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INITIAL USE OF THE POSITIVE-ION INJECTOR OF ATLAS*

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ABSTRACT

The positive-ion injector of ATLAS consists of an ECR heavy-ion source coupled to a 12-MV superconducting injector linac. The ECR source and a 3-MV version of the partially completed linac have been used to accelerate successfully several species of heavy ions. The operating experience is summarized, with emphasis on the excellent beam quality of beams from the new injector. Two new fast-timing detectors are described.

I. INTRODUCTION

Until this year, ATLAS has consisted of a 9-MV tandem coupled to a superconducting linac.[1)] The layout of the system is shown in Fig. 1. The linac has two main parts: the "booster" linac built during the 1970's as a prototype machine and the "ATLAS addition" completed in 1985 as part of a line-item construction project.

The beam from ATLAS can go either into experimental area II, directly from the booster linac, or through the whole linac into areas III and IV. Since its first operation in 1978, ATLAS (in all of its various phases) has delivered about 40,000 hours of beam on target for research.

Although ATLAS is an excellent research tool now, it has two significant limitations: (1) it cannot accelerate ions in the upper half of the periodic table and (2) its beam current is less than some users need. Both of these limitations originate in the tandem injector, especially because of the short life time of the stripping foils in the 9-MV tandem terminal. Consequently, we have undertaken

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to upgrade ATLAS by replacing the tandem with a positive-ion injector. The primary objectives in this upgrade are: (1) to extend the mass range of projectiles up to uranium, (2) to increase the beam intensity by a large factor, and (3) at the same time, to preserve the good characteristics of the tandem injector. That is, we still want CW operation, easy energy variability, and good beam quality. A small longitudinal emittance $\Delta E \bullet \Delta t$ is especially important because our users make extensive use of very short beam pulses.

II. DESCRIPTION OF THE POSITIVE-ION INJECTOR

The main elements of our positive-ion injector (PII) have been discussed many times[2-5] and are shown in Fig. 2. The ion source is an electron cyclotron resonance (ECR) source on a 350-kV platform.[6] The slow-moving ions on this platform are analyzed and bunched, accelerated to ground potential, and analyzed again while being transported through an isochronous line to the injector linac. A second-stage room-temperature buncher is mounted directly in front of the linac.

The injector linac needs four kinds of accelerating structures[7] to boost the incident-ion velocity (which may be as low as 0.008c) to the value of 0.04c required for acceptance by ATLAS. All four types are 4-gap superconducting niobium resonators, as shown in Fig. 3. All types have on-line performance that exceeds the design goals, which are an accelerating field of 4.5 MV/m for the β=0.009 unit and 3.0 MV/m for the others at a power dissipation of ~4 W.

When completed in late 1990, the injector linac will consist of 18 resonators housed in three cryostats, providing a total of 12 MV of acceleration. One of these accelerator sections, which gives 3 MV of acceleration, is now in operation and is used occasionally to provide ATLAS users with beams that are not available from the tandem. The injector-linac voltage will be increased to ~8 MV in early 1990.

All parts of PII, including the injector linac, are now controlled independently of the main ATLAS control system. This permits the new injector to be installed and thoroughly tested without much interruption of routine operation of ATLAS with the tandem injector. When all testing of PII has been completed, its control will be transferred to the ATLAS control computer.

III. OPERATING EXPERIENCE

In its present form, PII is complete in all respects except that the injector linac provides only 3-MV of acceleration rather than 12-MV. This prototype linac is too small to be generally useful for research, but it can provide some beams that are not available from the tandem, and the ability to test all parts of the system has been very valuable.

The 3-MV version of PII accelerated its first beam on February 28, 1989, and by now it has been used to accelerate $^{3}He^{2+}$, $^{86}Kr^{19+}$, and (on two occasions) $^{40}Ar^{12+}$. Also, in December, $^{13}C^{3+}$ will be used as a guide beam for the acceleration of $^{39}Ar^{9+}$ (an unstable nuclide) in an accelerator-mass-spectrometry experiment. The operating characteristics of PII in these runs are summarized in Table 1. Also, see Ref. 8 for more details about the initial test with $^{40}Ar^{12+}$.

