STATUS REPORT ON GANIL

presented by J. FERME.

GANIL (Grand Accélérateur National d'Ions Lourds) CAEN, France.

Summary

The GANIL* heavy ion accelerator is composed of three isochronous cyclotrons in cascade. The first stage is a small compact cyclotron fitted with a conventional PIG source. The two following stages are two identical Separated Sector Cyclotrons (K = 400). The charge state of the ions is multiplied by a factor of 3.5 by the means of a stripper located between the two SSC's.

The beam characteristics in the small injector cyclotron have been observed on a full scale working model at CERN in 1976. The shimming and the trim-coils for the two SSC's have been determined from magnetic measurements made on a one fourth model of the magnets. Recently an RF cavity,scale one third, has been realized and is under experiment.

The magnets and vacuum chambers for the SSC's are already ordered. The accelerator is due to be in operation in 1982.

1. General description

The general lay-out of the accelerator is shown in figure 1. It has been found convenient to install two injector cyclotrons. When the first is in operation, the second is being serviced for the next experiment.

The low energy beam from the injector cyclotron goes through an emittance defining system of slits, then through a buncher before being injected into the first separated sector cyclotron SSC 1. The phase width of the beam is 15 degrees at the exit of the injector cyclotron, and has to be reduced to 6 degrees after being injected into SSC 1.

The stripper located between the two SSC's increases the charge state by a factor of 3.5 (approximately) which is also the ratio between the ejection radius of SSC1 and the injection radius of SSC2.Under normal conditions, the magnetic field levels in both SSC's are equal.

The second buncher is needed to compensate for the deteriorating effects of the energy dispersion on the phase width. The stripper induces an important energy dispersion, up to 1.5 10^{-3} in the case of the heaviest ions, and the phase width in SSC 2 must be no greater than 6 degrees if a beam resolution of $2\cdot10^{-3}$ has to be obtained.

A system of two spectrometers acting as a monochromator has been provided at the exit of SSC 2 to control the energy dispersion down to $\pm 5\cdot10^{-4}$.

The main characteristics of the accelerator are given in table 1. It should be mentioned that in the case of light ions the first SSC and the stripper can be by-passed. The maximum energy is then reduced to 40 MeV per nucleon. As one SSC only is involved in this configuration, this mode of operation is called the "solo mode".

*Grand Accélérateur National d'Ions Lourds. Project supported jointly by Commissariat à l'Energie Atomique (C.E.A.) and Institut National de Physique Nucléaire et de Physique des Particules (IN2 P3). GANIL - B.P. 5027 - 14021 CAEN Cedex, France.

2. Beam characteristics

The energy range is given in figure 2. The maximum energies for the heaviest ions are based on the performance of the PIG source . If some progress were made with the sources, the benefit for GANIL would be limited in principle by the stripping factor which must stay near the value of 3.5 for optimal performance of the whole accelerator.

The intensities are expected to be to the order of one particle-microampere for light ions, down to one thousand times less for the heaviest ions.

The focusing characteristics of both SSC's are shown in figure 3. The radial and vertical emittances of the beam are indicated in figure 4. The initial values are based on measurements made on a model of the injector cyclotron. It should be expected that the emittances will not stay constant when the energy of machines is varied. But the beam is collimated in many parts of the accelerator, especially in the ejection systems so that the emittances will be nearly the same in the whole energy range.

One of the most important properties of the beam is the phase width. The future experimentalists will make an extensive use of the time of flight technique for particle identification purpose. They have strongly recommended that the pulse duration not exceed one nanosecond. This corresponds to a maximum phase width of no more than 6 degrees in SSC 2. In addition, a beam dispersion of 10^{-3} has been found convenient. For these reasons, the implementation of flat-topping has been postponed.

An extensive discussion of these problems can be found in a paper presented in this conference [1] .

3. Accelerator's components.

We present a general coverage of the various components of the GANIL accelerator.

The two SSC's being almost identical deserve a common description.

3.1 Injector cyclotron (Fig. 5).

The injector cyclotron[2] is a small compact cyclotron fitted with an internal ion source.

The poles are circular and flat. The vertical focusing is given by the negative gradient of the magnetic field. The radial field law can be controlled by the means of circular trim-coils in order to maintain the axial betatron frequency ν_z around the convenient value of .1 , and at the same time keeping the phase slip within an acceptable limit.

The RF system consists of a pair of dees having an aperture of 60 degrees suitable for running the beam on harmonic 4 or 8. The dees are driven in phase by a single resonator. The central region has to be carefully adapted to the operating mode. It has been found more practical to have two pairs of dees constructed, one for each harmonic. The switch from one harmonic to the other requires a shut-down of two hours.

