THE ITALIAN STORAGE RINGS

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This talk will have two parts. In the first part I shall report on the work done with "AdA" (anello d'accumulazione: storage ring), a storage ring for 250-Mev positrons and electrons, built at Frascati and now located at the linear accelerator laboratory at Orsay, France. In the second part I shall give a very brief outline of the state of the project "Adone", a 1500-Mev positron-electron storage ring under construction at Frascati.

I. AdA

This reports on work carried out by C. Bernardini, U. Bizzarri, G. Corazza, G. di Giugno, G. Ghigo, R. Querzoli and B. Touschek (Frascati); J. Haissinski, P. Marin and F. Lacoste (Orsay).

The interest in storage rings at Frascati was started by a visit of Dr. Panofsky in the autumn of 1959. In a program meeting held at Frascati (February, 1960) it was decided to try the construction of a 250-Mev storage ring for positrons and electrons. The design was concluded with the help of Dr. Sacerdoti (magnet) and Dr. Puglisi (rf system) by the end of May.

Fig. 1 illustrates the location of the ring in relation to the synchrotron. The gamma rays travel about 15 meters to strike a target mounted inside the donut of the storage ring. Some of the positrons formed in

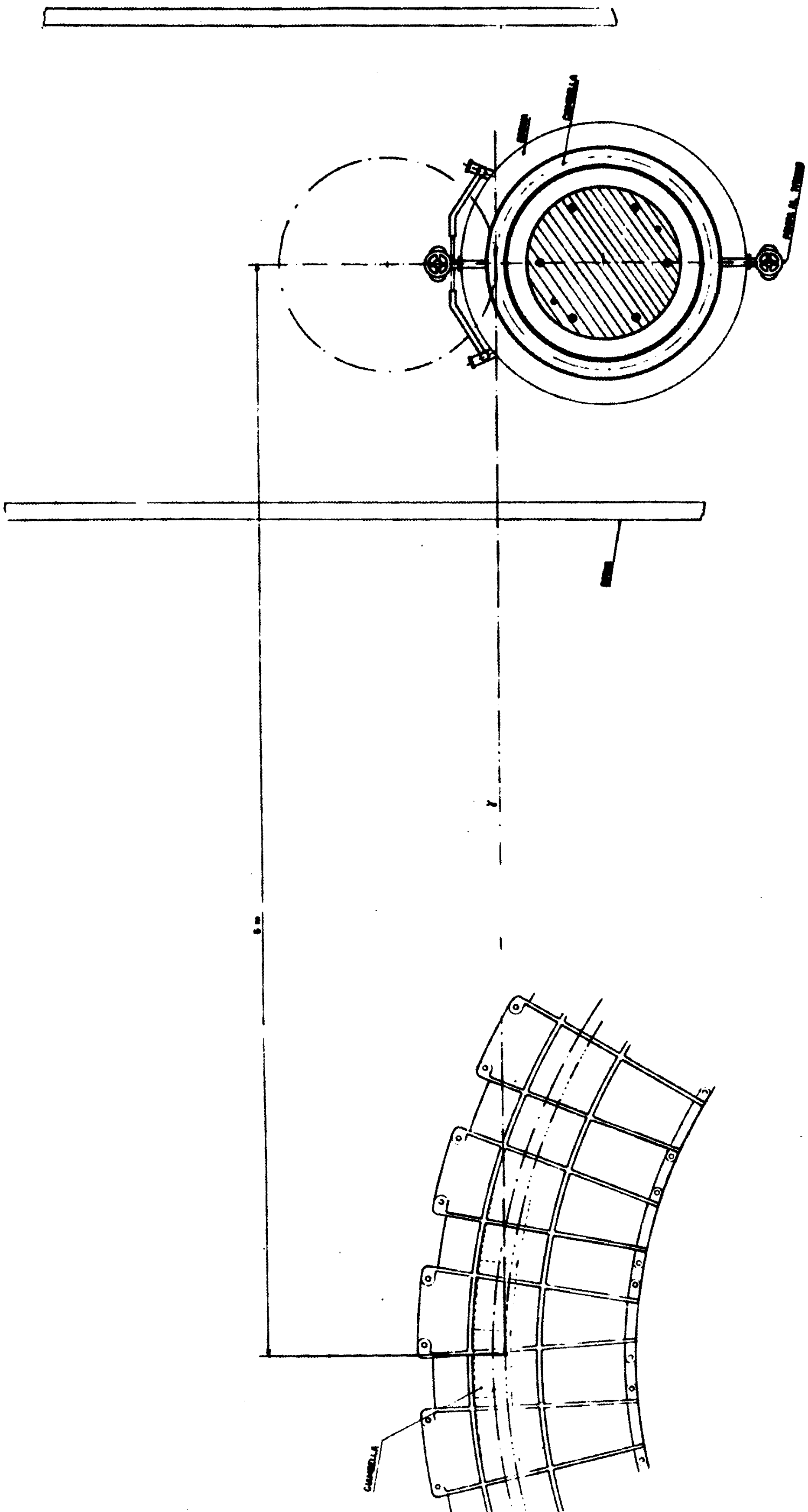


Fig. 1 - Storage ring in relation to the synchrotron

pair production are captured in a near-circular orbit. If a sufficient number of positrons is accumulated, the whole ring is moved laterally on rails and the electrons produced on a second target (placed at 180° to the first) are then accumulated. Thus the ring is charged with positrons and electrons, which for reasons of symmetry travel in identical orbits. The ring was put into the "machine hall" of the Frascati synchrotron and supported by a moving tower of approximately 4 yards in height, so that the height above ground of the stored orbits coincided with the height of the synchrotron orbit (Fig. 2). Fig. 3 shows the ring as assembled for the first tests. One can see the rf cavity (147 Mc, second harmonic; length of orbit approximately 400 cm), a titanium pump and one of the target ports. The entire ring could be rotated through a small angle, in order to optimize the capture efficiency. Fig. 4 illustrates the design of the stainless-steel vacuum chamber and shows the target ports on either side. Targets could be moved in and out by means of selsyn motors. The rf cavity is seen in the lower part of the figure and two viewing ports (for synchrotron radiation) on top. Note that the orbit contains 4 quasi-straight (half-field) sections for the insertion of the rf cavity, the injection ports and experimental equipment in the section opposite to the cavity.

Magnetic testing started in December 1960, and showed that the magnetic field ($n = 0.55$) was good to 220 Mev and still usable at 250. This was confirmed by observing with thin counters up to about thirty revolutions made by coasting electrons.

The storage ring was first operated in May 1961, with an unbaked vacuum chamber in which the initial pressure was about 3×10^{-6} torr

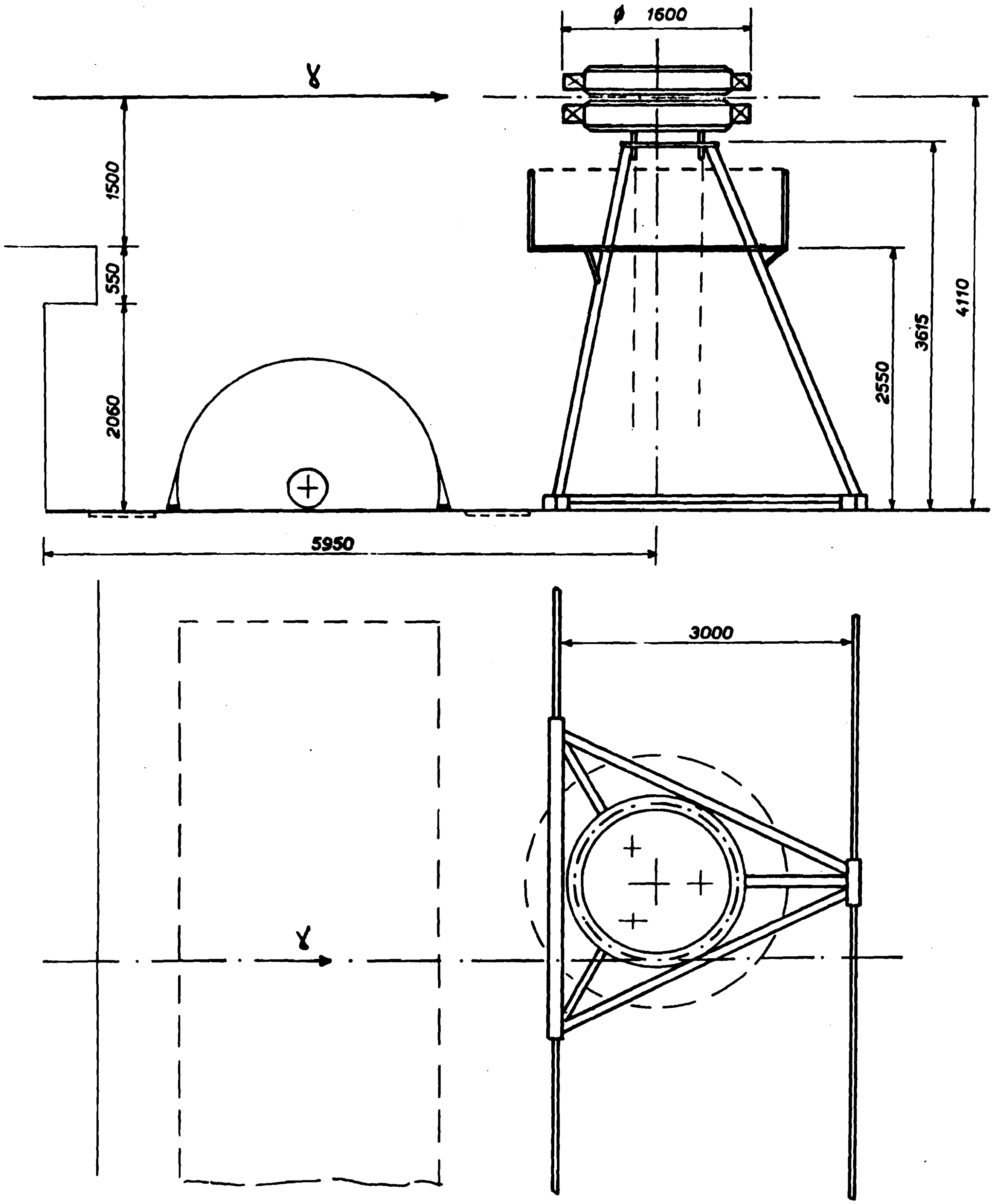


Fig. 2 - Movable tower for support of storage ring

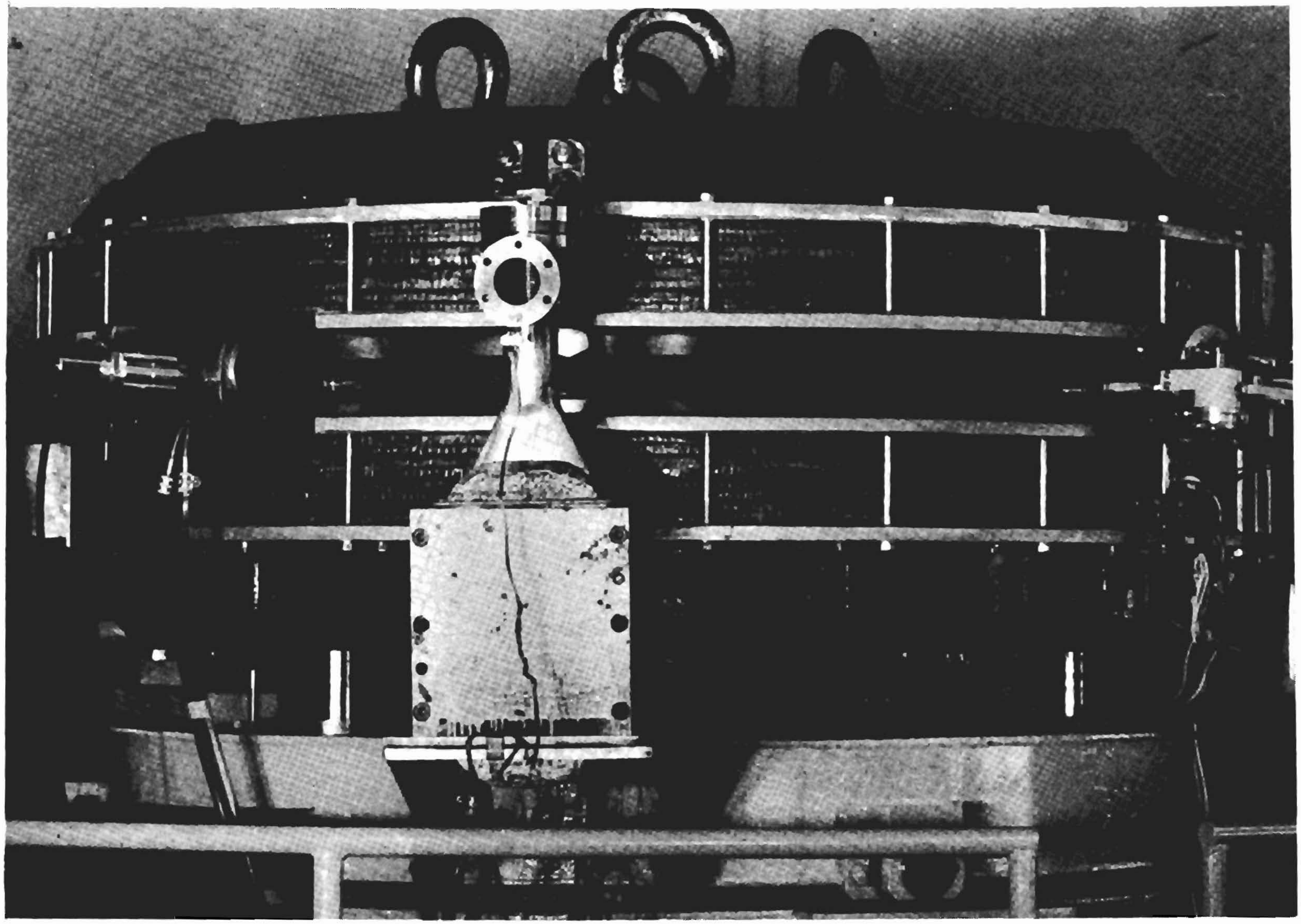


Fig. 3 - Storage ring assembled for first tests. The titanium pump is located near the center of the picture, the rf cavity to the left and target port on the right.