The ECR ion source worked stably and well over long periods of time with only minor adjustments. However, the voltage of the source platform had to be limited to 250 kV (rather than the design value of 350 kV) because of repeated failures of the isolation transformers used to provide power to the ECR source and associated equipment. The higher voltage is not needed now, but at least 300 kV will be needed to accelerate uranium. The transformers will probably have to be replaced to achieve this.

In all of the beam-acceleration tests of PII, the superconducting resonators operated stably for long periods of time and were capable of having an average accelerating field greater than the design goal. In some runs, the field levels of the first two units were reduced in order to match better the high velocities of the incident beams. In spite of the low frequency (large size) of the structures, phase control was not a problem.

The transverse emittance of the beam could not be measured accurately, but the measured beam transmission through a pair of apertures indicates that the normalized emittance (see Table I) is about what we had expected. That is, it is about the same as the emittance for a beam from our tandem with a foil stripper.

The measured longitudinal emittance ϵ_z of the beam from the ECR source and out of the injector linac is remarkably small for the beams that have been studied, as is seen in Table I. Even these excellent results may not be the limit on what will be achievable, since the longitudinal emittance is now dominated by an AC component in the platform voltage. This problem with ripple apparently became worse after the first test run, which accounts for the larger pulse widths for the three later runs. Equipment that is expected to reduce greatly the ripple is now under construction.

In the initial test[8)] of PII in March 1989, all aspects of performance were excellent except that the beam transmission was poor. This problem, which probably resulted from the misalignment of components in the injector linac, has been mitigated by several changes, but we still need to understand why the transmission is not 100%, as expected.

The successful acceleration of beams through ATLAS under a variety of conditions shows that the acceleration process is stable, easily controllable, and does not badly distort the phase space of the beam. This result is important because the very large velocity increase in the first few resonators causes time-of-flight effects within individual resonators that greatly modify performance. In particular, the transit-time factor depends not only on the incident velocity but depends strongly on the relative velocity increase in an individual unit. Also, when the relative velocity increase is large, the dependence of energy gain on phase angle is pathological. Similarly, in transverse phase space, the acceleration process can provide focussing rather than the customary defocussing. In spite of this unusual behavior, however, we were able to tune and operate the injector linac with ease, and our fears about the possibility of serious beam-quality degradation proved to be groundless.

IV. BEAM BUNCHING

The 2-stage beam-bunching system of PII deserves special attention because it involves several features and capabilities that are different from those of a tandem bunching system. The most important difference is that there is no stripper between the 1st- and 2nd-stage bunchers. As a result, in principle the good beam quality of the source can be preserved. Also, there is no need for the 1st buncher to form a time focus at some particular place (such as at a terminal stripper) and consequently the amplitudes of the two bunchers can be varied so as to adjust somewhat the ratio $\Delta E_0/\Delta t_0$ (energy spread/time spread) of the beam delivered to the injector linac.

Another important feature of our bunching system is the means used to remove the background of unbunched ions, ~30% of the total. In most bunching systems this is done with a beam chopper. However, beam tests have shown that this is not a satisfactory approach for PII because the energy spread induced by the fringing fields of the chopper is a serious source of beam-quality degradation. This well-understood effect, which is usually unimportant, has a major impact on the PII beam because its initial energy spread is so small.

Fortunately, there is an easy solution to the problem of removing unbunched ions, as illustrated in Fig. 4. Because of the correlation between beam energy and time, the second-stage magnetic analyzer can be used to remove unbunched ions near the main beam pulse, and then the chopper can remove more distant ions without inducing much energy spread for the bunched beam. This 2-step process results in narrow beam pulses that are remarkably free of tails, as illustrated schematically in Fig. 4. As far as we know, this simple but effective approach has not been consciously used previously in a bunching system.

Another use of the 2nd-stage magnetic analyzer is to improve the longitudinal emittance ϵ_z of the beam. This is done by bunching the beam in the way described above except that the slits of the analyzing magnet are made narrow enough to limit the buncher-induced energy spread of the beam accepted for acceleration. This procedure, which can reduce ϵ_z by a factor of ~3, also reduces the beam current, of course, but it is often useful because the ECR source provides more beam current than is needed for many experiments. The range of ϵ_z given in the table for $^{40}Ar^{12+}$ illustrates the range of values measured for various analyzer-slit settings.

In summary, then, the beam-preparation system of PII is turning out to be very flexible and effective in ways that were not fully foreseen when the system was designed.

