Status report on the Alice project

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ABSTRACT

This report summarises the main characteristics of the Orsay project; the injection of a 1 MeV/amu heavy ion beam into the isochronous cyclotron.

The capabilities of this hybrid machine are shown along with the field of new experiments.

The present status and the results of several tests are given.

1. MAIN FEATURES OF THE ALICE PROJECT

The project consists of a combination of a linac and a cyclotron.[1,2] The linac[3] accelerates heavy ions to an energy of 1 MeV/amu and the beam, injected in the cyclotron, is stripped by a thin foil located in the central region of the machine and is then accelerated with much higher charges than those delivered by conventional ion sources. We give in Table 1 the main features of the two machines.

Fig. 1 shows an overall picture of the arrangement. It is worth noting that each machine may be used separately: the stripping foil has then to be replaced by the usual ion source in the cyclotron.

2. CAPABILITIES OF THE PROJECT

2.1. *Maximum energy and energy range*

Fig. 2 shows the maximum energy reached by the most probable charge Z_i of the stripped ions, and by $Z_i + 1$ and $Z_i + 2$ as a function of the mass number A. On the same figure, one sees a plot of the maximum energies obtained with the cyclotron only.

Table 1.

		Linac	*Cyclotron*
Main features	Accelerated particles	$Z_i/A \geqslant 0{\cdot}1$	$0{\cdot}1 \leqslant Z_i/A \leqslant 0{\cdot}75$
	Kinetic energy	$E_{Final} = 1{\cdot}16$ MeV/amu	$75 \times Z_i^2/A$ MeV max
		$E_{injection} = 14$ keV/amu	$25 \times Z_i^2/A$ MeV min
	Duty factor	$20\% \leqslant \tau \leqslant 100\%$	$20\% < \tau \leqslant 100\%$
	Ion source	Kurtchatof type	Kurtchatof type
Rf structure	Resonator	$\lambda/4$ twin-lined (four)	$\lambda/4$ coaxial with movable short
	Resonant frequency	24·3 MHz	4·5–10·5 MHz
	Accelerating electrodes	Number: 56–variable diam. grids	One 180° dee
	Length and diameter of resonator	Length: 10·5 m–diam.: 1·2 m.	Length: 6·5 m–diam.:1·2 m.
	Average shunt impedance	60 MΩ/m	
	Rf power (100% duty factor)	250 kW	75 kW
	Rf power tube	CFTH amplifier 300 kW to 450 kW (pulsed)	150 kW self-oscillator
	Rf regulation	In construction	2×10^{-4}
	Rf voltage	From 130 kV to 550 kV	75 kV peak value
Vacuum	Volume of tank	13 m³	11 m³
	Pumps	One 30·000 1/s diffusion pump	Three 10·000 l/s diffusion pumps
	Best vacuum	$\simeq 2 \times 10^{-7}$ torr	$\sim 1{\cdot}10^{-6}$ torr
	Pumping speed	$7 \cdot 10^{-7}$ torr in 4 h	$2 \cdot 10^{-6}$ torr in 10 h
Magnets	Diameter		2 m
	Number of sectors		3 radial ridge
	Correction coils		One 4000 A and one 6000 A
	Harmonic coils		Two 500 A
	Power supply		360 kW
	Magnetic gap		430 mm
	Magnetic variation		Isochronous between 8 and 15 kG
	Magnetic regulation		$2{\cdot}10^{-4}$
Auxiliary equipment		Buncher	Electrostatic deflector (50 kV $< V <$ 100 kV)
			Extraction radius: 82 cm
		Analysing magnet following the ion source	Two magnetic channels