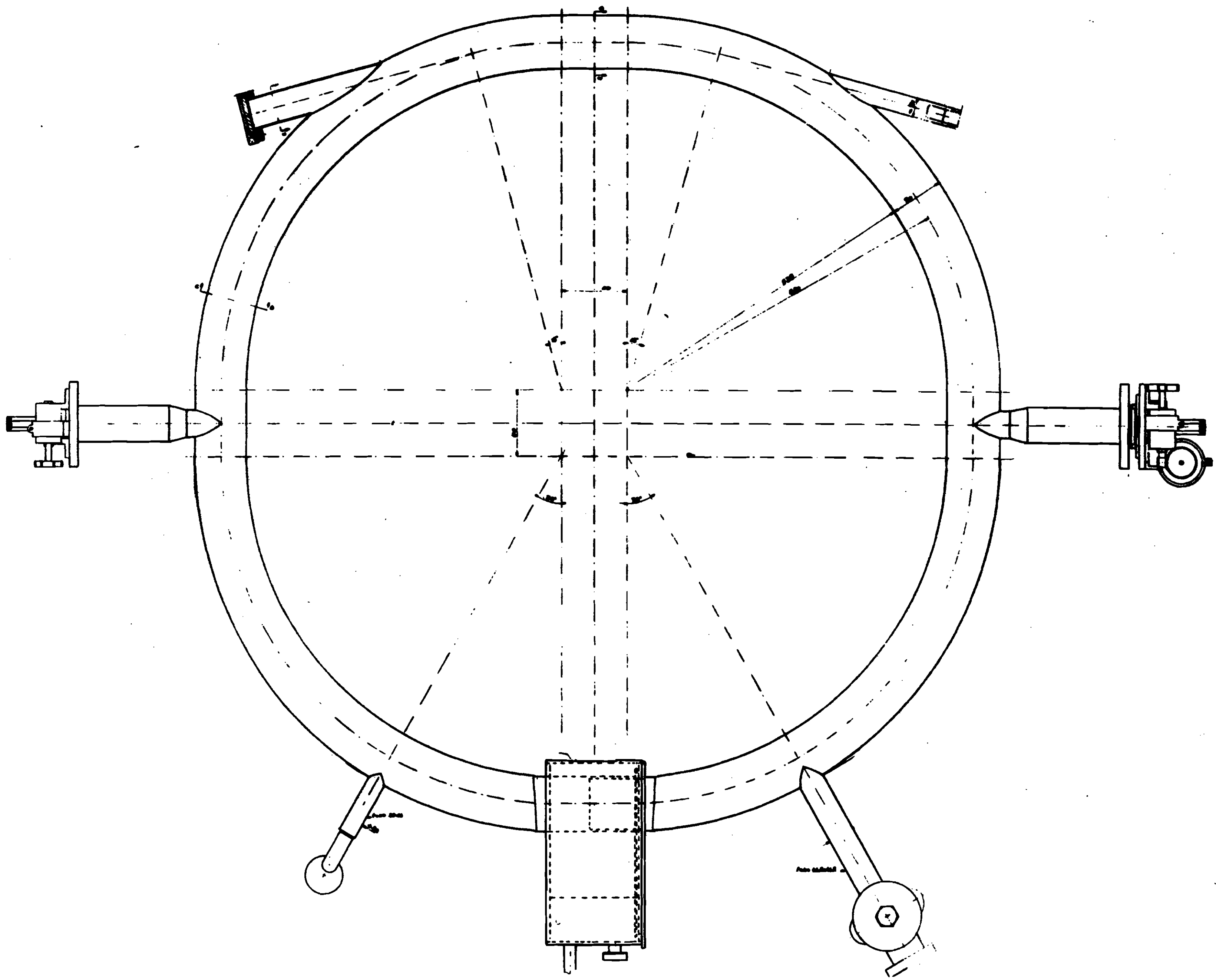


Fig. 4 - Stainless-steel vacuum chamber, showing viewing ports (top), target ports (sides), rf cavity (bottom), and vacuum ports, on either side of the rf cavity.

(this improved to about 10^{-7} in the course of time). Fig. 5 shows the dc output of a photomultiplier set to observe the synchrotron radiation of the captured electrons. The sudden rises and falls of the current occur as one or more electrons are added or lost from the accumulated beam. The lifetime in these first tests was 20 sec. This method of measuring the beam intensity is still employed. We start our runs by looking at single electrons and then reduce (by reducing the voltage) the sensitivity of our photomultipliers in steps of 10 by a factor of up to 10^4. The linearity of this process has been checked by comparison with a photocell.

A beam of about five or more electrons can be seen with the naked eye. Fig. 6 is a photograph taken through one of the observation windows and there is agreement between the observed cross section of the beam and that predicted theoretically and determined by the fluctuation of the radiation losses. The photographic method cannot be applied for measuring the height of the beam, however, since the synchrotron radiation is emitted in a very narrow angle. The resolution is about 1 micron $\times$ ($\gamma = E/mc^2 \cong 400$); that is of the order of 0.3 mm. On the other hand the height of the beam is the most important parameter in a colliding-beam experiment. In a perfect machine it should be about 1.5 micron (for a vacuum better than 10^{-8} torr) and I shall show later that there are strong indications to make one assume that it is in fact considerably bigger.

Effort was now applied to increase the injection efficiency, which at this point was only about 0.4 electrons (or positrons) per second. The electrons formed at the target go into betatron oscillations as they move around the donut and would eventually strike the target again if it

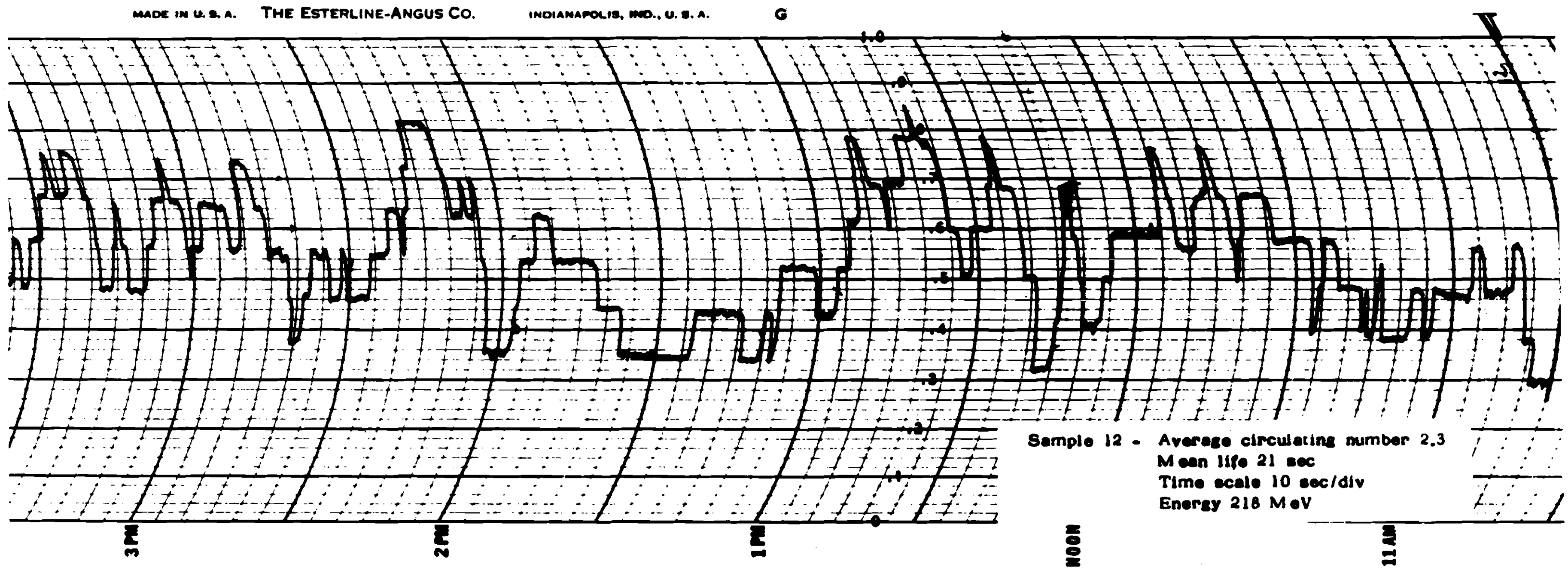


Fig. 5 - Output of photomultiplier observing synchrotron radiation from captured electrons

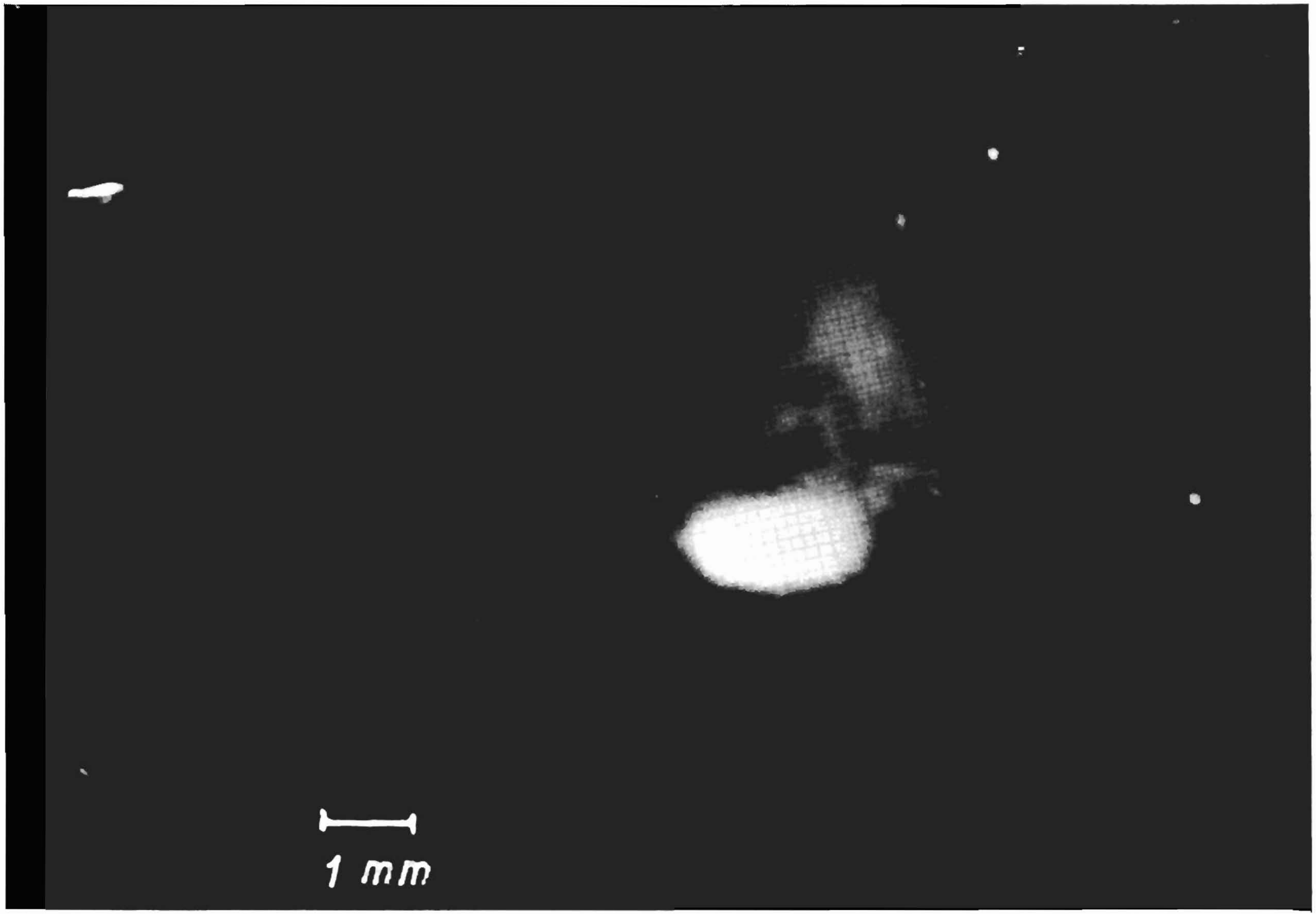
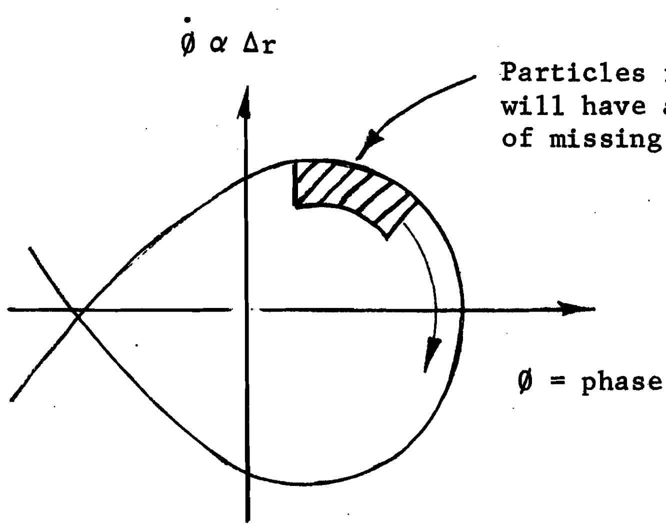