V. BEAM DIAGNOSTICS

Refined diagnostic tools are needed to achieve optimum beam bunching in PII and thus to preserve the excellent beam quality of the ECR source. The heavy-ion detectors normally used to measure energy and time distributions are ineffective because of the low velocity and heavy mass of the ions involved. Consequently, we have concentrated on diagnostic techniques that measure time spectra with two new kinds of detectors.

(a) Single-Wire Detector. This detector (which may be similar to one built earlier at Stony Brook) is designed to sample, with good time resolution, the arrival time of individual ions in the beam. A very fine wire (10 μ) mounted in the beam is the interaction target. Each ion striking the wire produces a burst of electrons, which are accelerated radially by a coaxial anode and some of which pass through an aperture into a channel-plate detector. Because of the axial geometry, the time resolution in this detector should be much better than is required for PII.

The performance of the single-wire detector is as expected. Beam pulses as narrow as 130 ps have been measured and this is almost surely dominated by the width of the beam pulse. A drawback of the detector is that the beam intensity must be attenuated by a large factor in order to limit the counting rate.

(b) Fast Faraday Cup. This detector is designed to measure directly the time distribution of beam current. The time response of most current probes is poor for slow-moving heavy ions because of the signal induced on the probe while the ion approaches. In our fast Faraday cup, this effect is minimized by shielding the probe with a grid that is only 0.3 mm from the probe. Thus, the probe senses the moving ion for only a very short time.

As is shown in Fig. 5, the basic structure of the fast Faraday cup[9] is in the form of a 24-ohm strip line. Great care was taken to preserve the 24-ohm impedance throughout the line, including at the detection cup. Thus, the line has a well-understood wide-band response up to very high frequencies (6 GHz), and the effective time resolution of the system is limited mainly by the frequency response of the electronics available to us. Beam pulses as narrow as 400 ps have been observed, and much better resolutions would immediately be obtained with better electronics.

A fast Faraday cup located between the voltage platform and the 2nd-stage analyzing magnet is provi- to be a valuable tool for tuning and for checking on the performance of the 1st-stage buncher. When the beam current is >100 enA (as it usually is), the pulse width can be observed directly on an oscilloscope. When it is necessary to observe much weaker beams, one requires some form of information averaging such as a sampling oscilloscope coupled to a digital storage device. Design changes now in progress are expected to increase the detector sensitivity by a factor of ~5.

VI. CONCLUSION

We had expected that the serious problems with PII, if any, would be associated with the need to bunch very slow-moving heavy ions and with the beam optics of the front end of the injector linac. Neither problem was evident in our beam-acceleration tests.

Indeed, the operating experience with the 3-MV system (which included all worrisome elements) was so successful and free from serious difficulties as to encourage us to expect that all of the design goals for the complete 12-MV system will be met. The good beam quality is especially gratifying since there are so many ways in which the beam quality can be degraded.

REFERENCES

1. Bollinger, L. M., Ann. Rev. Nucl. Part. Sci. 36, 475-503 (1986). See for numerous references for ATLAS.
2. Bollinger, L. M. and Shepard, K. W., in Proc. 1984 Linear Accel. Conf., Seeheim, Fed. Rep. of Germany, May 7-11, 1984, pp. 24-30 (1984).
3. Pardo, R. C., Bollinger, L. M., and Shepard, K. W., Nucl. Instr. and Meth. B24/25, 746 (1987).
4. Bollinger, L. M., Pardo, R. C., and Shepard, K. W., in Proc. 1986 Linear Accel. Conf., Stanford Univ., Cal. June 2-6, SLAC-Report-303 (1986).
5. Den Hartog, P. K. et al., Nucl. Instr. Meth. in Physics Research B40/41, 900 (1989).
6. Pardo, R. C. and Billquist, P. J., in Proc. 1989 IEEE Part. Accel. Conf, March 20-23, 1989, Chicago, IL., Cat. No. 89CH2669-0, 1, pp. 319-321 (1989).
7. Shepard, K. W., Markovich, P. K., Zinkann, G. P., Clifft, B., and Benaroya, R., in Proc. 1989 IEEE Part. Accel. Conf., March 20-23, 1989, Chicago, IL., Cat. No. 89CH2669-0, 3, pp. 974-976 (1989).
8. Bollinger, L. M. et al., in Proc. 1989 IEEE Part. Accel. Conf., March 20-23, 1989, Chicago, IL., Cat. No. 89CH2669-0, 2, pp. 1120-1022 (1989).
9. Bogaty, J. M., private communication (1989).