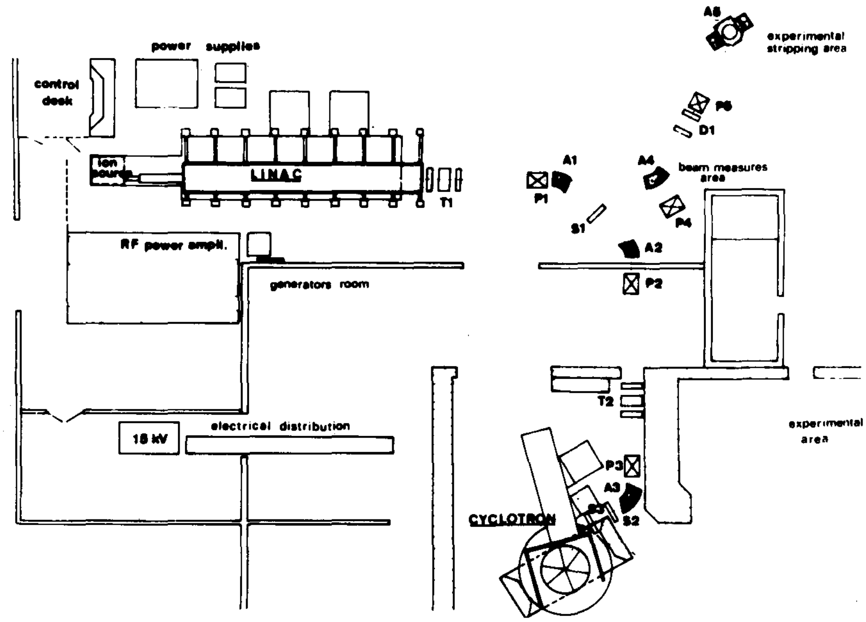

Fig. 1. Plan view of the ALICE project

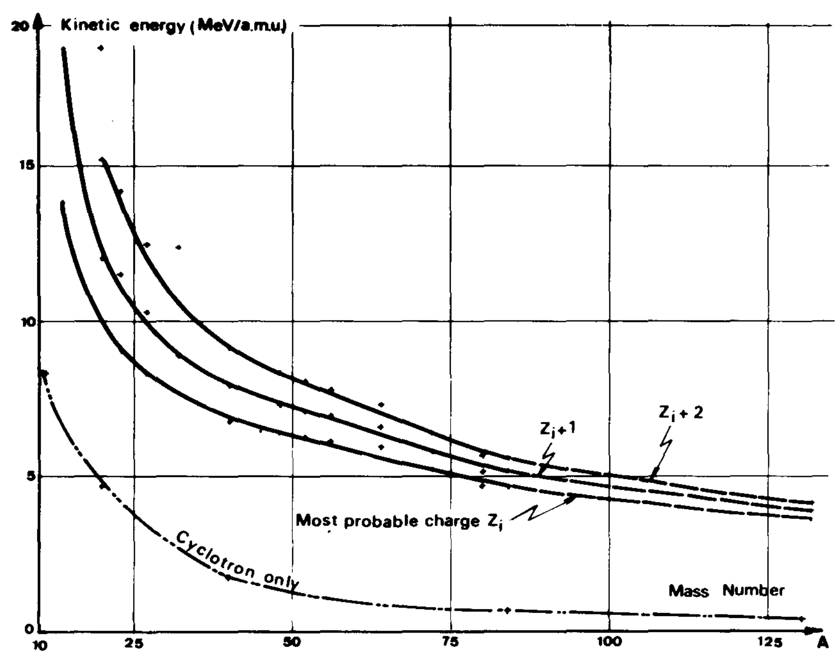

Fig. 2. E *MeV/nucleon* = f(A)