Fig. 6 - Photograph taken through one of the observation windows

were not for radiation damping which contracts the envelope of their trajectories at a rate of about 10^{-6} cm/sec. The resultant rate of capture corresponds to an effective target width of about 10^{-9} cm.

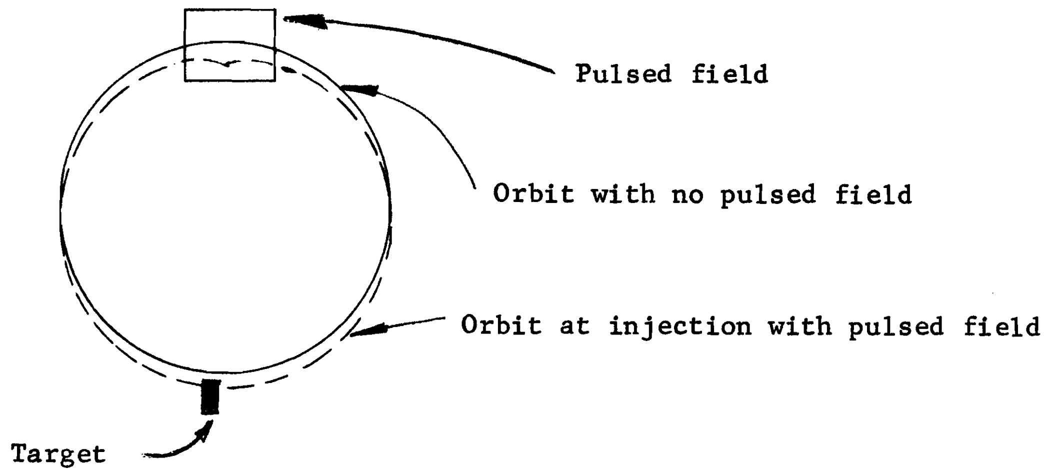
The presence of the radiofrequency complicates this situation a little. The beam initially suffers a radial displacement of about 2 mm and particles injected with an energy corresponding to a large Δr will follow the stability contour. In this way they gain time (one complete synchrotron oscillation) for being "damped" and their chance of missing the target is increased. Initial calculations, which took account of



this phenomenon, predicted about 5 electrons/sec. More realistic calculations carried out later gave about 0.8 electrons/sec in good qualitative agreement with the experiment.

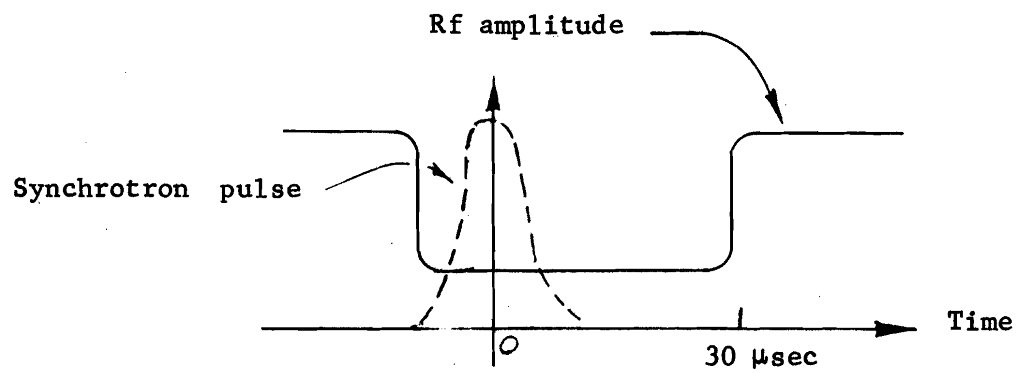
The first and unsuccessful attempts to improve the capture rate were carried out in the autumn of 1961. A pulsed magnetic field of several hundred gauss was applied in a small region (about 10 cm in length) at

180° from the point of injection. The purpose of this field was to distort the equilibrium orbit during injection time in the way shown in the sketch:



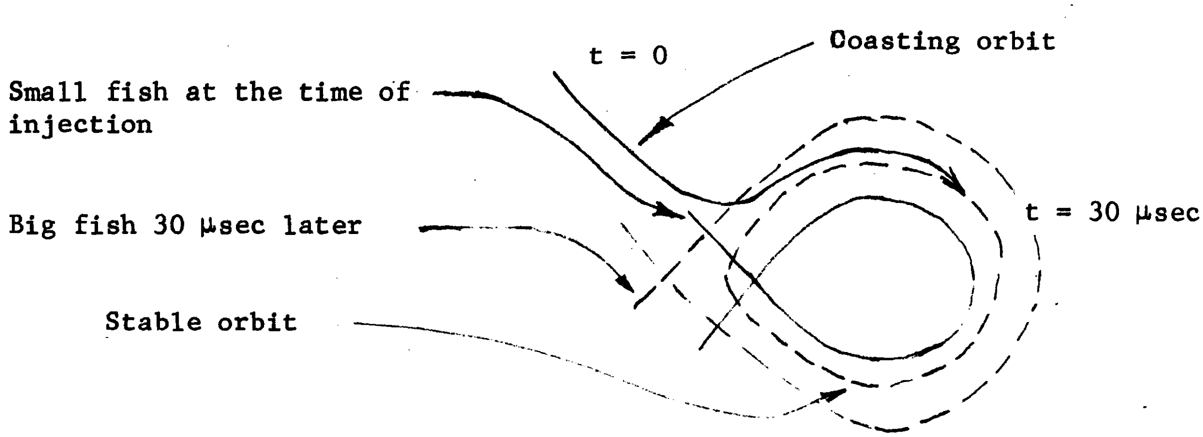
As the magnetic field was removed it was expected that the orbit would shrink away from the target. If the shrinkage was sufficiently slow no betatron (or synchrotron) oscillations would be excited and it was expected that this should improve the capture by a factor of about 10 with a 15 μsec synchrotron pulse. No such improvement was observed, though a factor 3 to 5 was observed if the magnetic field was delayed by about 30 μsec relative to the synchrotron pulse. But this effect was hardly altered when the sign of the impulse was changed! The displacement of the orbits was checked by running the target into the beam, a method which allowed the localization of the beam with an accuracy of about 0.2 mm. The pulsed magnetic field was checked in model experiments. The tentative conclusion was that there were some nonlinear couplings, probably causing synchrotron oscillations, which annulled the beneficial effect of pulsing. A very important conclusion from these tests was, however, that even quite violent pulsing did not show any influence on the lifetime of the accumulated particles (which at the time of the tests was about 5 minutes).

The marginal improvement obtained with the delayed magnetic pulse suggested that one try a modulation of the radio frequency. A pattern shown in the sketch immediately gave an improvement of more than a factor of



20 in injection efficiency, so that at 15 meters from the synchrotron, 8 particles instead of 0.4 particles could be accumulated per second.

The mechanism of this improvement is the following. The rf amplitude at the time of injection is small and we consider an electron which has been injected with an energy of a few Mev in excess of the synchronous energy. Its trajectory in phase space is shown in the sketch. The



electron will lose energy owing to its uncompensated radiation loss. The consequent spiralization (which is proportional to the radius of about 60 cm) will be about 40 times higher than that of the particles normally captured in the rf bucket, whose damping is only proportional to the amplitude of betatron oscillations ($\Delta r = 1.5$ cm). In about 30 μsec the particle will be sufficiently far from the target and the expanding bucket or fish converts its unstable orbit into a stable one.

In December 1961 a "good", well-baked stainless-steel vacuum chamber was installed in the storage ring. Fig. 7 shows the result of a lifetime measurement on a beam containing initially 80 electrons. The pressure was about 4×10^{-9} torr (at the pump) and the measured lifetime was about 5 hours. At present we have lifetimes of more than 50 hours with a pressure of about 3×10^{-10} torr.

In an attempt to increase the intensity, AdA was moved nearer to the synchrotron (Fig. 8). In its new position it was impossible to translate the ring sideways to inject both types of particles. To inject positrons the entire ring was revolved about a horizontal axis (perpendicular to the direction of the synchrotron beam) - like a pancake. Fig. 9 shows the actual arrangement. The distance between the targets was thus reduced from 15 to 3.5 meters. It was found that in this manner one gained only a factor 5 in intensity and not a factor of $(15/3.5)^2$ as expected from an inverse square law. The reason was the incomplete illumination of the internal target by the very fine high-intensity peak of the synchrotron beam.

At the invitation of Professor A. Blanc-Lapierre, AdA (complete with vacuum) was transferred to the Laboratoire de l'Accélérateur Linéaire at