In the solo mode, the cyclotron can run on harmonic one. The two dees are to be replaced by a single dee of 180 degrees.

The central region was first studied using electrical field maps obtained from an electrolytic tank. Then a cyclotron model was constructed at CERN in 1976 with the help of the synchrocyclotron team. This model was tested with a beam of N 2+ on harmonic 4 and also on harmonic 8 for a short time. The shape of the dees in the central region was optimized in order to get a correct centering of the beam and a good axial focusing.

The model had no extraction system. The emittance measurements had to be performed on the internal beam with a set of slits.

The extraction of the injector cyclotron is accomplished by an electrostatic deflector and an iron channel. In the solo mode, the extraction is more difficult, owing to the greater energy of the particles, so a regenerator will be used in addition.

The required vacuum shall be better than 10^{-6} mm Hg. Two cryogenic pumps and a turbomolecular pump have been provided.

A prototype of the hot cathode source has been constructed. Ions of argon have been extracted on a bench at 24 kV only. We have observed over a long period of time an average beam intensity of 50 particle-microamperes for Ar 4+ within an emittance of 100 mm mrad in both planes. We will now direct the development of the source toward the production of metallic ions.

3.2 Sector magnets[3]

The structure of the magnetic sectors consists of a pile of horizontal pieces of laminated iron weighing 60,000 kg each. The poles are made of low carbon forged iron (figure 6).

Three stainless steel spacers maintain the gap constant within ± .05 mm even under the influence of the magnetic forces, 6.10^6 N at maximum excitation.

Each pole is flat and fitted with removable side shims. For SSC 1, the relativistic effect is negligible. The shims are straight, but near the injection and ejection radii they are flared up in order to compensate for the field drop in these regions.

The side shims for SSC 2 are shaped to satisfy the isochronism law for medium energy particles ($\gamma = 1.05$).

The trim-coils are made of pyrotenax conductors enclosed in a vacuum tight stainless steel box. They are wound so as to follow the hard-edge pattern of the equilibrium orbits. The radial spacing of the conductors measured along the pole axis is 80 mm. In the extraction region, the spacing is smaller, and in the injection region a special array of independant conductors has been provided. Fifteen power supplies are needed to achieve the isochronism law at all energies.

The magnetic properties of the sectors were studied on a one fourth scale model. The profile of the shims and the trim coil pattern were determined from the measurements.

3.3 Vacuum chamber[4]

The vacuum chamber has a monolithic structure (figure 7). It is made of 316 L stainless steel. Its volume is 46 cubic meters, its mass 57,000 kg.

In order to simplify the design of the chamber, it was decided to put the pole pieces inside the vacuum. The main coil and the trim-coils are enclosed in vacuum tight boxes.

The external pressure induces a radial force on the vacuum chamber estimated to be 10^6 N per sector. The chamber is not strong enough to hold such a force and the magnets themselves cannot be used to relieve the horizontal stress, for they are subject to a radial (and vertical) deformation caused by internal magnetic forces. The vacuum chamber had to be reinforced radially by a pair of rings located near the centre of the machine which are independent of the magnetic structure in the horizontal plane (figure 6).

The vacuum system consists of 8 cryo-pumps at 20°K fitted with active carbon panels. The pumping speed for each pump is 20,000 l/s for air and 10,000 l/s for hydrogen. The chamber is pumped down initially by a conventional roughing pump system and 4 turbomolecular pumps with a speed of 3,500 l/s each. To go down to a pressure of 5.10^{-8} mmHg will take about 30 hours.

The seals are metallic in principle.

3.4 RF system for the SSC

The general lay-out of the resonators is shown in figures 8 and 9.

For a frequency range of 6.5 to 14 MHz a resonator with coaxial lines would have been too large. In the adopted design the resonator is more compact, has good mechanical properties and can be easily removed from the vacuum chamber.

The coarse tuning is achieved by means of a movable panel with an overall displacement of .40 meter. The current density in the sliding contacts is 20 amperes per centimeter. This allows the possibility of adjusting the tuning with the RF on. The surface of the panel is corrugated so as to increase the capacitance by a factor of about 1.7 at the lowest frequency. A small mechanical plunger is provided for fine tuning.

A model of the resonator, scale one third, has been built. The results converted to scale one are shown in figures 10, 11 and 12.

In the vicinity of 9 MHz we have observed a parasitic resonance on harmonic 3 with a Q factor 1.5 higher than for the fundamental. This resonance is observed when the moving panel and the dee behave like a quarter wave line while the dee stems have an infinite impedance. We are presently looking into two different ways to control this resonance. One possibility is to find a means to introduce a small shift of the resonance frequency. Another idea is to install a filter between the power amplifier and the resonator.