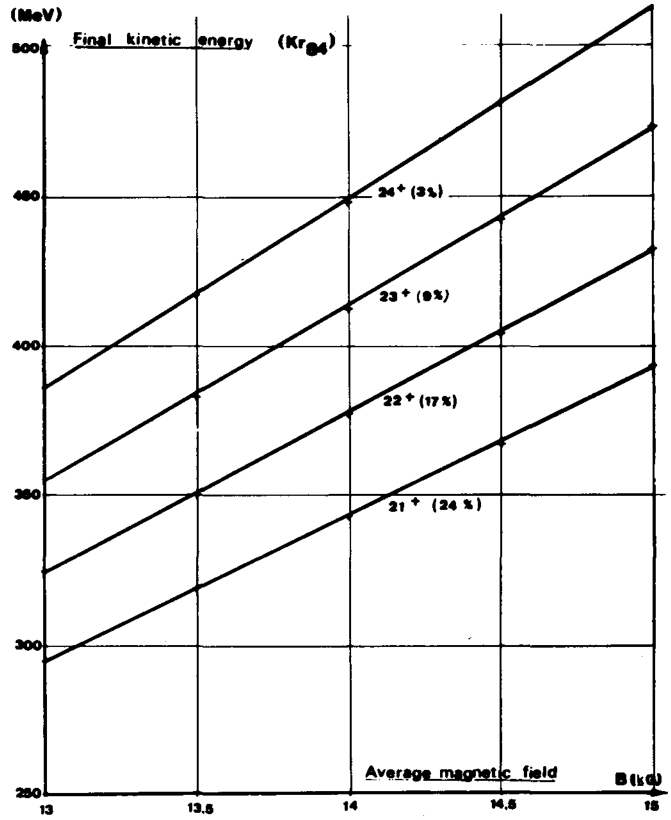

Fig. 3. E *MeV Krypton* = f(B) *kG*

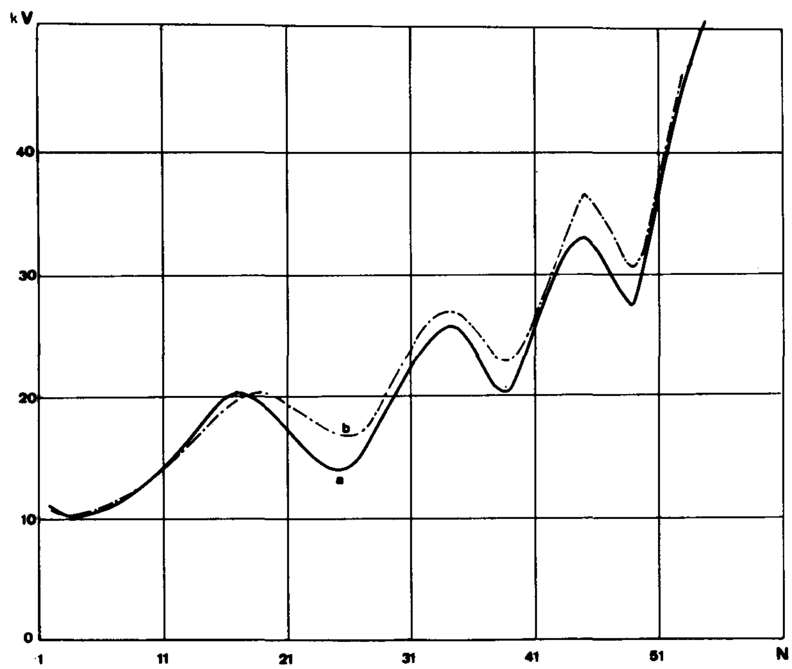

Fig. 4. Voltage distribution V = f(1)

The final energy may be varied in two ways: fixing the charge and varying the magnetic field or conversely. The first method gives rise to continuous changes in energy, whilst the second gives stepwise variation. Fig. 3 shows the possibilities of variation for krypton between the limits 13-15 kG,

2.2. *Transmission efficiency*

It is planned to have the injector working with a high duty cycle, reaching 100% in certain cases. This provides a significant increase in intensity compared with existing linac-linac arrangements. On the other hand, the rf acceptance and extraction efficiency of the cyclotron are unfavourable.

One can estimate that the ratio of the average particle intensity arriving on the experimental target to the intensity entering the buncher is of the order of 10^{-3}.

2.3. *Research programme*

First of all, the present experiments made with the cyclotron only will be carried on at higher energies. With N^{7+}, O^{7+}, Ne^{8+} beams in the range of 200 to 240 MeV, the transfer reaction studies and the production of transuranic elements will become more important.

A second point is that with 'moderately' heavy ions like A^{13+} at 315 MeV and heavy ions like Kr^{21+} at 400 MeV, new problems may be dealt with, such as induced fission by Coulomb excitation (Peter and Lefort experiment), production of peculiar ions like ^{100}Sn and evidently production of super heavy elements like those with $Z = 114$ or $Z = 126$. This last experiment, actually prepared by Jacmart, Lefort, Peter, Roynette, Riou, Stephan, and Tarrago, consists in bombarding a $^{230}_{92}Th$ with $^{80}_{36}Kr$ ions, in order to produce a $^{310}_{126}$ nucleus almost without excitation energy. In the same manner, they propose the reaction:

$$^{86}_{36}\mathrm{Kr} + {}^{198}_{78}\mathrm{Pt} \longrightarrow {}^{282}_{114} + 2\mathrm{n}$$

The identification is made by a magnetic analysis followed by solid state detectors and a time of flight method.

3. PRESENT STATUS OF THE PROJECT

3.1. *The heavy ion cyclotron*

We have already accelerated the following ions: C^{3+}, C^{4+}, N^{3+}, N^{4+}, N^{5+}, O^{4+}, O^{5+}, A^{4+}, A^{5+}, Ne^{4+}, Ne^{5+}, Ne^{6+}, each of them at different energies.