Table I. Summary of performance of PII prior to November 1989. Explanations: (a) values given include 12-kV extraction. (b) Pulse width after 1st-stage bunching. (c) Pulse width at first accelerating structure. (d) Both transverse emittance ϵ_r and longitudinal emittance ϵ_z are given in terms of an area in phase space.

	1st Test	Research			Design
Characteristic	$^{40}Ar^{12+}$	$^{3}He^{2+}$	$^{40}Ar^{12+}$	$^{86}Kr^{19+}$	Goals
(a) Platform Voltage (kV)	192	262	262	262	350
β into injector linac	0.011	0.019	0.013	0.011	>0.008
β out of injector linac	0.044	0.045	0.043	0.037	>0.044
Linac Voltage (MV)	3.4	2.5	3.0	3.1	3.1
Transmission of linac	~0.2	0.90	~0.65	~0.60	~1.0
(b) Δt_1 (ns) FWHM	1.2	2.5	2.8	3.5	<3
(c) Δt_2 (ns) FWHM	~0.25	~0.3	~0.4	~0.4	<0.5
(d) $\epsilon_r E^{1/2}$ (mm-mrad-MeV$^{1/2}$)	~20π	<20π	~20π	~20π	~20π
(d) ϵ_z (keV-ns) linac input	(1.5-4)π				<20π
(d) ϵ_z (keV-ns) linac output	5π	<1.0π			<50π

