NS 28, June 81, pp 2122-2124.

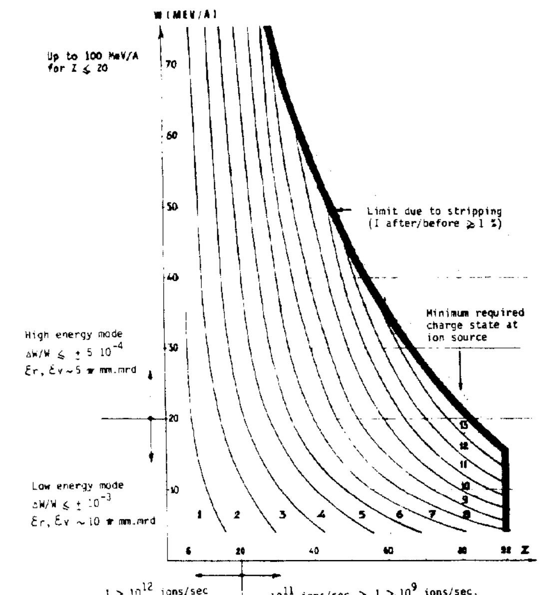

Fig. 1 : Main characteristics of expected beams.

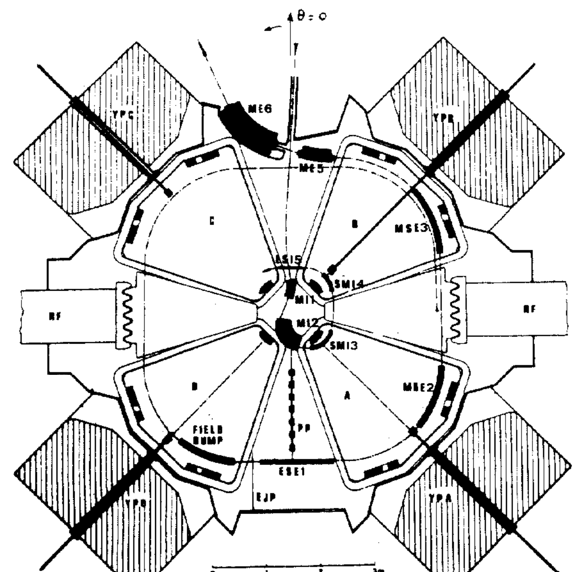

Fig. 3 : Injection and ejection systems. Yoke probes (YP), ejection probe (EJP), phase probes (15 PP).

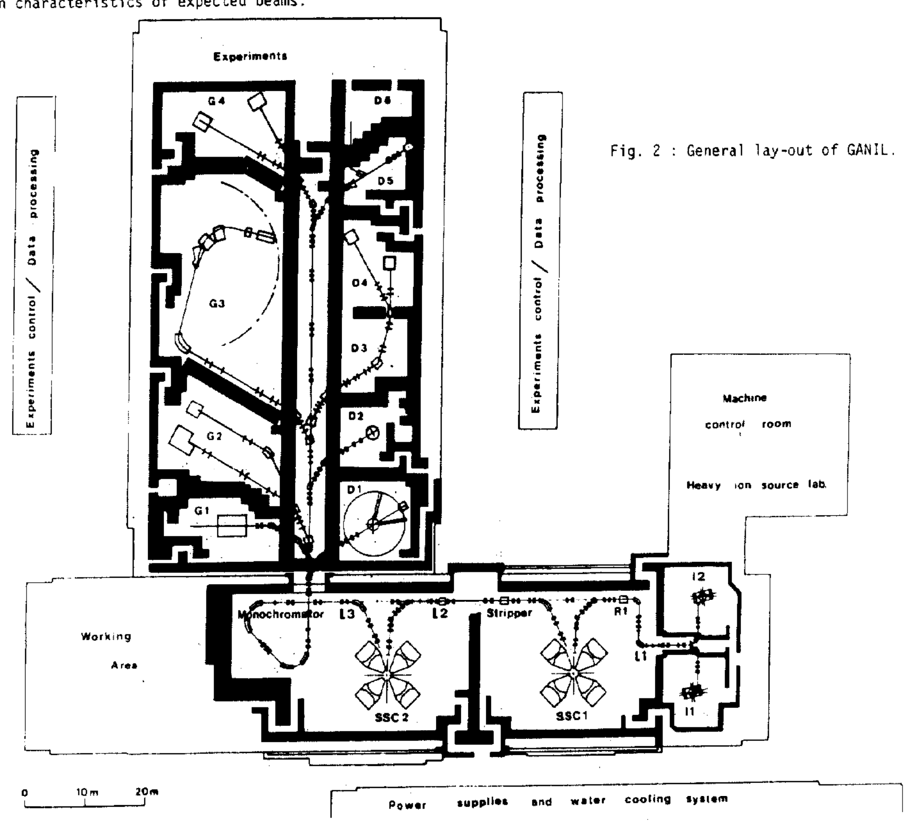

Fig. 2 : General lay-out of GANIL.