With a continuously operated ion source, the average extracted intensities are: C^{4+}: 15 μA, N^{5+}: 3 μA, O^{5+}: 2 μA.

When the source is pulsed ($t = 1{\cdot}5$ ms, $T = 5$ ms), the average intensity is larger by a factor of two or three for the highest charges.

Operation with the injector requires the mounting of the stripping foil dispenser, which is at present under construction, and a calibration of its position. The time necessary to go from one mode of operation (cyclotron + linac) to the other (cyclotron only) should be of the order of a few minutes.

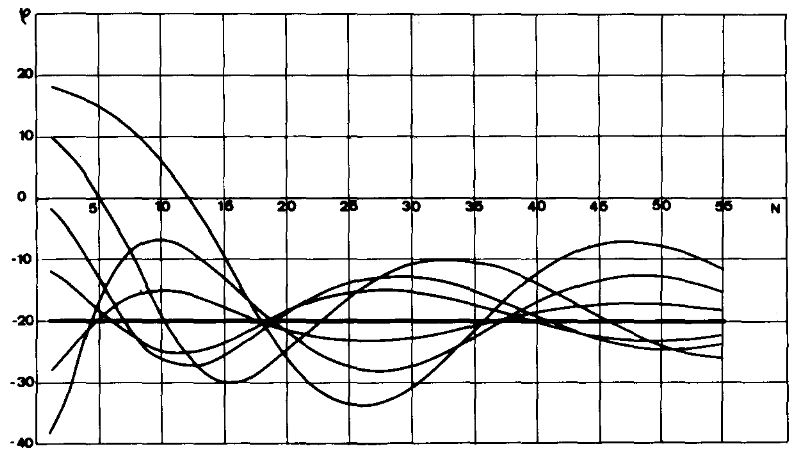

Fig. 5. Theoretical phase oscillation

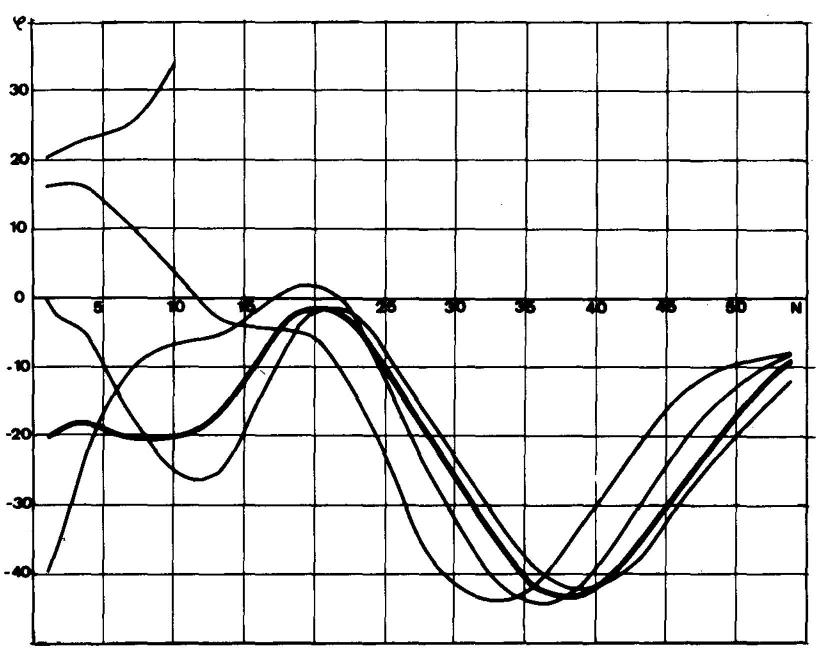

Fig. 6. Real phase oscillation

3.2. *Tests of the linac*

3.2.1. **Voltage distribution**

The electrodes were designed from measurements made on a quarter scale model;[4] the resulting voltage distribution is shown in Fig. 4.

The experimental plot is obtained from measurements using the perturbation method: a silver ball 8 mm diam. is introduced into the cavity, which constitutes the oscillating circuit of a self-oscillator. The $\Delta f = kE^2$ curve is plotted, from which the voltage distribution may be drawn (Fig. 4).

(Δf = frequency deviation, E = electric field, k = constant.)

Fig. 5 shows the theoretical phase oscillation across the cavity for different initial phases.[5]

Fig. 6 shows the phase oscillation calculated from the measured voltage distribution.