The power amplifier is a TH 581 tetrode rated for 100 kW. The coupling is inductive. A π network will be installed to match the loop and the amplifier impedances, 25 to 100 Ω and 500 to 700 Ω respectively.

The GANIL RF system is synchronized by a master oscillator to within ± .5 degrees.

The quality of the beam implies not only an amplitude stability better than 10^{-3} but also the addition of phase loops between the injected beam and the accelerating voltage, once the beam has been set.

3.5 Injection and ejection

Injection and ejection are of conventional design and technology (figure 7).

The injection systems in both SSC's are almost identical, but in the case of SSC 1 the electrostatic channel is not needed, the radial gain per turn being very large (60 millimeters). All elements, with the exception of the electrostatic deflector in SSC2, are magnetic and occupy a fixed position. The two Septa SMi 3 and SMi 4 are mainly passive elements.

The ejection systems are identical in both SSC's. The coil needed for resonant extraction, called "BUMP", will not be installed in the SSC 1, owing to the large turn spacing (20 millimeters at extraction radius). The electrostatic septum and the two magnetic Septa Mse 2 and Mse 3 are movable.

Full scale models of injection magnet Mi 2 and septum SMi 3 have been made and are being tested. The field in the gap of these elements should reach 2.1 teslas with a homogeneity better than one per cent.

3.6 Beam probes

The beam position and intensity in the acceleration area are measured by three conventional probes moving along the axis of the magnetic sectors (figure 8).

The isochronism is monitored by a series of 15 capacitive phase probes installed radially in a valley.

The relative accuracy of the central phase measure is expected to be better than one degree.

The phase probes located in the vicinity of the injection and ejection radii are used to determine the average value of the beam phase during the acceleration process and this signal will be used to synchronize the RF phase for the best performance.

3.7 Beam lines

The general lay-out of the beam lines is shown in figure 1. The horizontal and vertical profiles of the beam are measured with wire detectors[5]

The stripper[6] is located near a waist of the beam envelope to reduce the deterioration of the emittance. A gas stripper is used for light ions and carbon foils for heavy ions (A > 40).

Experiments were made at the MP tandem laboratory in Strasbourg for the determination of the angular and energy dispersions induced by the stripping process. The life-time of a carbon stripper was also measured.

3.8 Computer control

The accelerator is fully controlled by computers and microprocessors. Computers are two Mitra 125 equipped with 128 K 16 bits words memory and two 5 Mbytes disks each. In normal operation, one computer controls the accelerator while the other performs auxiliary tasks. Should the first computer fail, the accelerator operation is switched to the second one. Microprocessors are JCAM 10 equipped with Intel 8080 chips. They work as controllers in stand alone Camac crates.

Microprocessors are intended to help the main computer in controlling the consoles, and also to perform such local tasks as special beam measurements. The advantage of using microprocessors is to provide pre-treatment of the information and to reduce the number of interrupts sent to the main computer. All the interfaces between the main computer on one hand and the consoles and the accelerator on the other hand are made in Camac. One uses the serial Camac loop in bit mode at the speed of 2.5 M bauds. Camac modules include special modules for interfacing the consoles and families of standard modules such as stepping motor drivers, line surveyors, power supply controllers and so on...

Microprocessors are linked to the main Camac system by special data links.

4. Planning

The eight magnetic sectors for the two SSC's were ordered in June 1977. Magnetic measurements for the first SSC will take place before the end of 1979.

The two vacuum chambers have been ordered in January 1978. The first one will arrive on the site in January 1980, to be followed by the second one nine months later.

The RF cavities are still on the drawing board. We plan to order them in March 1979.

The first beam is expected in 1982.

References

1. A. Chabert, G. Gendreau, P. Lapostolle, "Limited energy spread in an SSC". This conference.

2. P. Attal, E. Baron, C. Bieth, M.P. Bourgarel, R. Gayraud, C. Pagani, "The GANIL injector design" This conference.

3. D. Bibet, A. Daël, M. Ohayon, "The GANIL magnet" This conference.

4. J.M. Baze, P. Bernard, M. Feldmann, C. Lecoeur, "The vacuum chamber of GANIL SSC". This conference.

5. R. Anne, M. Van Den Bossche, "A secondary emission-multiwire chamber for GANIL heavy ion beams tuning" This conference.

