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THE ATLAS POSITIVE ION INJECTOR*

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ABSTRACT

This paper reviews the design, construction status, and beam tests to date of the positive ion injector (PII) which is replacing the tandem injector for the ATLAS heavy-ion facility. PII consists of an ECR ion source on a 350 KV platform injecting a very low velocity superconducting linac. The linac is composed of an independently-phased array of superconducting four-gap interdigital resonators which accelerate over a velocity range of .006 to .05c. In finished form, PII will be able to inject ions as heavy as uranium into the existing ATLAS linac. Although at the present time little more than 50% of the linac is operational, the independently-phased array is sufficiently flexible that ions in the lower half of the periodic table can be accelerated and injected into ATLAS. Results of recent operational experience will be discussed.

INTRODUCTION

Since the first operation of a superconducting heavy-ion linac in 1978 [1], the number and size of this class of accelerator has steadily increased [2]. Until the present project, all these machines have served as post-accelerators, increasing the energy of beams from tandem van de graaf accelerators. Several years ago, we undertook to replace the tandem portion of ATLAS with a new injector which would provide greatly increased beam current, and extend the mass range of ATLAS to uranium[3,4].

With the completion of the ATLAS linac in 1985, performance of the ATLAS facility has been limited in several respects by characteristics of the 9 MV tandem injector: the principal limitations are mass A < 127 and beam currents of at most a few particle nanoamperes. The positive ion injector (PII) project was motivated by the availability of electron-cyclotron resonant (ECR) ion sources which can provide highly- positively-charged ion beams with good transverse and longitudinal emittance. The technical challenge has been to incorporate an ECR source into a linac-based injector which preserves excellent beam quality while accelerating the ions up to $\beta = v/c \approx .05$, and matching the beam into ATLAS.

In what follows, the design and status of the several elements of PII are reviewed, then results of operational tests are discussed.

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PII DESIGN AND CONSTRUCTION

The basic elements of PII (shown in Fig. 1) are as follows:

1. An ECR source on an open-air, 350 KV high-voltage platform, designed to produce beams up to uranium at velocities above .008c.

2. A two-stage harmonic bunching system which produces bunches of typically a few hundred picoseconds time width.

3. A very-low-velocity superconducting linac, which accelerates over the range $.007 < \beta < .06$, and which produces negligable emittance growth.

Construction has proceeded in several phases. The ECR source and voltage platform, the beam transport and bunching system, and a small (3MV) portion of the linac were first tested with beam in early 1989. Early this year, the system was operated with 6 MV of linac installed. PII will be completed in early 1991 with the linac enlarged to 12 MV. This final injector is designed to accelerate uranium ions up to ≈ 1 MeV/A, enough for ATLAS to accept the beam and further accelerate to ≈ 8 Mev/A.

ECR Source and Voltage Platform

The ECR source is a typical 14 GHZ source (1), with unique features being operation on a 350 KV platform, and provision for radial access to the plasma region. This latter feature is to permit introducing solid source materials (in the form of wire, for example) into the plasma. To provide good beam bunching and longitudinal beam quality, the platform voltage must be stable to better than 1 part in 10^4. Construction of the ECR source and high-voltage platform was completed in 1987, and the system has been used since then both for beam tests and for atomic physics experiments.

The Injector Linac

The injector linac is formed from four types of independently-phased, four-gap accelerating structures (shown in Fig. 2.) The linac is based on the fact that short, high-gradient superconducting accelerating structures can be closely interspersed with short, powerfully focussing superconducting solenoids. The rapid alternation of radial and longitudinal focussing elements maintains the beam in much the same way as does a Wideroe-type rf structure with magnetic lenses in the drift-tubes, but with the simplicity and versatility of independently controlled, modular elements.

The construction sequence for PII has been based on this versatility. Fig. 3 shows the velocity acceptance charactaristics of the four resonator types of PII. The discrete points represent the single-resonator velocity increments for a

$^{238}U^{20+}$ beam, and the whole string of points show the passage of such a beam through the 18 resonant cavities that will form the final configuration of the PII linac. Beams of lower mass, however, enter the linac typically with much higher charge to mass ratios: the velocity increments are correspondingly larger and the linac requires fewer resonant cavities to bring such beams up to β=.05 for injection into ATLAS.

TESTS AND OPERATION

First beam through PII was obtained in February 1989, with a 3 MV configuration of the linac(5). Early this year, with the linac in a 6 MV configuration a series of beam tests were performed, including several weeks of operation delivering beams (Ar^{40}, Kr^{86}) for experiments.

Longitudinal emittance of several beams were measured, with the results shown in Table I. It should be noted that the observed beam quality by no means represents a limit for PII, as the machine is in several respects not in optimum configuration. It is already clear, however, that the beams are significantly better than similar tandem beams, and that this device sets a new standard of quality for heavy-ion beams.