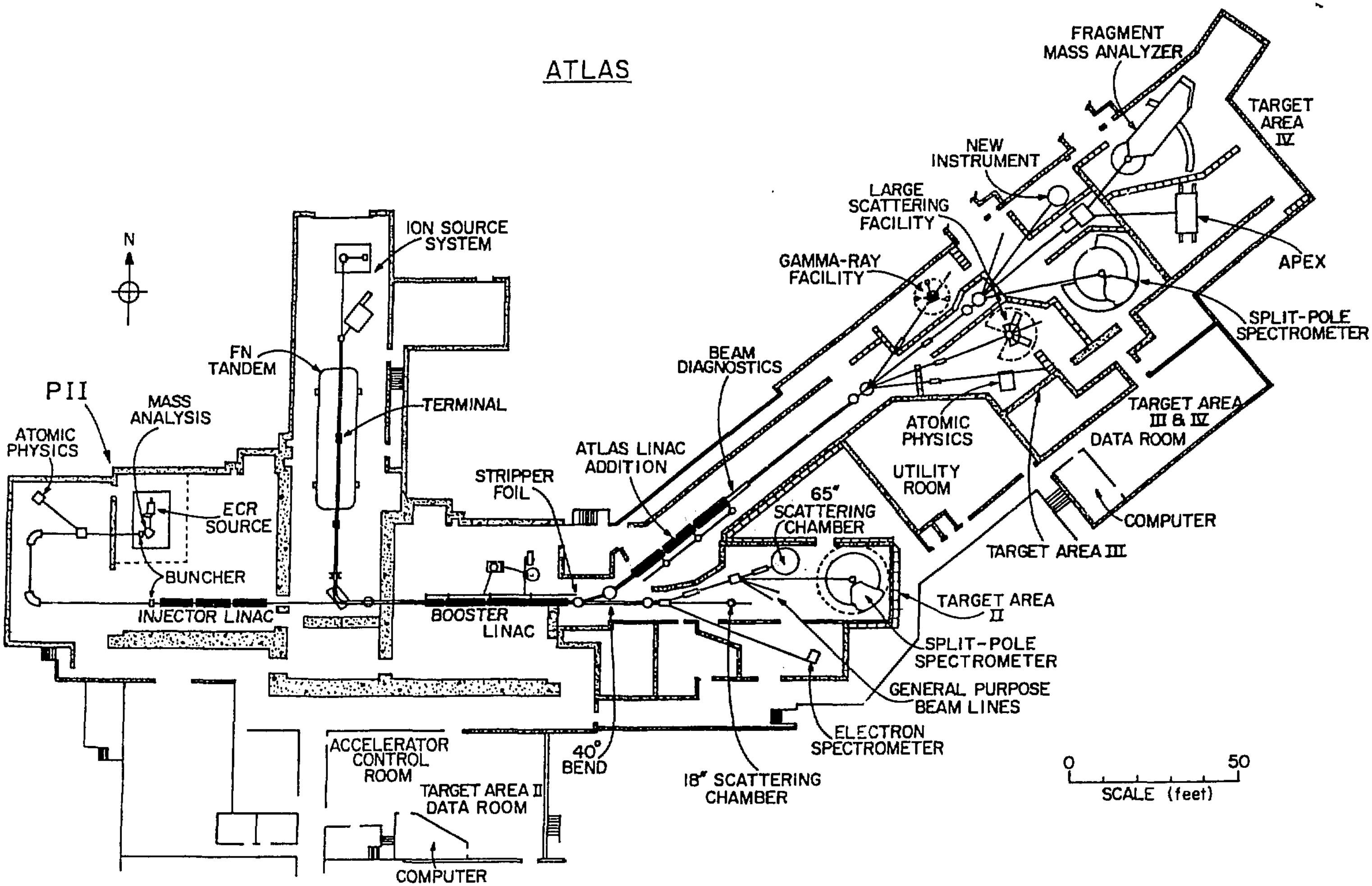

Fig. 1. Layout of ATLAS.