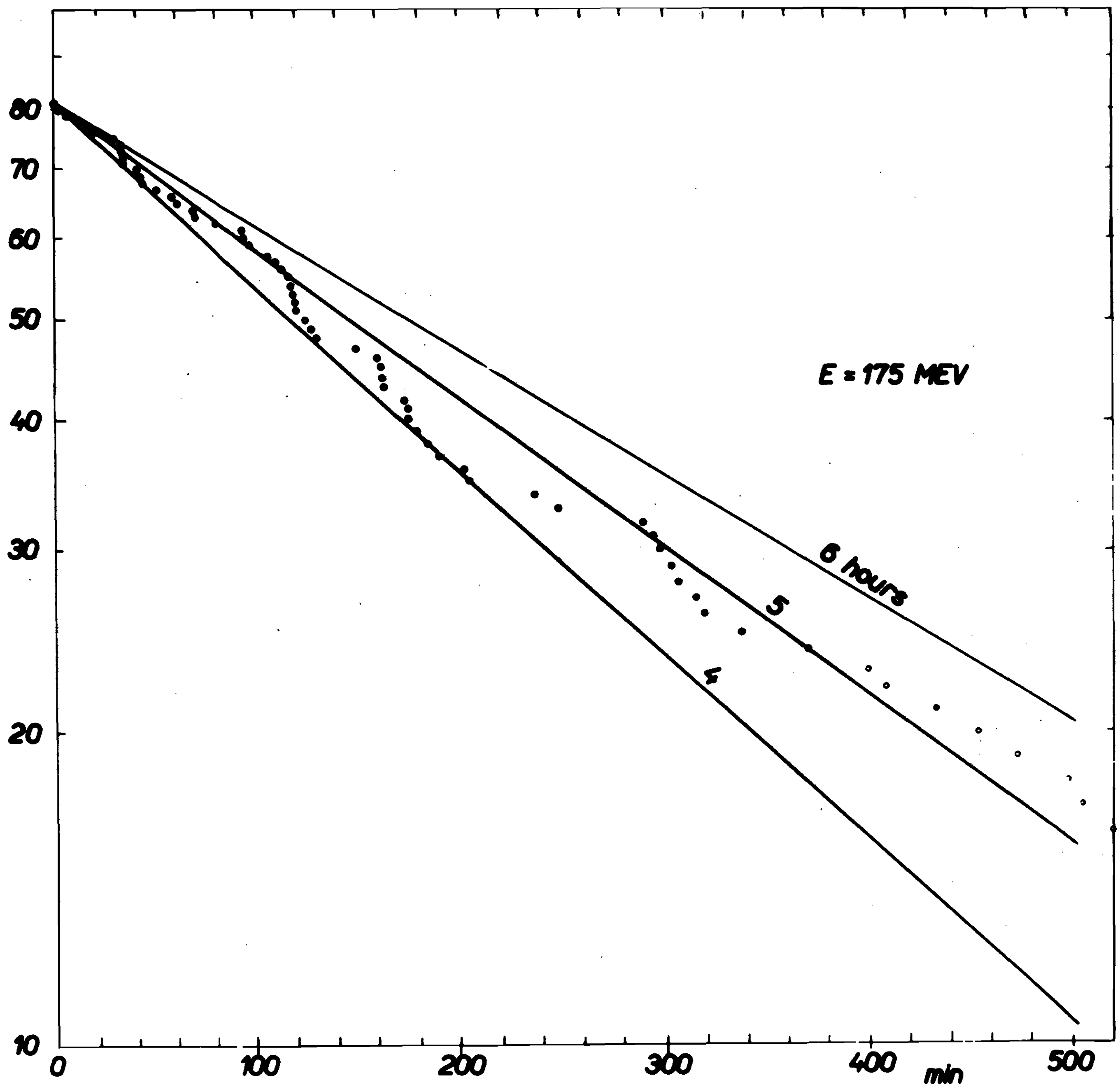


Fig. 7 - Lifetime measurement. Each dot represents the loss of one electron. Initially there were 80 electrons, pressure = 4×10^{-9} torr (at pump).

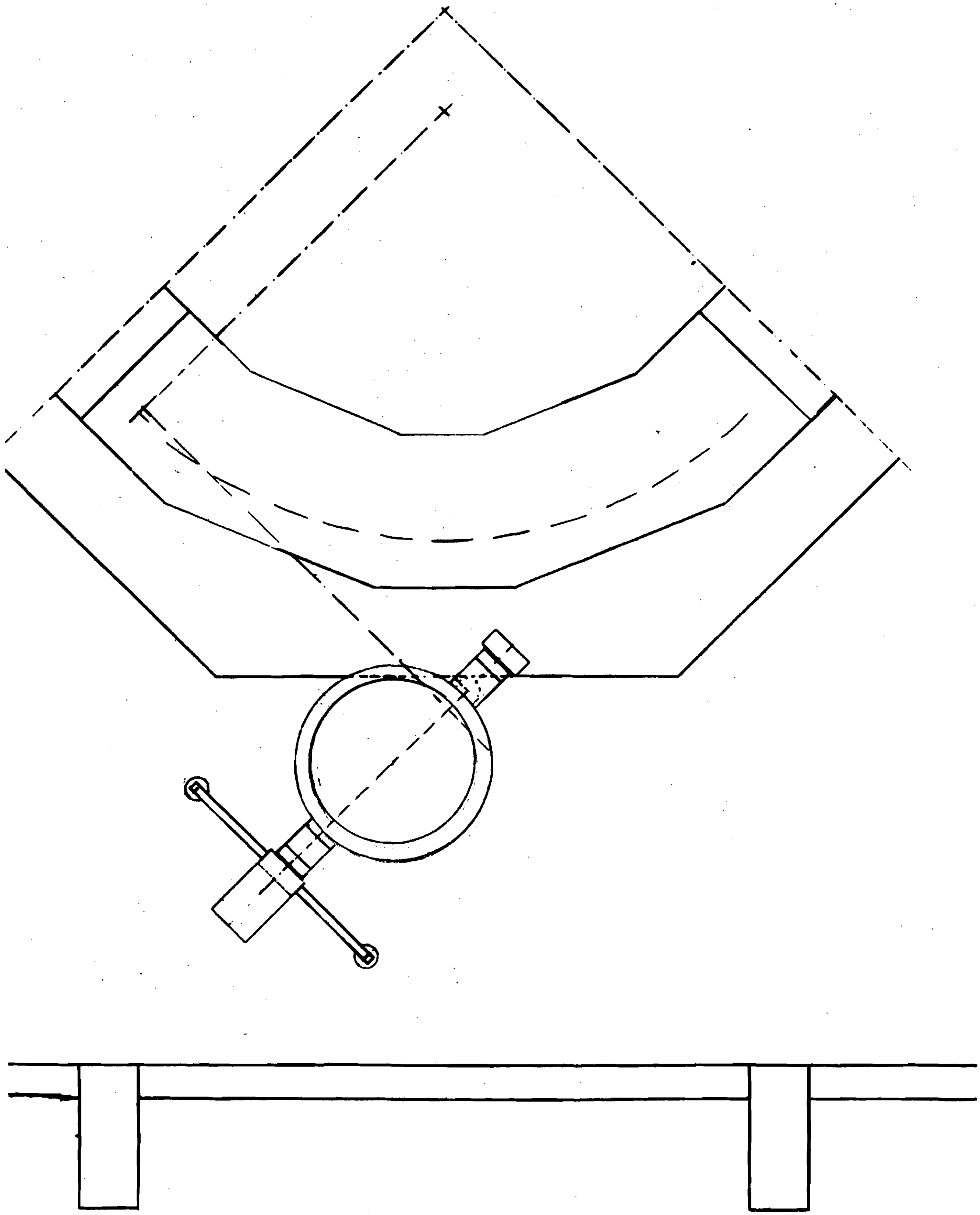


Fig. 8 - Position of storage ring after being moved closer to the synchrotron. To inject positrons, the ring was revolved 180° about a horizontal axis.

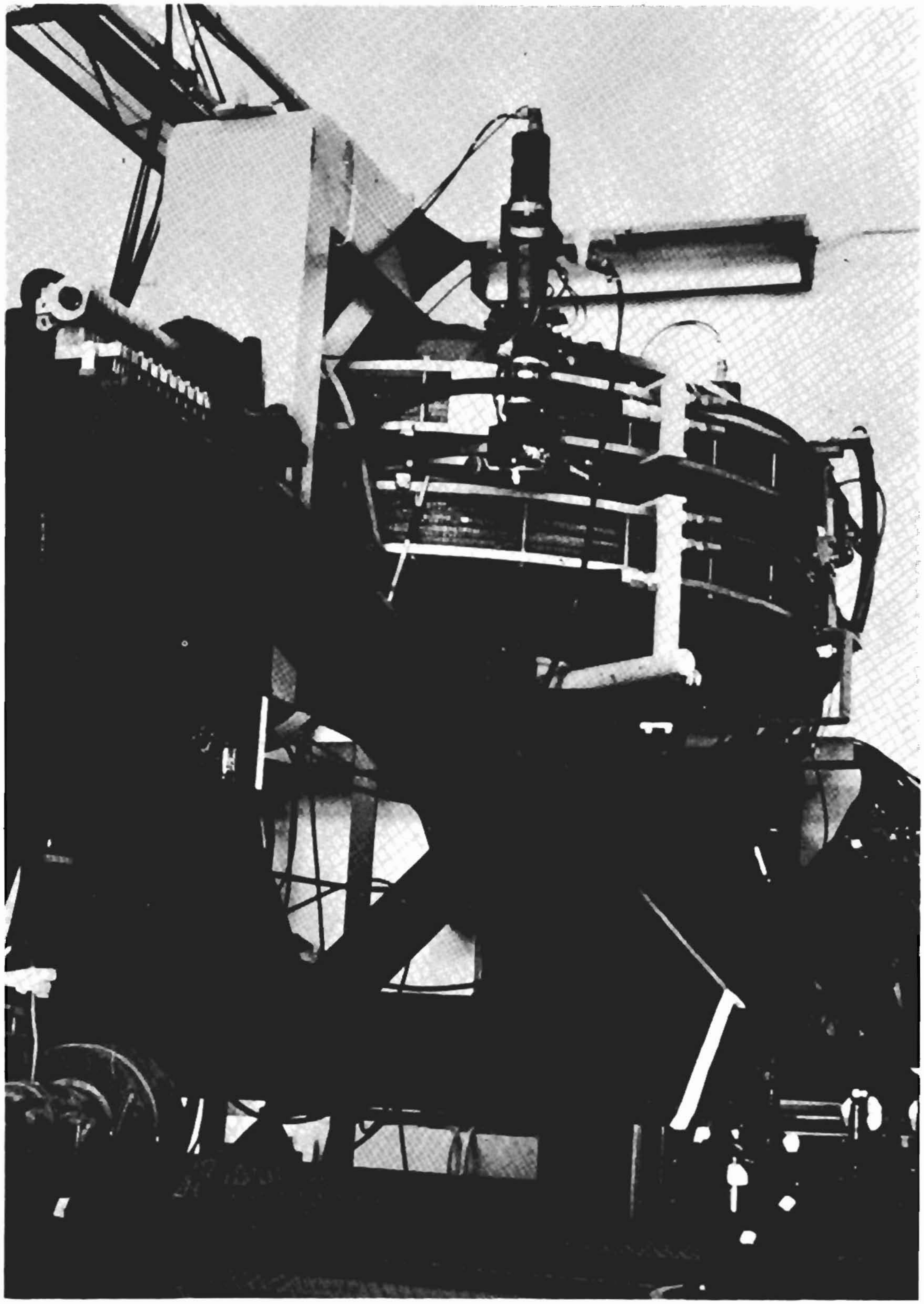


Fig. 9 - AdA mounted on a horizontal axis

Orsay and installed in the 500-Mev beam room. At 450 Mev the linac has a peak current of 0.6 microamperes. The anticipated injection rate was about 8000 electrons/sec. A thin target (about 0.2 radiation lengths) was placed in the electron beam about 80 cm from the internal target of AdA. In June 1962 the capture rate was about 3000/sec and has improved to peaks of about 10,000/sec.

After the move to Orsay the ring started to behave in a startlingly erratic fashion. We lost particles when changing the energy of the beam (we could change energy without preoccupation at Frascati by just changing the magnet current). Also, characteristic losses of 10 to 90 percent of the stored beam occurred when, or a short time after, "flipping the ring". In October we found that the reason for this was slightly magnetic dust, which had somehow accumulated inside the vacuum chamber and which had a habit of falling into the beam.

G.K. O'Neill (Princeton): Did this chamber have organic gaskets in it?

B.F. Touschek: No. All joints were soldered. It is possible that the dust was formed inside the titanium pump.

To obviate the difficulty of the falling dust it was decided to remount the ring. After particles of one sign have been injected, the ring is translated by one diameter and then rotated by 180° around a vertical axis, so that particles of opposite charge come from opposite faces of the inner target. The arrangement is shown in Fig. 10. The new arrangement was ready for operation in December 1962. No losses have been observed after that date.