6. E. Baron, "The beam-stripper interaction studies for GANIL". This conference.

** DISCUSSION **

G. MACKENZIE: Your first slide showed a by-pass section in the beam line between the two SSC's. Is this for intermediate momentum analysis, or for phase matching?

J. FERMÉ: The by-pass between the two SSC's can be used to investigate the properties of the beam from the SSC1 with the monochromator. This is also the normal path of the beam when using only the SSC2 (and not the SSC1) for light ions, to get up to 40 MeV/amu.

G. DUTTO: Could you tell us something more about your 140 kV buncher?

J. FERMÉ: The design study is not yet completed. We plan to use at least two gaps for easier operation.

		Unit	Injector Cyclotron Co	First Separated Sector Cyclotron SSC 1	Second Separated Sector Cyclotron SSC 2
	K* Factor		32	400	400
MAGNETS	Number of sectors		Circular pole	4	4
	Sector angle	degree		≃ 51	≃ 51
	Injection mean radius	meter		.814	.857
	Ejection mean radius	meter	.465	3.0	3.0
	Magnetic gap	meter	.21	.1	.1
	Maximum field	tesla	1.67	1.64	1.64
	Iron weight	kilogram	54 10^3	1,700 10^3	1,700 10^3
	Main coil weight	kilogram	4 10^3	14 10^3	14 10^3
	Main coil power	kilowatt	265	950	950
	Main field stability		5.10^5	10^{-5}	10^{-5}
	Number of trim coils		6	15	15
	Trim coils power	kilowatt	50	140	140
RADIO FREQUENCY					
	Frequency range	megahertz	6.5-14.0	6.5-14.0	6.5-14.0
	Number of dees		2	2	2
	Dee width	degree	60	34	34
	Peak voltage	kilovolt	90	250	250
	Total RF power	kilowatt	60	100	100
	Amplitude stability		10^{-3}	10^{-3}	10^{-3}
	Harmonic number(RF/orbit F)		4/8	7/14	4/2
VACUUM	Normal pressure	mmHg	5.10^{-7}	5.10^{-8}	3.10^{-7}
BEAM LINES	Buncher 1	Frequency : Fundamental - Peak voltage 140 kV			
	Buncher 2	Frequency : Harmonic 4 - Peak voltage 250 kV			
	Monochromator	Bending radius : 1.80 meter - maximum field 1.6 tesla			

*For non relativistic ions, the maximum energy is given by the formula $E_{MeV/amu} = K * (\frac{n}{A})^2$
n : charge state A : atomic mass number