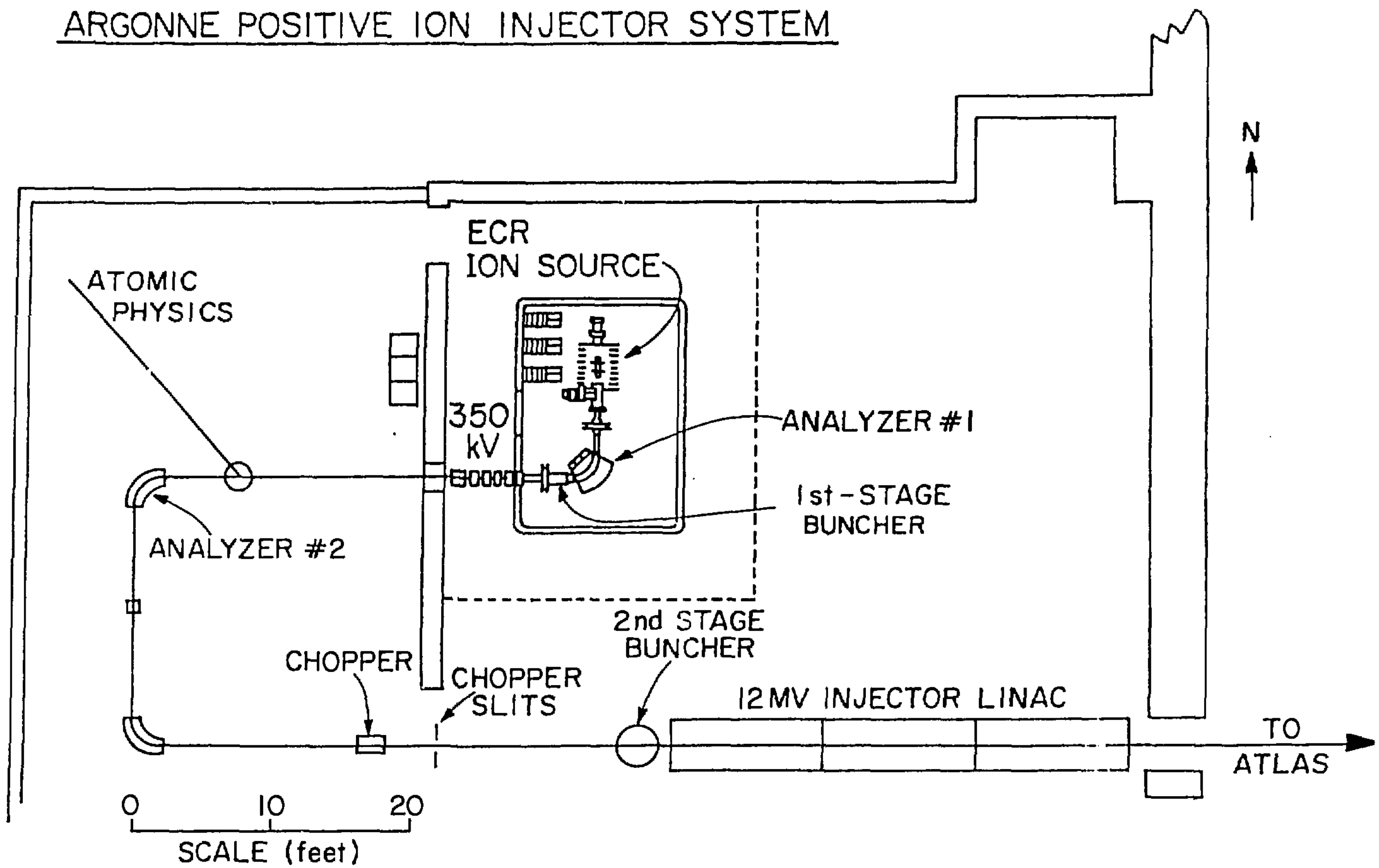

Fig. 2. Layout of the positive-ion injector of ATLAS. For the work described herein, only one of the three linac cryostats was installed.

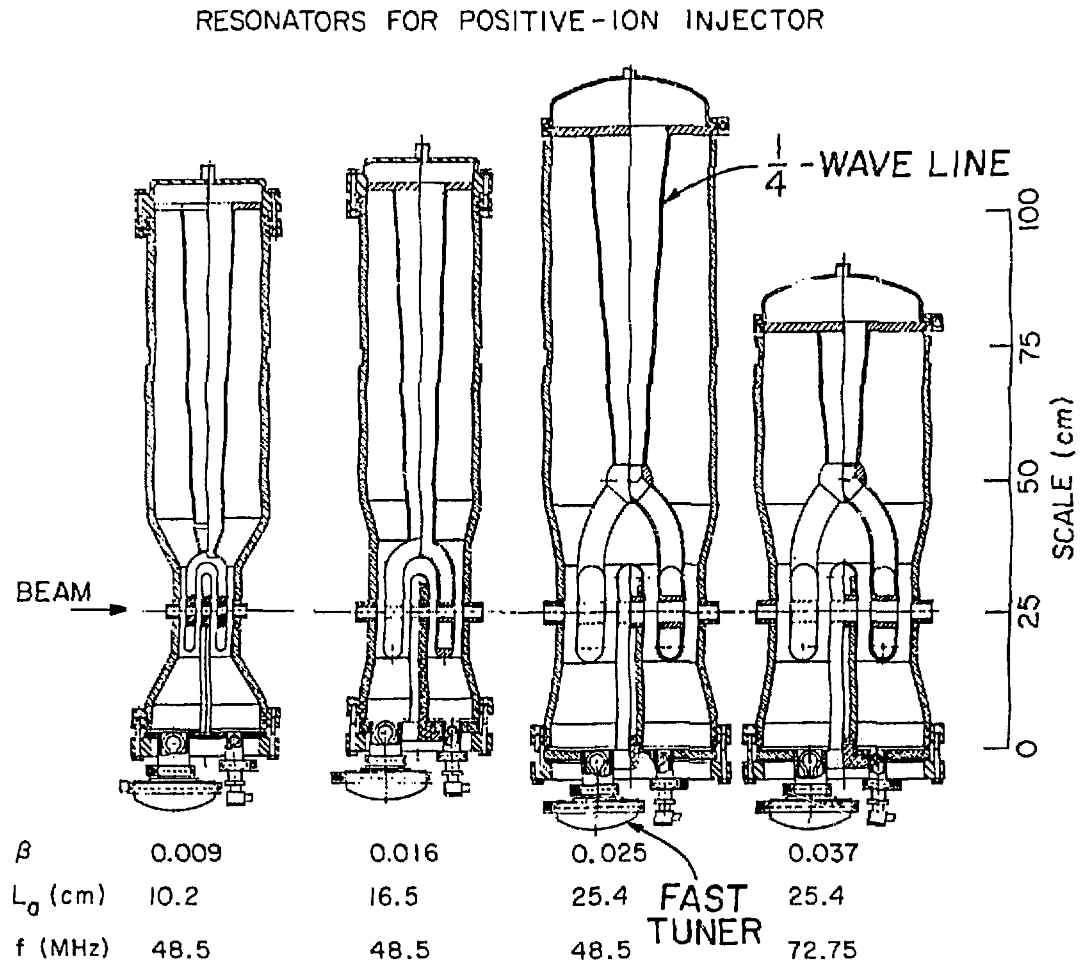

Fig. 3. Superconducting accelerating structures of the injector linac.