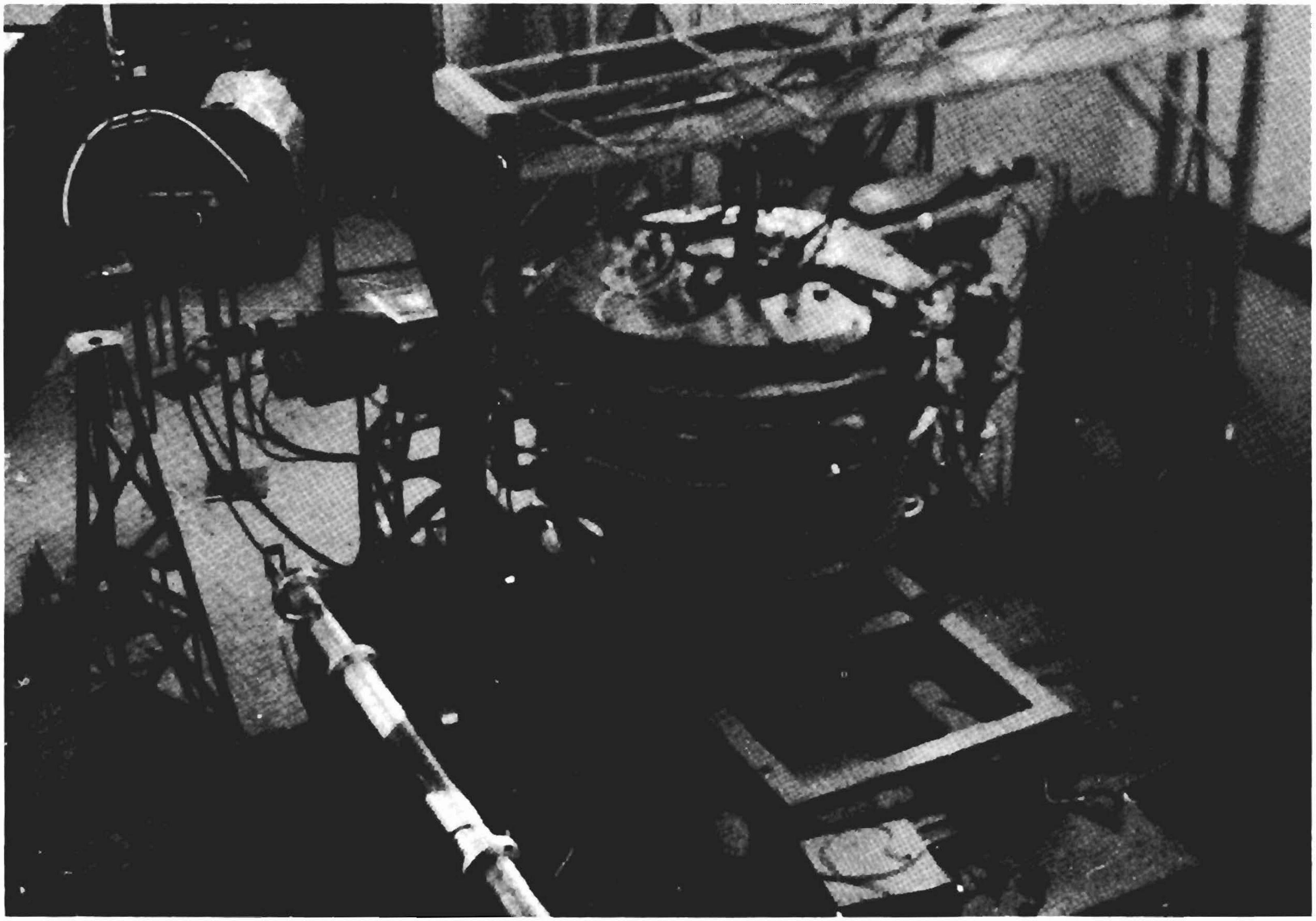


Fig. 10 - AdA mounted on translation and rotation (about vertical axis) mechanism at Orsay

At this time it was possible to store up to 5×10^7 particles and the maximum effective charge so far realized was

$$N_+ N_- = 4.5 \times 10^{14} \text{ particles}^2 .$$

With these numbers we thought that it should be quite possible to observe the two-quanta annihilation of positrons and electrons which at an energy of about 200 Mev has a cross section of about 10^{-29} cm^2. To detect the γ's, two Cerenkov counters (1), Fig. 11, were placed tangentially to the encounter region (about 8 cm in length) opposite to the rf cavity. Scintillation counters (3) provided anti-coincidences against cosmic rays and counters (2) against electrons. The pulses were displayed on an oscilloscope, the time resolution for equal size pulses was about 2 nsec, and the "window" for the check of accidental coincidences was about 30 nsec wide. Later on it was also possible to study synchronization of coincidences with the phase of the radiofrequency, but we are not certain that this synchronization (which should give a phase correlation for genuine beam events) is yet quite reliable.

The experimental situation may provisionally be summed up thus:

1) There is no background.

2) There are a few (about 10) genuine beam-beam events.

3) These events do not look like annihilation γ's because none have produced the right pulse height in both Cerenkov counters.

4) The synchronization with the rf does not show up and is subject to doubt: the times to be resolved are 3 nsec and the rf sweep does not seem to be quite linear.

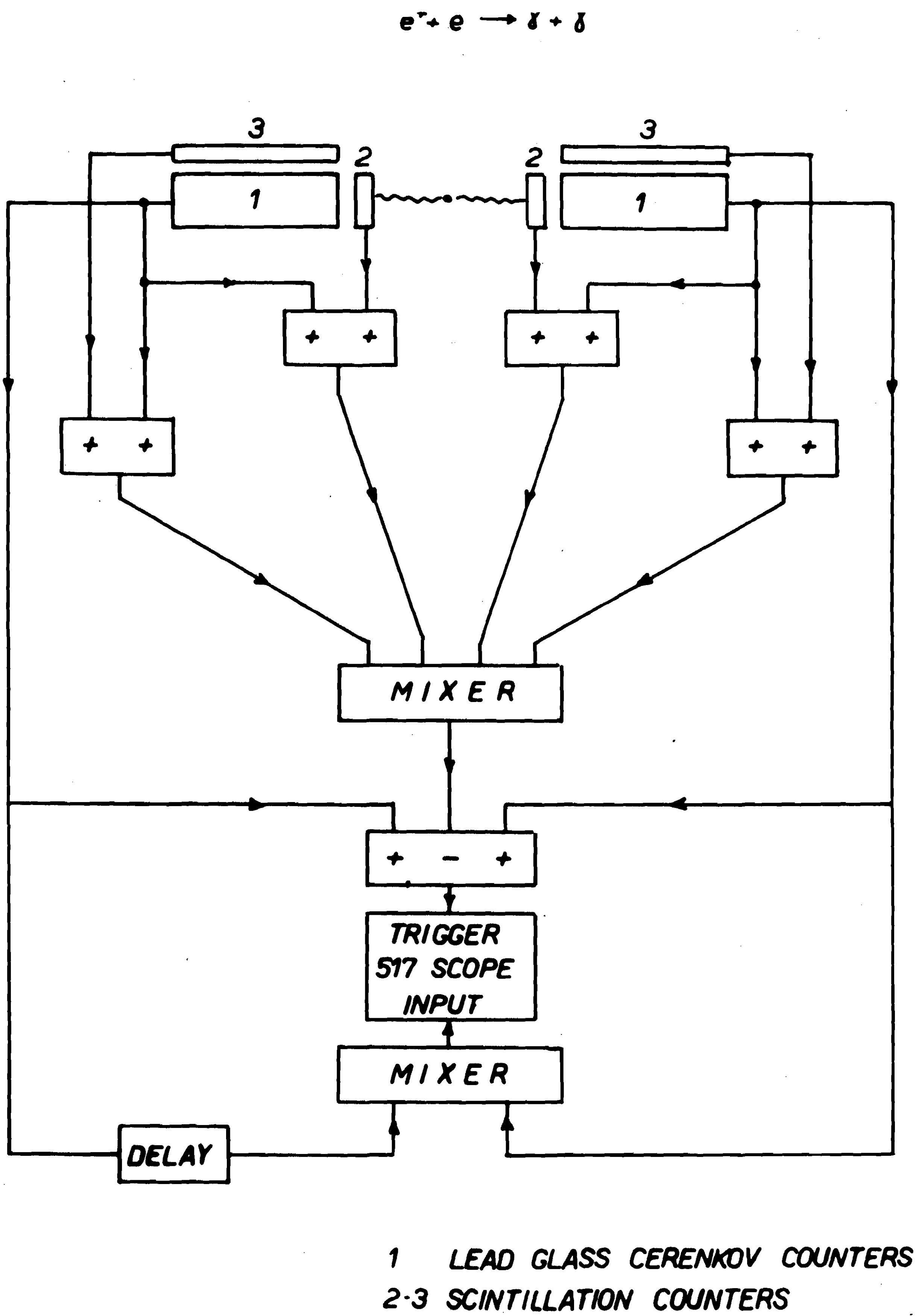


Fig. 11 - Experiment to detect two-quanta annihilation of positrons and electrons

Two preliminary conclusions can be drawn from this:

a) The beam is higher than about 30 microns (at 1.5 microns, its natural height, we should have had at least 10 annihilations in the first hour of the run).

b) The events are probably radiative scattering of electrons by positrons.

To see that the second process can be very important so as to mask completely two-quanta annihilation, the following consideration of orders of magnitude is indicated.

Apart from factors 2π, etc., the cross section for annihilation is given by

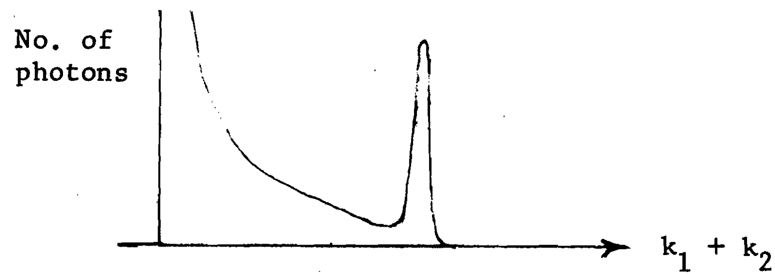
$$\sigma_{ann.} \simeq \frac{r_o^2}{\gamma^2}$$

where r_o is the Lorentz radius = 2.8×10^{-13} cm and $\gamma = E/mc^2 = 400$. On the other hand the cross section for double bremsstrahlung accompanying electron-positron scattering should be of the order

$$\sigma_{brem^2_.} \simeq \frac{r_o^2}{(137)^2} \frac{dk_1}{k_1} \frac{dk_2}{k_2}$$

where k_1 and k_2 are the energies of the two photons. Most of these photons will continue in the direction of the particles which produced them and this process is therefore likely to lead to "annihilation-like" coincidences. No accurate calculation of the process is known to me.

With an "ideal" Cerenkov counter (of infinite energy resolution) the spectrum should look like this:



where the continuous part is due to double bremsstrahlung and the line is annihilation radiation. The actual resolution of our Cerenkovs is about 20% and it is therefore doubtful that the annihilation line can be resolved at all. This would only be possible if $\sigma_{brem.^2} \ll 5\ \sigma_{ann.}$, which is not the case if one takes the above qualitative considerations literally. The situation is probably worse for bigger storage rings, since the annihilation cross section decreases with energy, but the cross section for double bremsstrahlung does not.

During the initial operations at Orsay there was already evidence that the lifetime of the beam was shorter than expected. Part of this effect was probably due to the degassing caused by the "waste beam" of the linac on the walls of the vacuum chamber. There was also some drift of the photomultipliers and it took quite some time to get correct lifetime measurements. To avoid the influence of induced radioactivity on the photo tubes we had to place them at a large distance from the equatorial plane of the machine and we had to learn that the cleanest method of reducing the efficiency (by the required factor of 10^4) was to change the voltage.

Lifetime measurements are of paramount importance when considering the feasibility of coincidence experiments since the ratio of "significant events" to "target background events" varies as the lifetime squared.

The first accurate measurements were made in February 1963. Fig. 12 shows that the lifetime is dependent on the number of particles and can be fitted by

$$\frac{1}{\tau} = \frac{1}{\tau_o} + \alpha(E)\, N$$

with τ_o = 50 hours. $\alpha(E)$ is an energy-dependent parameter and N is the number of particles in the ring. The energy dependence of $\alpha(E)$ is shown in Fig. 13. It is seen that this curve shows a maximum (short lifetime) at about 75 Mev and that it can be fitted by $\alpha(E)\ E^{5.5}$ = const. in the region 100 Mev $< E <$ 207 Mev. The presence or absence of the other beam does not have any influence whatsoever on the lifetime.