TABLE 1 - MAIN CHARACTERISTICS

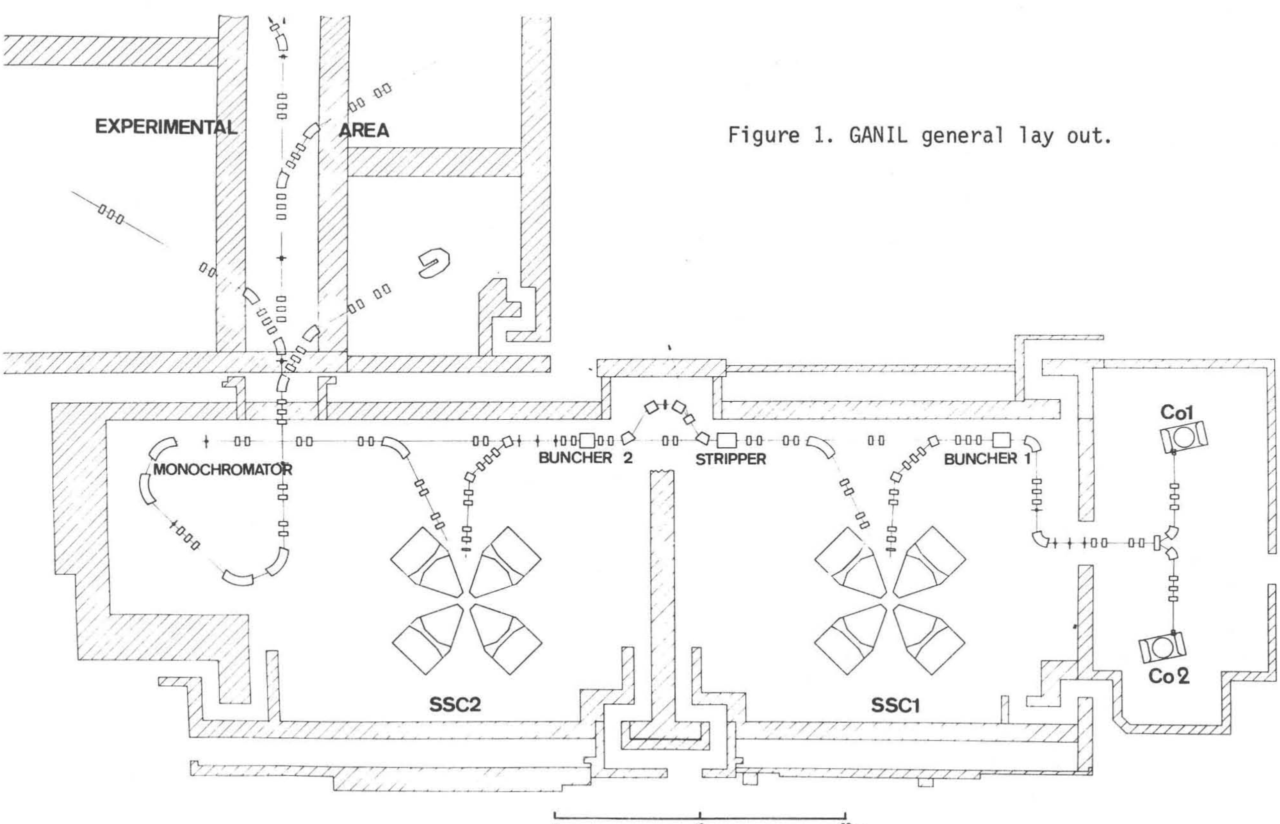

Figure 1. GANIL general lay out.

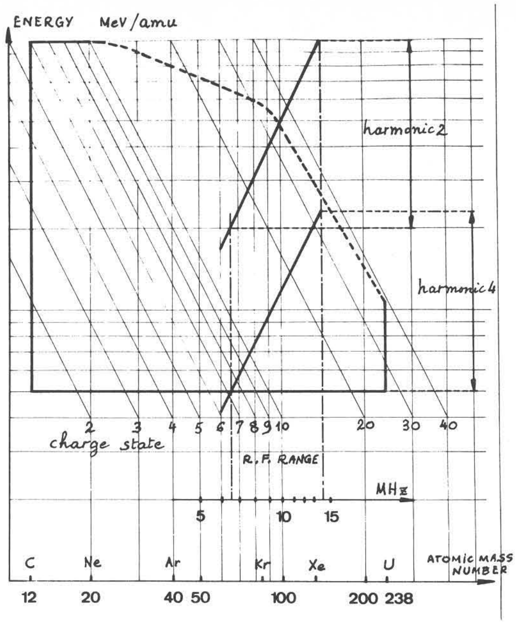

Figure 2. Energy range as a function of atomic mass and charge state.

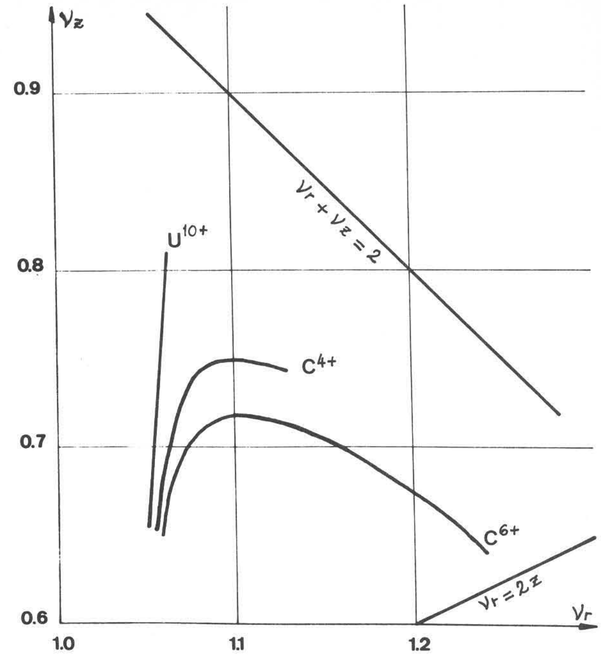

Figure 3. ν_r ν_z Diagram.

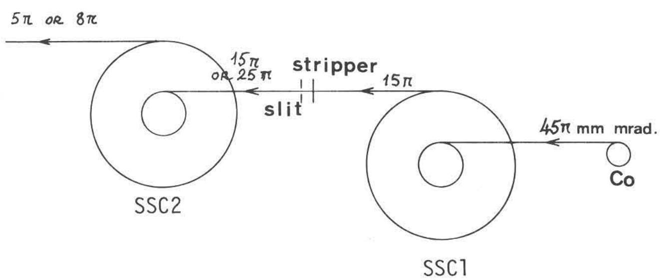

Figure 4. Beam emittances.
The emittances are expected to be of the same value in both horizontal and vertical planes.