BUNCHING AT PII

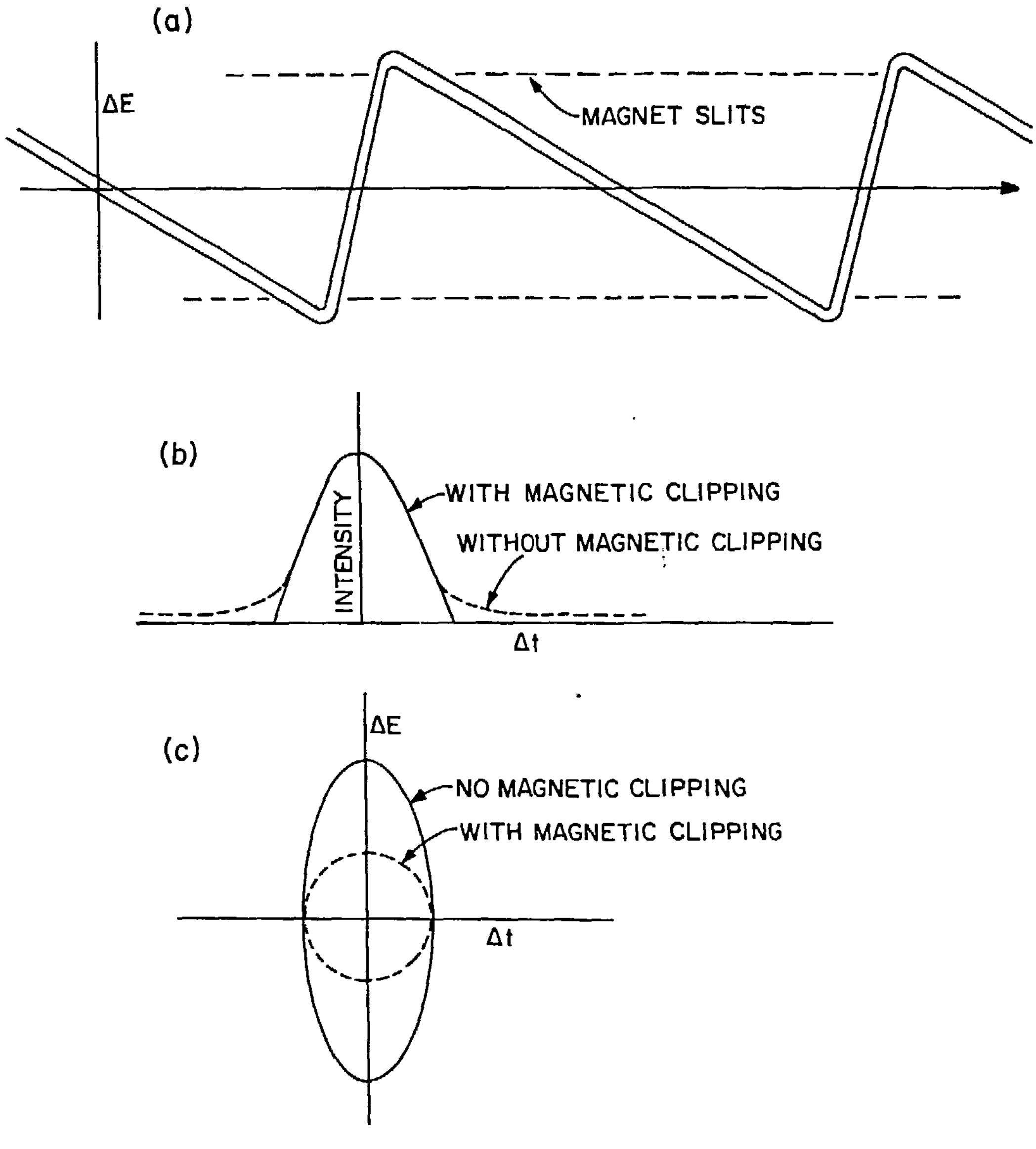

Fig. 4. (a) Bunching wave form at the 2nd-stage analyzing magnet. (b) Time distribution of the bunched beam pulse. (c) Longitudinal phase space at a time focus formed by the first buncher.