TABLE I
Measured Longitudinal Emittance for Various Beams

Projectile	Post-injector Stripping	ϵ_z (KeV - nsec) Tandem	PII
$^{3}He^{2+}$	no		<1.0π
$^{16}O^{6+}$	no	15π	
$^{16}O^{8+}$	yes	20π	
$^{40}Ar^{12+}$	no		4π
$^{58}Ni^{10+}$	no	30π	
$^{58}Ni^{19+}$	yes	40π	
$^{86}Kr^{15+}$	no		19π

CONCLUSIONS

The results of beam tests to date indicate that all design goals for the PII system will be met. The results also demonstrate that the combination of an ECR ion source with a low-velocity superconducting linac provides an alternative to tandem electrostatic accelerators that is not only costeffective, but can also provide increased beam quality and increased beam current.

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REFERENCES

1. J. Aron, et al., in Proc. 1984 Linear Accelerator Conference, Seeheim, Germany, May 7-11,1984,GSI Report GSI-84-11, p132 (1984).

2. K. W. Shepard, Proceedings of the 1989 IEEE Particle Accelerator Conference, Chicago, Illinois, March 20-23, 1989

3. L. M. Bollinger and K. W. Shepard, Proceedings of the 1984 Linear Accelerator Conference, Seeheim, W. Germany, 7-11 May 1984, GSI Report GSI-84-11, p217 (1984).

4. R. C. Pardo, L. M. Bollinger, and K. W. Shepard, Nucl. Instrum. and Methods B24/25, p746 (1987).

5. L. M. Bollinger, P. K. Den Hartog, R. C. Pardo, K. W. Shepard, R. Benaroya, P.J. Billquist, B. E. Clifft, P. Markovich, F. H. Munson Jr., J. M. Nixon, G. P. Zinkann, Proceedings of the 1989 IEEE Particle Accelerator Conference, Chicago, Illinois, March 20-23, 1989.