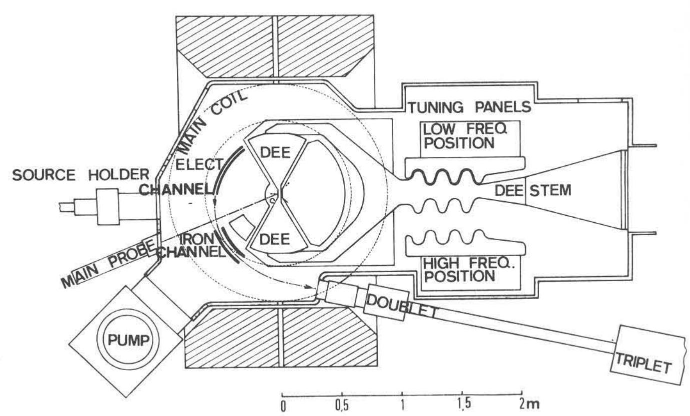

Figure 5. Plan view of the injector cyclotron.

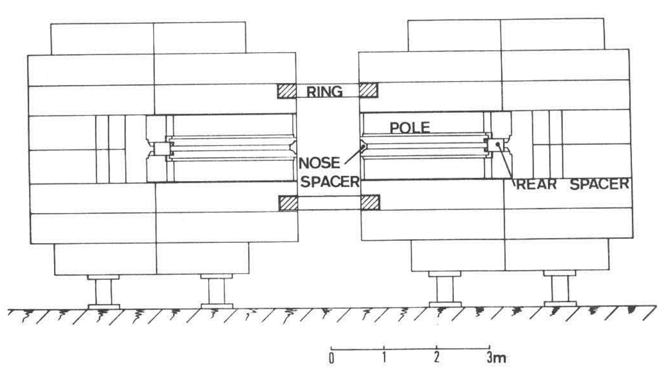

Figure 6. Vertical cross section of two opposite sectors.

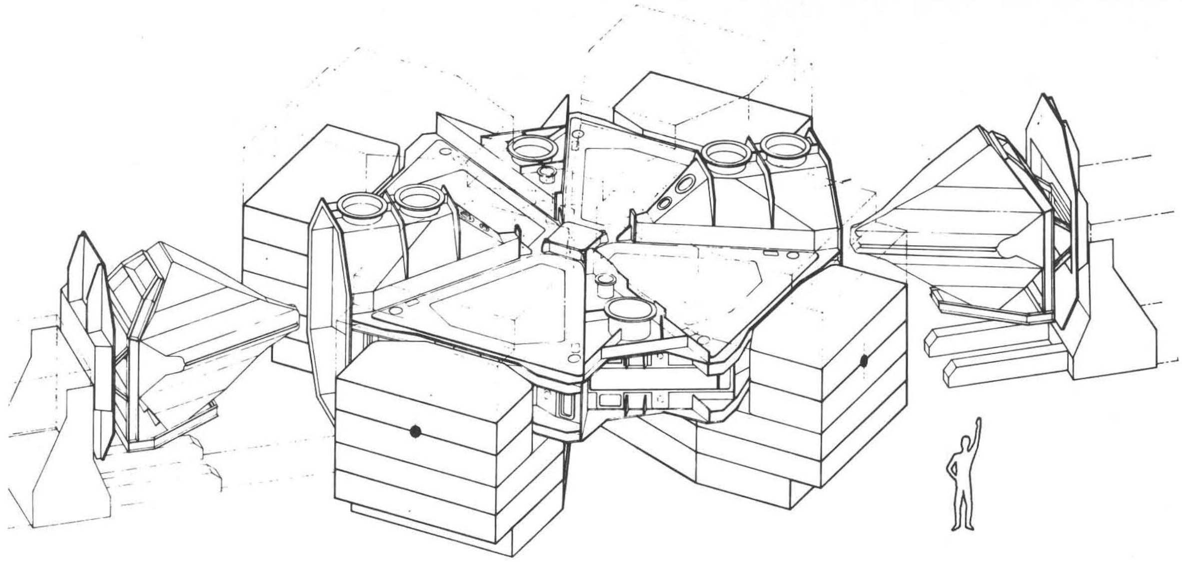

Figure 7. General view of a SSC.
The upper parts of the sectors and the poles are withdrawn.
The two resonators are removed.