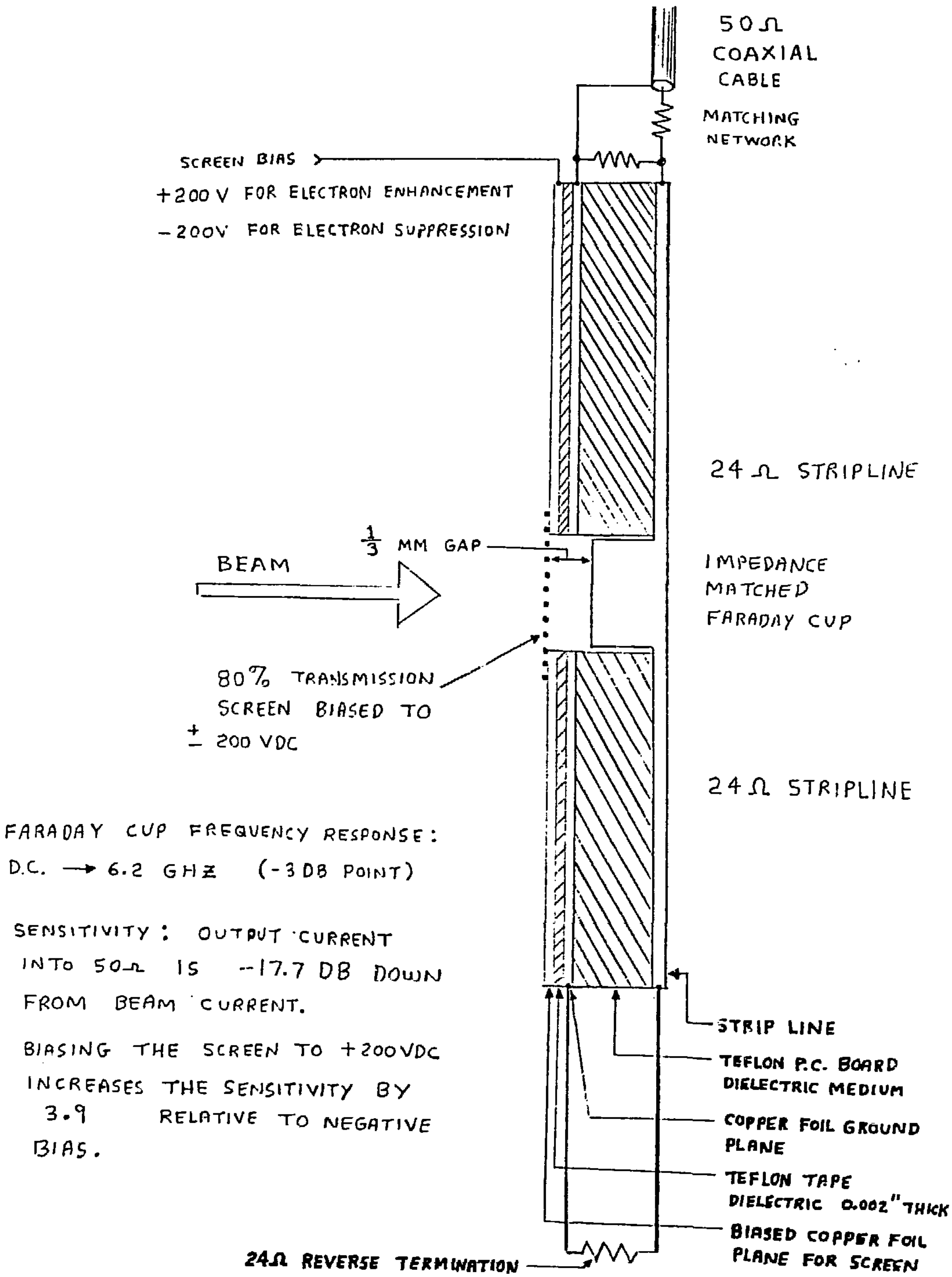

Fig. 5. Main features of the fast Faraday cup.