All this we think can be explained on the basis of the dimensions of the beam. The radial dimensions have been measured and are about 1 to 2 mm. The height is certainly at least six times smaller and in a natural beam should be of the order of 1.5 microns. The corresponding momentum distribution (in the rest system of the bunch) would show a large radial momentum spread q_r = 0.1 mc and much smaller longitudinal and vertical spreads. This situation is thermally unstable. Indeed Møller scattering between two electrons in the same bunch can transform radial momentum into longitudinal momentum q. This spread q in the bunch system corresponds to a spread

$$\delta p = q\gamma$$

in the lab system. If the average radial momentum is transferred into the

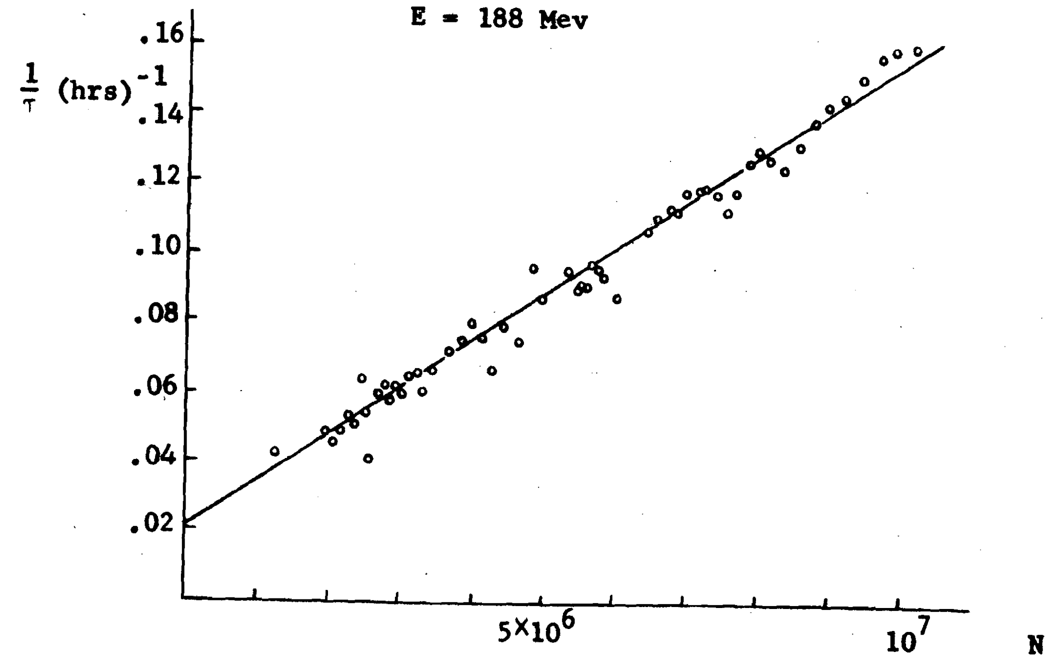


Fig. 12 - Lifetime τ vs N, the number of stored particles in a beam, at the energy of 188 Mev

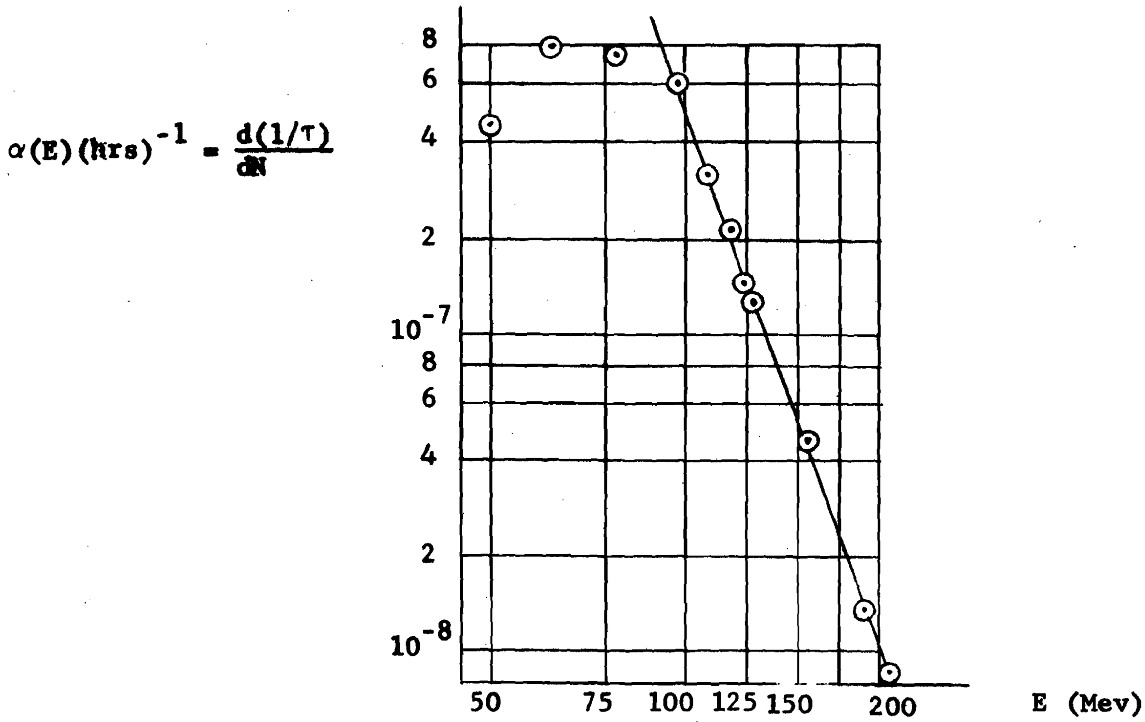


Fig. 13 - Plot of the rate $\alpha(E)$ versus the energy of electrons in the beam

longitudinal direction this will give a longitudinal momentum of about 20 Mev/c. Since the rf can at most contain a momentum deficit of a little less than 1 Mev/c, both particles undergoing this kind of Møller scattering will be lost.

Since q_r is large, comparable with the momentum tolerance (at least for energies > 100 Mev), the main contribution will come from small-angle scattering. The Møller cross section is then (neglecting numerical factors)

$$d\sigma = \frac{r_o^2}{q^4} \frac{d\theta}{\theta^3} \quad \text{(momenta in units of mc)} .$$

Losses will occur, when $q\theta > p/\gamma$, where δp is the limit of momentum acceptance of the rf. Upon integrating we get for the "lethal" cross section

$$\sigma = \frac{r_o^2 \gamma^2}{\delta p^2 q^2} \quad \text{(momenta in units of mc)} .$$

The death rate λ in the laboratory system is then

$$\lambda = \frac{N}{\gamma^2 V} \times q \times \frac{r_o^2 \gamma^2}{\delta p^2 q^2} .$$

V is the volume of the beam, measured in the lab system, and the factor $1/\gamma^2$ is due to the combined effects of Lorentz contraction and time dilation. The additional factor q measures the velocity of the particles. It follows that

$$\alpha(E) = \left(\frac{1}{T} - \frac{1}{T_o}\right) \simeq \frac{N r_o^2 C}{V \delta p^2} \left\langle \frac{1}{q} \right\rangle$$

where $\langle 1/q \rangle$ is determined by averaging over the radial momentum distribution of the particles.

If one calculates this (including factors 2π, etc.) one arrives at lifetimes of the order of 20 minutes instead of 6 hours for a natural size beam (i.e., a beam whose dimensions are only defined by the fluctuations of the radiation losses and whose height should therefore be 1.5 microns). Also, one finds that $\alpha(E)$ should vary as $E^{-4.5}$ and not as $E^{-5.5}$.

These discrepancies are eliminated if we assume that the beam is considerably higher than "natural" and that this increase in height is due to some unwanted coupling between radial and vertical betatron oscillations. Since for the natural beam the radial width increases as E, but the height is independent of E, coupling will also make the height vary as E and $\alpha(E)$ will then vary as $E^{-5.5}$ and not as $E^{-4.5}$.

As we have already observed, the inconclusive state of the $\gamma\gamma$ experiment can be interpreted as indicating a height of the beam $\gg$30 microns (the height is defined by $1/h = \int \rho^2 dx$, where ρ is the probability distribution of the vertical coordinate x; for a Gaussian distribution one has $h = 2\sqrt{\pi \, \overline{x^2}}$). The fact that the lifetime does not change when the second beam is present indicates the height should be $\gg$ 10 microns (the height resulting from multiple electron-positron scattering).

Accurate photometric measurements carried out by Marin and Haissinsky show a beam height of less than 150 microns. Measurements of beam height now in preparation involve the observation of forward-scattered electrons instead of the annihilation reaction. Measurements of background have shown this to be a feasible experiment. It is intended to observe scattering angles of about 25 milliradians.

As it stands it seems difficult to make use of AdA for a real high-energy experiment. Though a setup for the observation of pairs of muons and pions is ready, we do not think we can use it unless we succeed in increasing both the intensity of the stored beams and their lifetime. The latter can be done by working at higher energy. This is at the moment impossible because of limitations in magnet power supply. It also appears that the radiofrequency system is not "safe" at energies above about 220 Mev. The intensity of the stored beams can probably be improved by a factor of more than two by increasing the average intensity of the linac beam and by improving its geometry.

II. Adone

I shall be brief on this subject, giving only the definition of the project and its state of progress. The work was done by the following persons: F. Amman, R. Andreani, M. Bassetti, M. Bernardini, A. Cattoni, V. Chimenti, G. Corazza, E. Ferlenghi, L. Mango, A. Massarotti, C. Pellegrini, M. Placidi, M. Puglisi, G. Renzler and F. Tazzioli. This group, which was of course much smaller at the beginning of the planning stage, has been assisted by D. Ritson and generally enjoyed the services which the Laboratories of Frascati can offer.

The definition of Adone is: a storage ring for electrons and positrons of up to 1500-Mev energy. This energy was chosen because it was considered sufficient to produce pairs of all the then-known particles.

One of the first considerations was the choice between weak and strong focusing. This choice necessitated the study of the radial antidamping of betatron oscillations. A separated-function machine was decided upon, with the bending magnets having n = 0.5, which makes the damping of all oscillations independent of the focusing properties.

Another important problem has been termed coherent beam-beam interaction. The presence of an electron beam changes the focusing properties of the machine for positrons (electric and magnetic forces add in colliding beams!). If the electron beam is strong enough, a resonance might be reached, leading at least to an enlargement of the positron beam. The result of various numerical calculations is, that with a suitable choice of the parameters of the machine (working near and on the right side of a stop band of the empty ring) the effect is not prohibitive. With equal numbers N of both positrons and electrons the useful interaction rate increases with N^2, as long as N is less than a certain critical value. For $N > N_{crit.}$ the interaction-rate increase is only proportional to N.

Since the radiofrequency must be quite "exuberant" in a storage ring, it follows that it is not necessary to inject at the maximum energy of the ring. A low injection energy would be desirable from the point of view of inflector design and the cost of the linac injector. On the other hand the repetition rate of injection must be small, compared to the damping constants of the betatron and synchrotron oscillations, in order that the injected particles may have time to settle down before more are injected. Since damping is proportional to the third power of the energy, high injection energies are favored. A reasonable compromise is an injection energy of about 400 Mev and damping times of about 1 second. This would give a repetition rate of 1/sec.

The choice of the energy at which electrons are converted into positrons in the linac is the result of a compromise between a very clean, but feeble positron beam for low conversion energies and a less clean and less feeble beam at high energies. An energy of 40 Mev was chosen.

The following table gives the characteristics of the linac ordered from Varian:

	Electrons	Positrons
Maximum energy (0 ma)	440 Mev	360 Mev
Energy (100 ma)	375 Mev	
Current within 1% energy spread	25 ma	0.1-0.2 ma
Total current	100 ma	0.5-1.0 ma
Duty cycle	8×10^{-4}	8×10^{-4}

The positron-current estimates were based on measurements made at Saclay, Orsay and Stanford.

The following table shows the characteristics of Adone:

Maximum energy	1.5 Bev
Injection energy	0.35 Bev
Mean radius	15.9 meters
No. of radial betatron oscillations/circumference	3.3
No. of vertical betatron oscillations/circumference	3.2
Structure	$0\ Q_F\ Q_D\ B\ Q_D\ Q_F\ 0$
Closed-orbit displacement for 1% energy change	Max.: 1.8 cm Min.: .95 cm
Momentum compaction	.063
Rotation frequency	3.33 Mc/sec
Rf harmonic number	3
No. of interaction regions	6

Length of straight sections	2.5 meters
Magnetic bending radius	5 meters

The damping times for betatron oscillations are .01 sec at 1500 Mev and .8 sec at 350 Mev. Synchrotron oscillations are damped twice as fast.

The lifetime effect in Adone is less critical than in AdA. It is important only during injection. If one does nothing, the lifetime with a charge of more than 2×10^{11} particles should be of the order of an hour. The minimal lifetime should be at 500 to 600 Mev. The difficulty at injection could be overcome by broadening the beam. The short lifetimes at energies under 1 Bev do not make experimentation impossible. Since practically all relevant cross sections go as $1/E^2$, the intensity requirements at low energies are not so stringent.

The present status is as follows. The contract for the linac has been placed with Varian. Delivery is expected in two years. Excavation for the buildings has begun. Working models of all important pieces of hardware have been constructed.

Fig. 14 shows a model of a quadrupole with an elliptical aperture necessary to accommodate both the stationary and the injection orbits.

Fig. 15 illustrates the structure of the machine together with the deflecting magnet. The vacuum pipes leading from the deflection magnet to the ring contain differential pumping by means of which the pressure of 10^{-6} to 10^{-7} torr inside the linac is reduced to 10^{-9} torr or better in Adone. This has been tried at Frascati and it has been found that pressure drops by factors of 10^3 are quite feasible. As you can see there are 12 straight sections, two used for injection and three for the rf cavities.