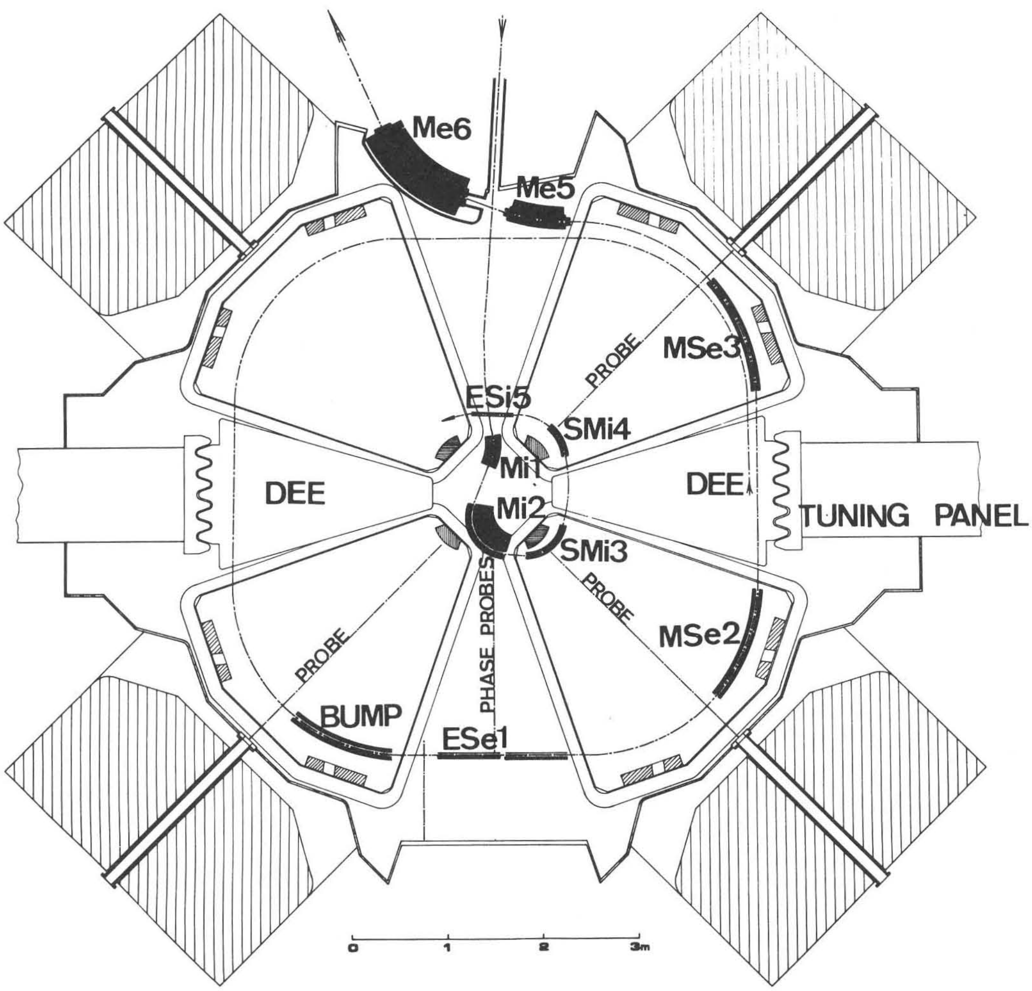

Figure 8. Horizontal cross section of a SSC.