The stable area is shown in Fig. 7. Although it seems to be small, the adiabatic diagram used for estimating the buncher yield is completely included inside.

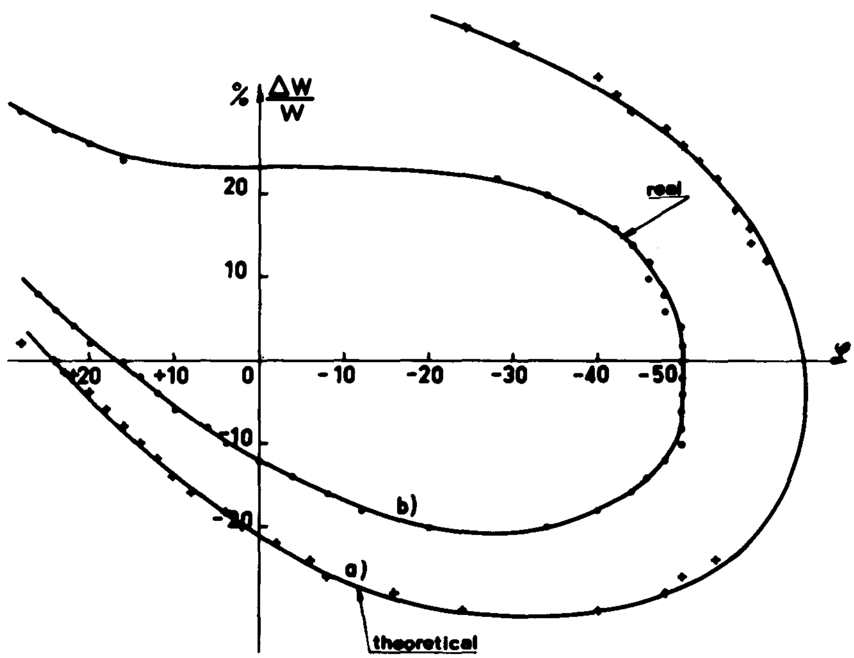

Fig. 7. Stable area

3.2.2. **Rf tests**

The resonant frequency is 24·3 MHz and the measured Q-value is 5800 (6000 calculated value). In these conditions, the rf power necessary for acceleration of a 0·1 charge-to-mass ratio is 250 kW.

High power tests have indicated the need for some modifications to the coupling loop. Actually we use a direct coupling system on one of the twin-lines.

To obtain the exact 75Ω impedance, the point to which the feeder is attached can be moved and a series capacitance is located between this point and the feeder.

Multipactor troubles such as sparking in the feeder and the coupling system in CW operation have led us to use high duty cycle pulsed operation as a first step. Two safety devices are used to switch off the power stage of the rf transmitter: one on the vacuum pressure at 10^{-5} torr, the other, by the means of a photo-cell which detects light emission in the cavity.

After some days of pumping, it is possible to age the system to hold voltages even higher than the 'theoretical' and therefore we think we will be able to accelerate heavy ions in the range of $N/A \geqslant 0{\cdot}08$. But actually, because of some rf heating in the coupling system, the maximum rf power is limited at present to about 60 kW. We are trying to obtain better rf contacts and to increase the power to 250 kW.

3.2.3. Acceleration test

The first test of beam acceleration was made with He^{+1} delivered by a duoplasmatron ion source. A 12 mm beam diam. was observed on a plastic probe placed at the end of the linac. New tests with the operational source[7] consisted in the acceleration of N^{2+}. Beam identification was made with an analysing magnet. These tests, without a buncher, gave quite good preliminary results. Actually tests on the ion source, focusing and analysing of the beam from the source to the entrance of the linac, and tests on buncher coupling with full rf power in the cavity are carried out separately. The buncher that will be used is a second-harmonic buncher with two-drift-tubes, one tuned on the frequency of the cavity, the other separated from the first and tuned to twice this frequency. These two drift-tubes simulate the first three harmonics of the Fourier expansion of the 'saw-tooth'[6] signal and should increase the beam current by a factor of 4 or 5 instead of the classical factor of 3.

Other experimental apparatus measures the beam emittance, the energy distribution, the accelerated beam efficiency, and the stripping at 1 MeV/amu.

3.2.4. Beam transport system

All the deflecting and focusing elements are at present being installed and the beam transport system should be finished during October. The stripping mechanism in the cyclotron will also be finished during October and the first test of injected beam should begin immediately afterwards.

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