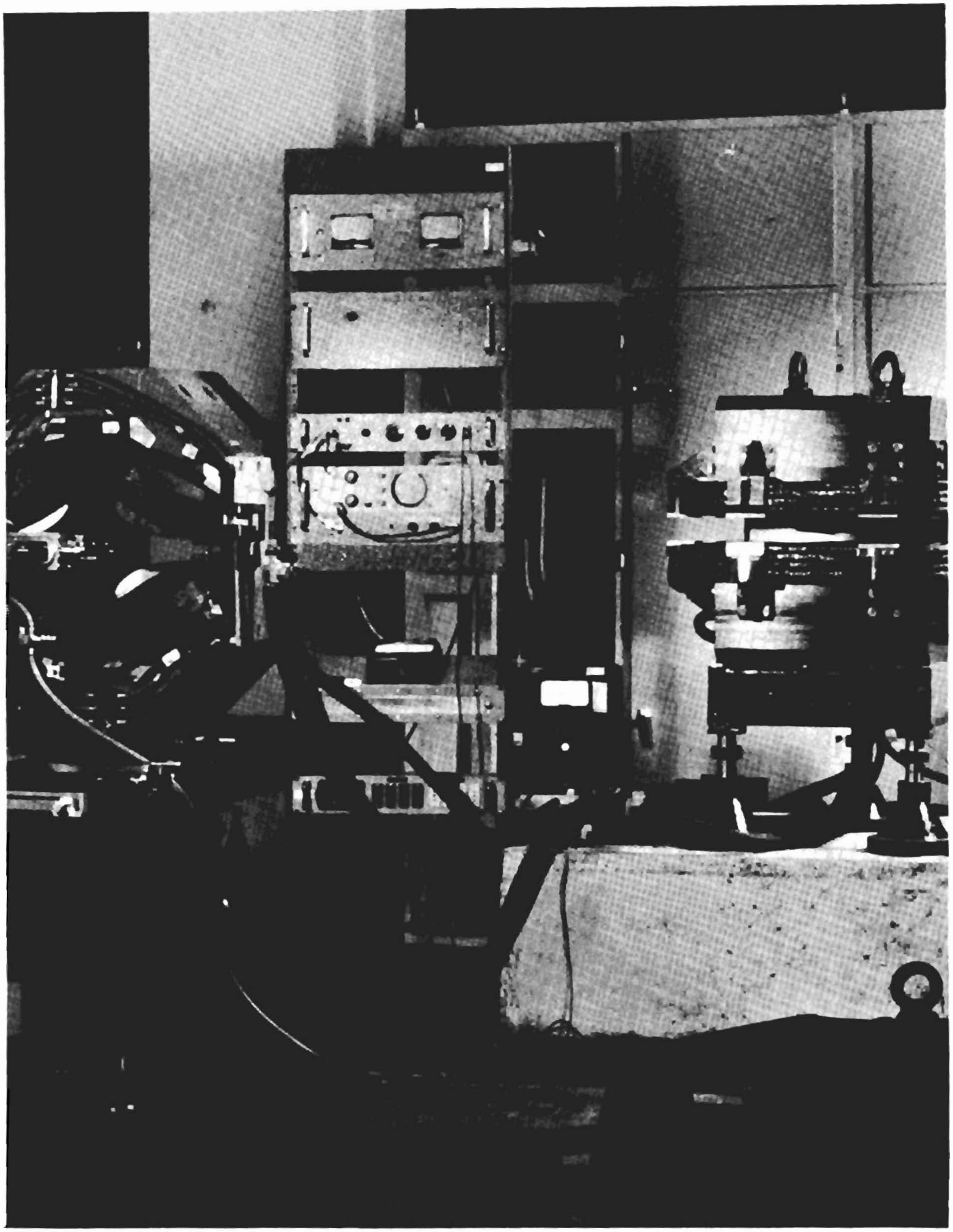


Fig. 14 - Model of a quadrupole for Adone with an elliptical aperture

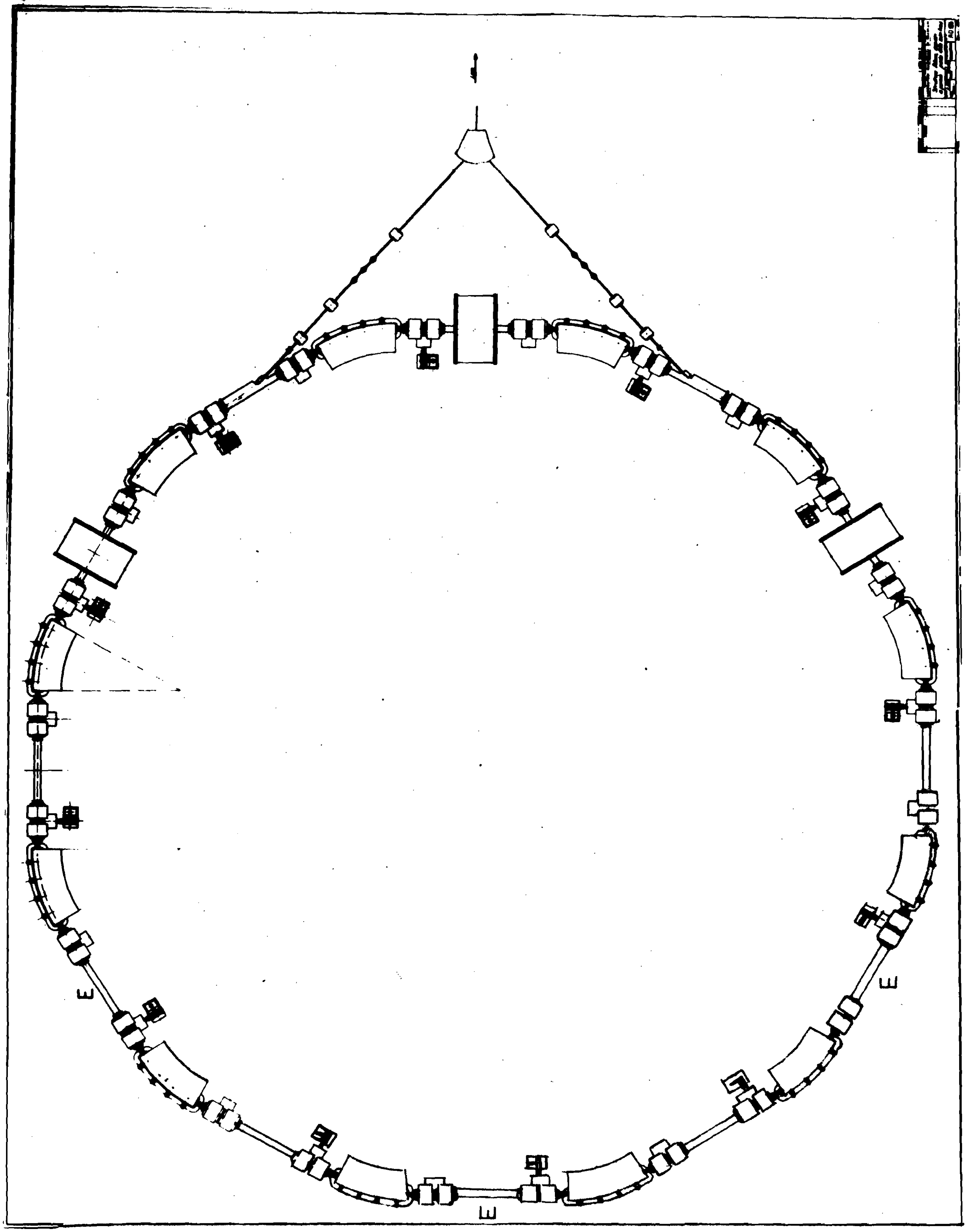


Fig. 15 - Structure of Adone

The three sections reserved for experiments are labeled E in the figure. Titanium pumps are placed between the quadrupoles to save space. Vacuum tests have been made on one half-periodic element. Pressure variations are of the order of 20%.

Fig. 16 shows details of the bending magnets, the quadrupoles, the titanium pumps backed by a molecular pump.

Fig. 17 shows a model of one of the inflectors. In principle the inflector consists of four parallel wires connected as a pulsed transmission line. The current produces a field of about 800 gauss, the electrical contribution adds some 150 gauss. For a deflection of 5^{o}, 100 kilovolts and 1000 megawatts peak will be required.

Fig. 18 shows half of the rf cavity.

Fig. 19 is a full-size model of the vacuum chamber (the flanges that will finally be used will be smaller!) A satisfactory treatment of the vacuum system has been developed. The system is baked out under vacuum at $400^{o}C$ and is allowed to cool. It is then filled with hydrogen at one atmosphere pressure and left for a day. It has been found that if the stainless steel is treated in this way the system can be opened and exposed to air for arbitrary periods of time. Upon closing it is necessary only to evacuate and bake out at $150^{o}C$.