0018-9499/79/0400-1894$00.75 ©1979 IEEE

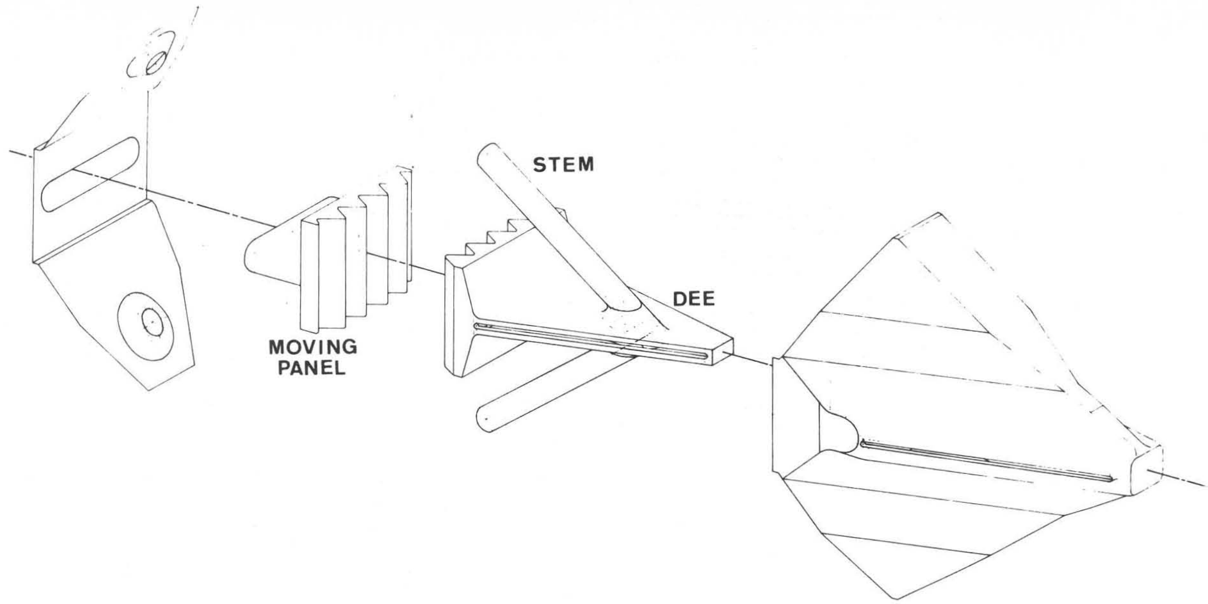

Figure 9. The resonator and the dee.

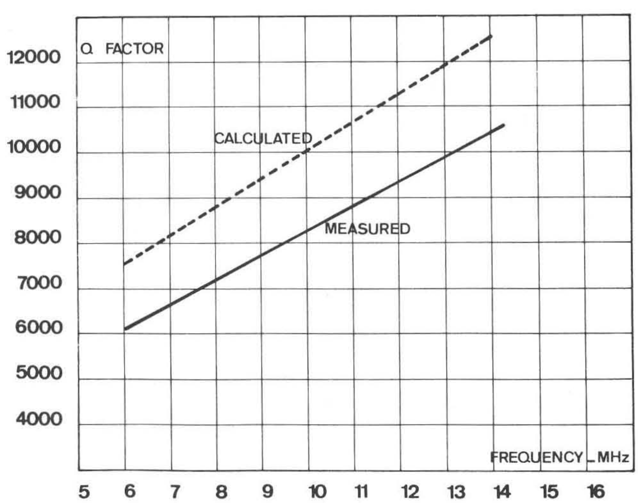

Figure 10. Q Factor.

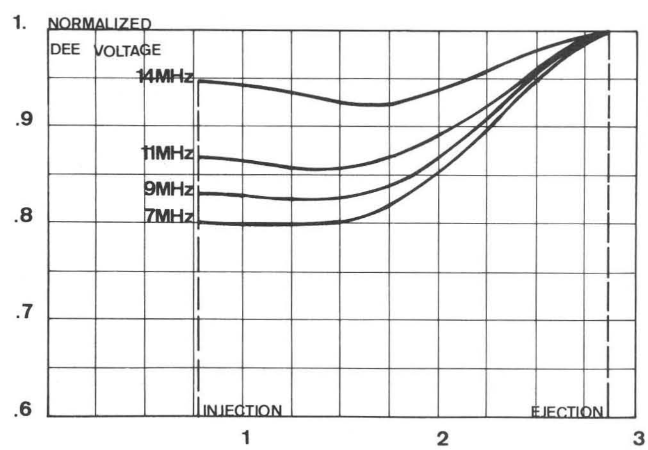

Figure 11. Radial distribution of dee voltage.

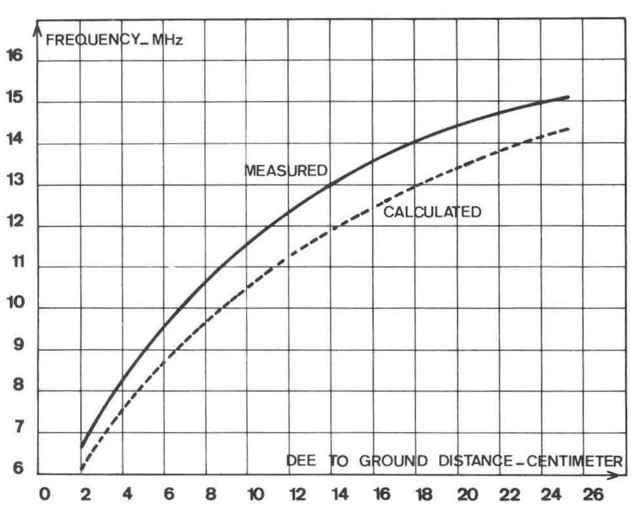

Figure 12. Frequency versus dee to ground distance

0018-9499/79/0400-1895$00.75 ©1979 IEEE