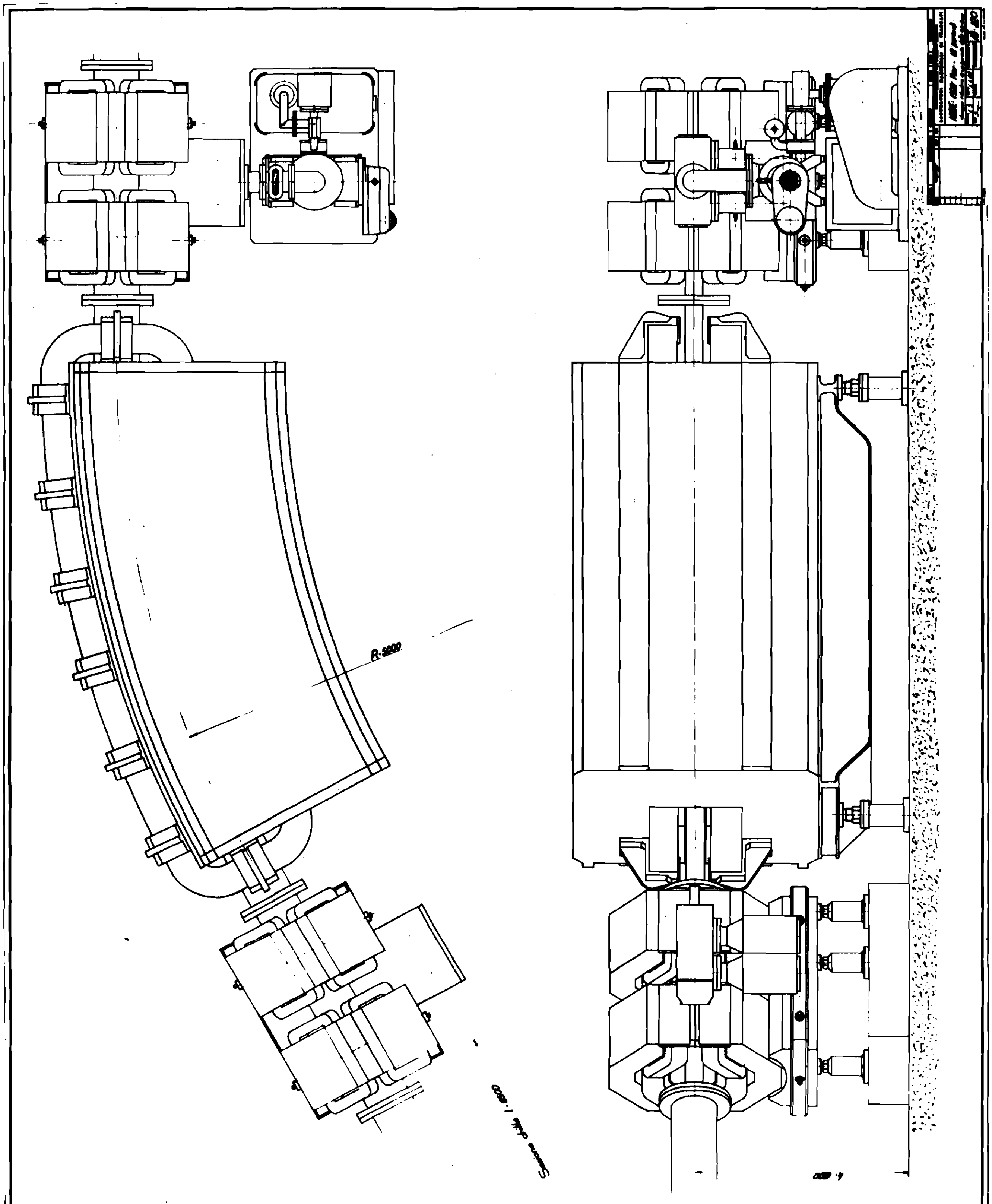


Fig. 16 - Details of Adone bending magnets and quadrupoles

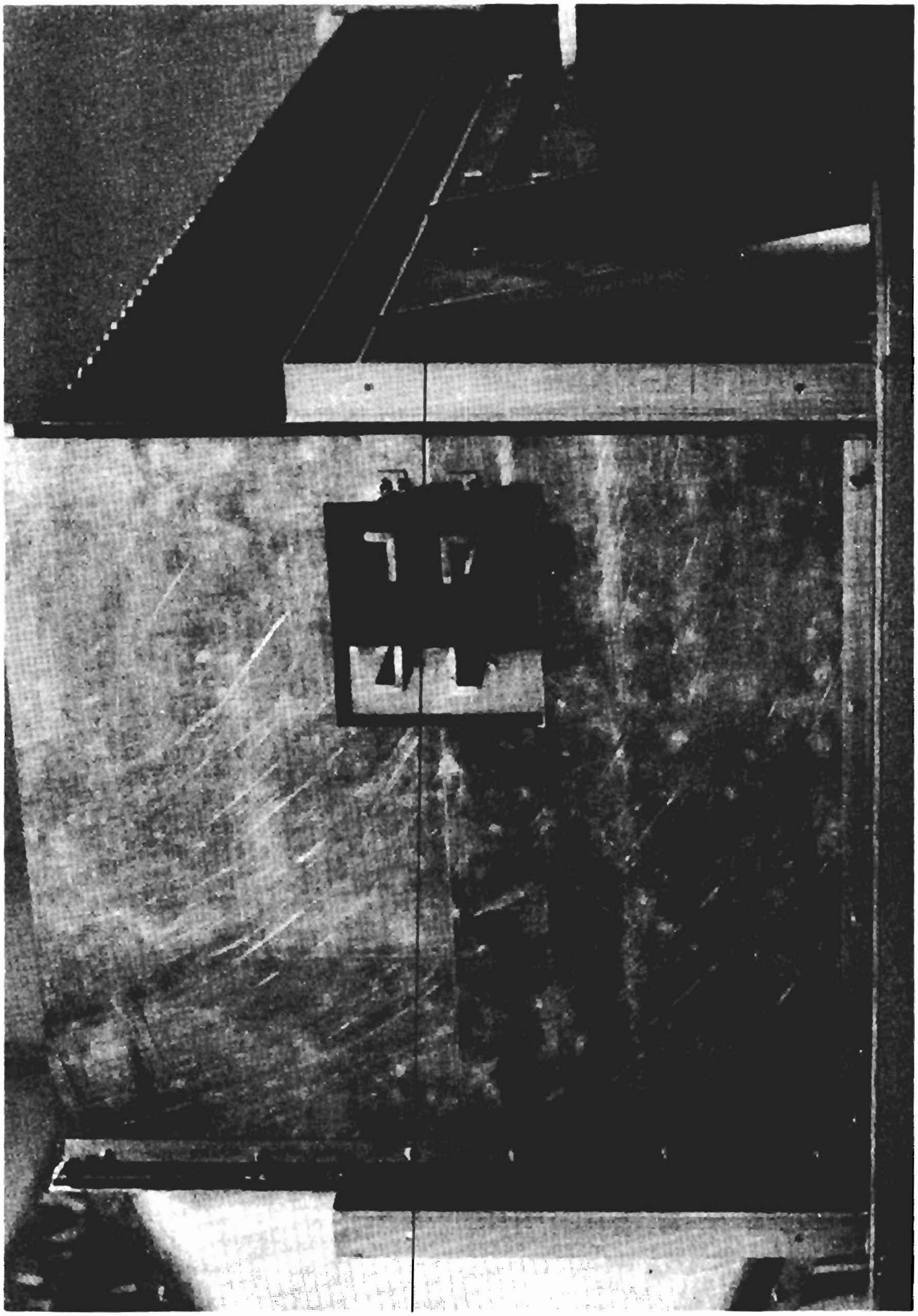


Fig. 17 - Model of one of the inflectors for Adone

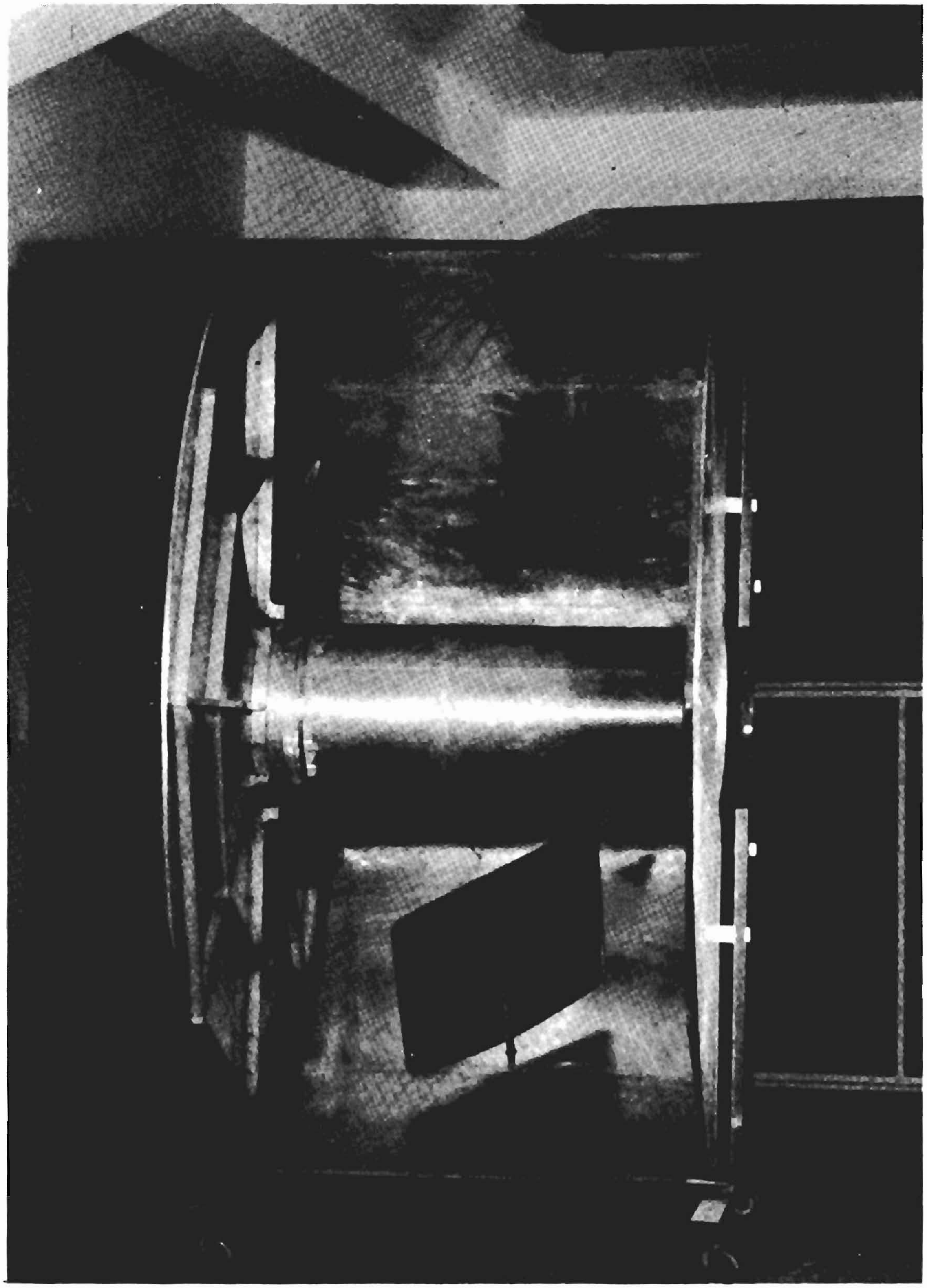


Fig. 18 - Rf cavity for Adone

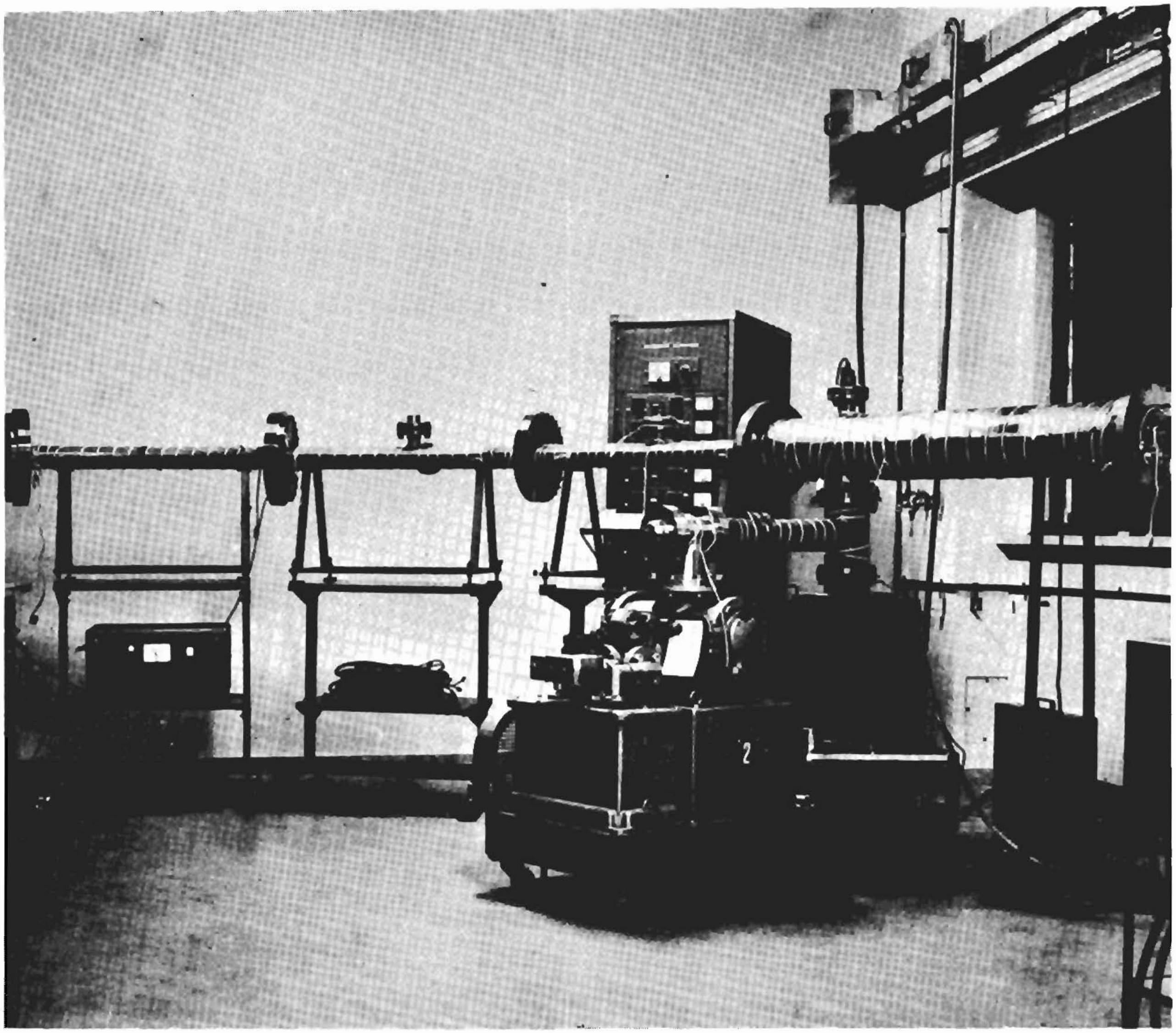


Fig. 19 - Full size model of Adone vacuum chamber. (Final vacuum flanges will be smaller than the ones shown.)

Discussion

G.B. Collins (BNL): It is my impression that for many experiments the intensity of 2×10^{11} circulating electrons is on the low side except for experiments with very large cross sections. Do you think 2×10^{11} is adequate?

B.F. Touschek: Yes, I think that this is adequate for giving a rate of several events per hour for most interactions. Furthermore, it should be quite possible to increase the number of electrons - not of positrons - by a factor 10. This would increase the reaction rate by approximately $\sqrt{10}$.

G.K. O'Neill (Princeton): Where does 2×10^{11} fall on the luminosity curve?

B.F. Touschek: It is definitely above the "coulomb limit".

J.P. Blewett (BNL): What happens to the luminosity curve if N_+ and N_- are unequal?

B.F. Touschek: Above the coulomb limit the luminosity is then proportional $\sqrt{N_+N_-}$.