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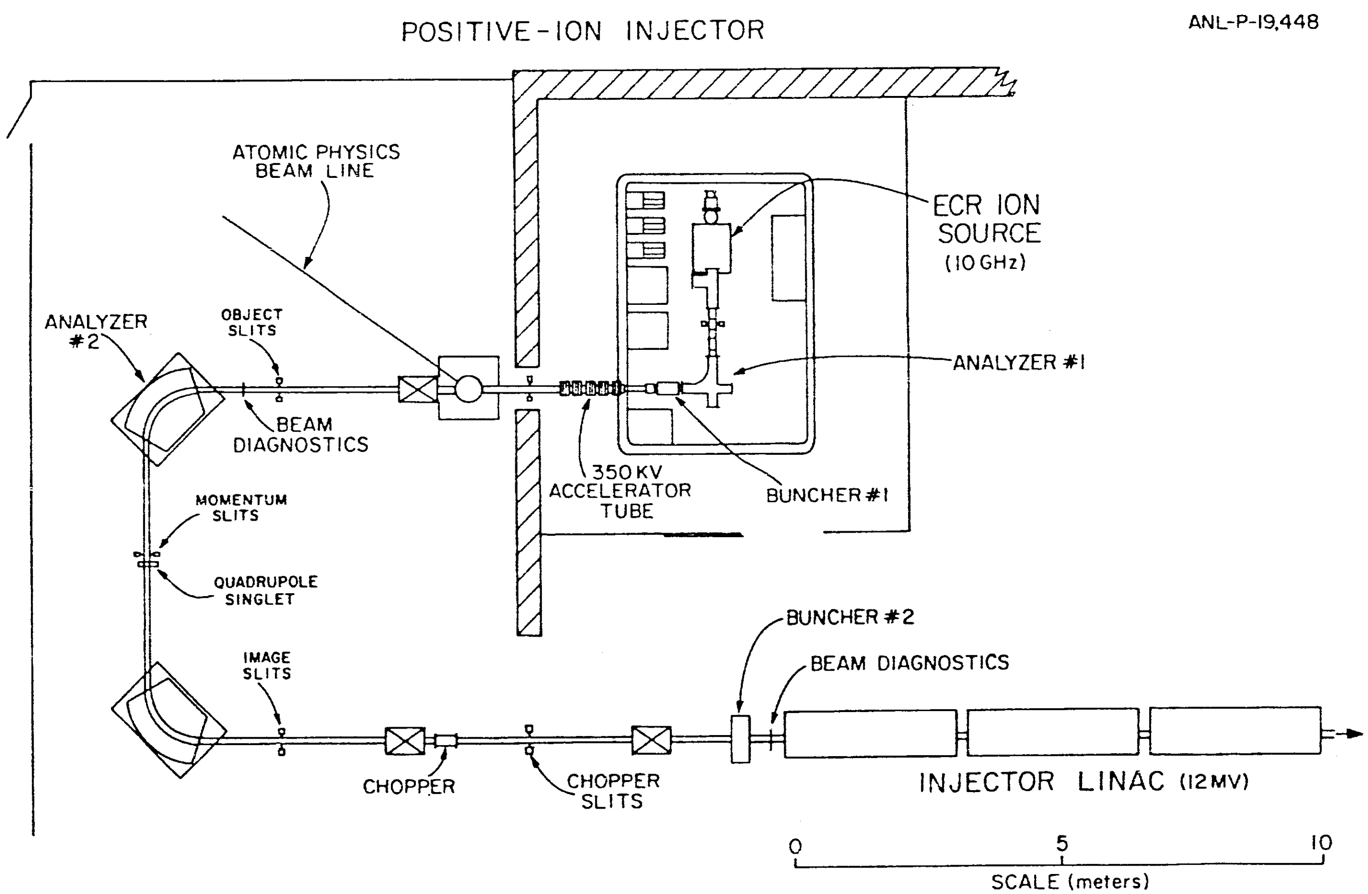
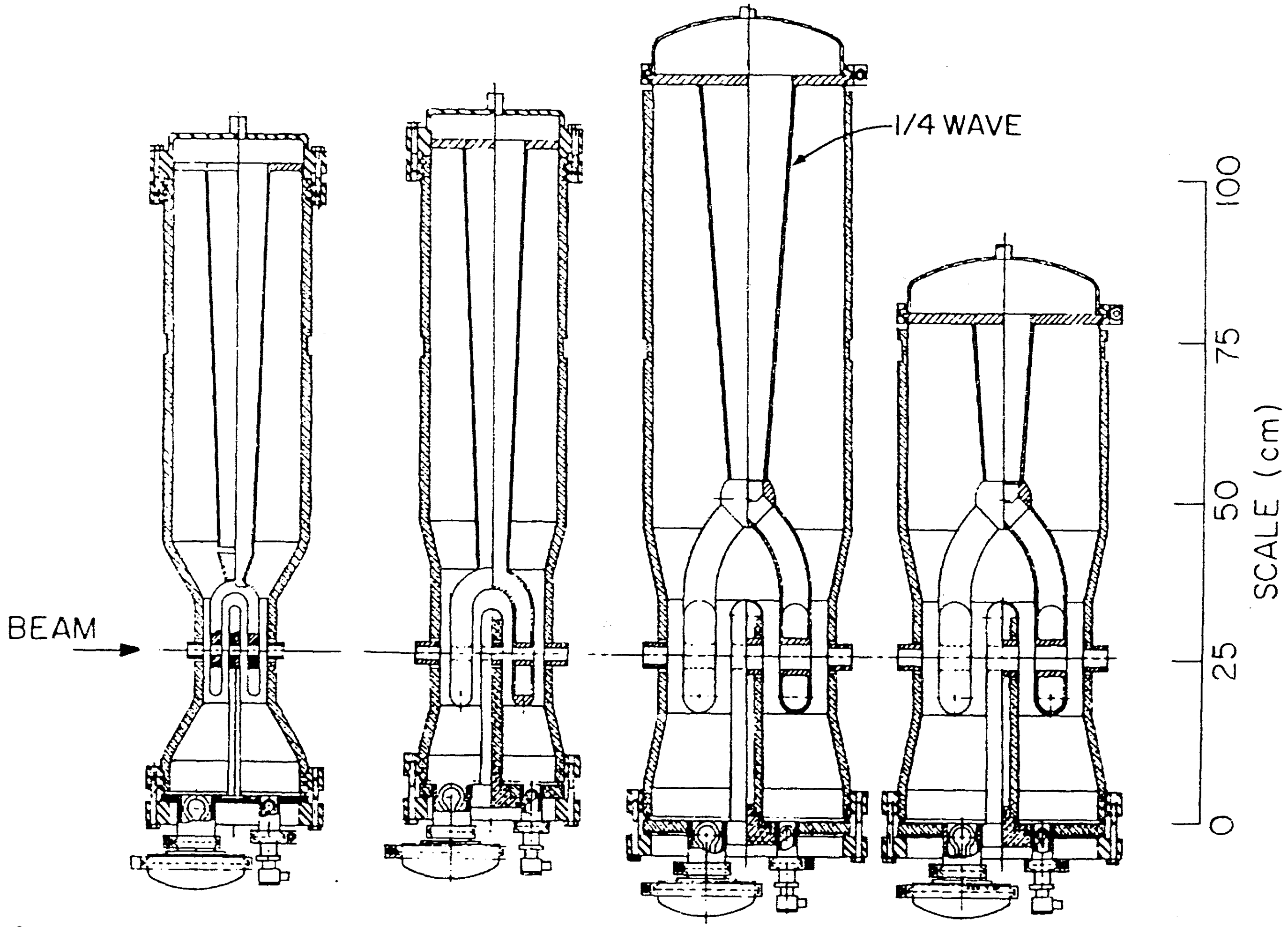
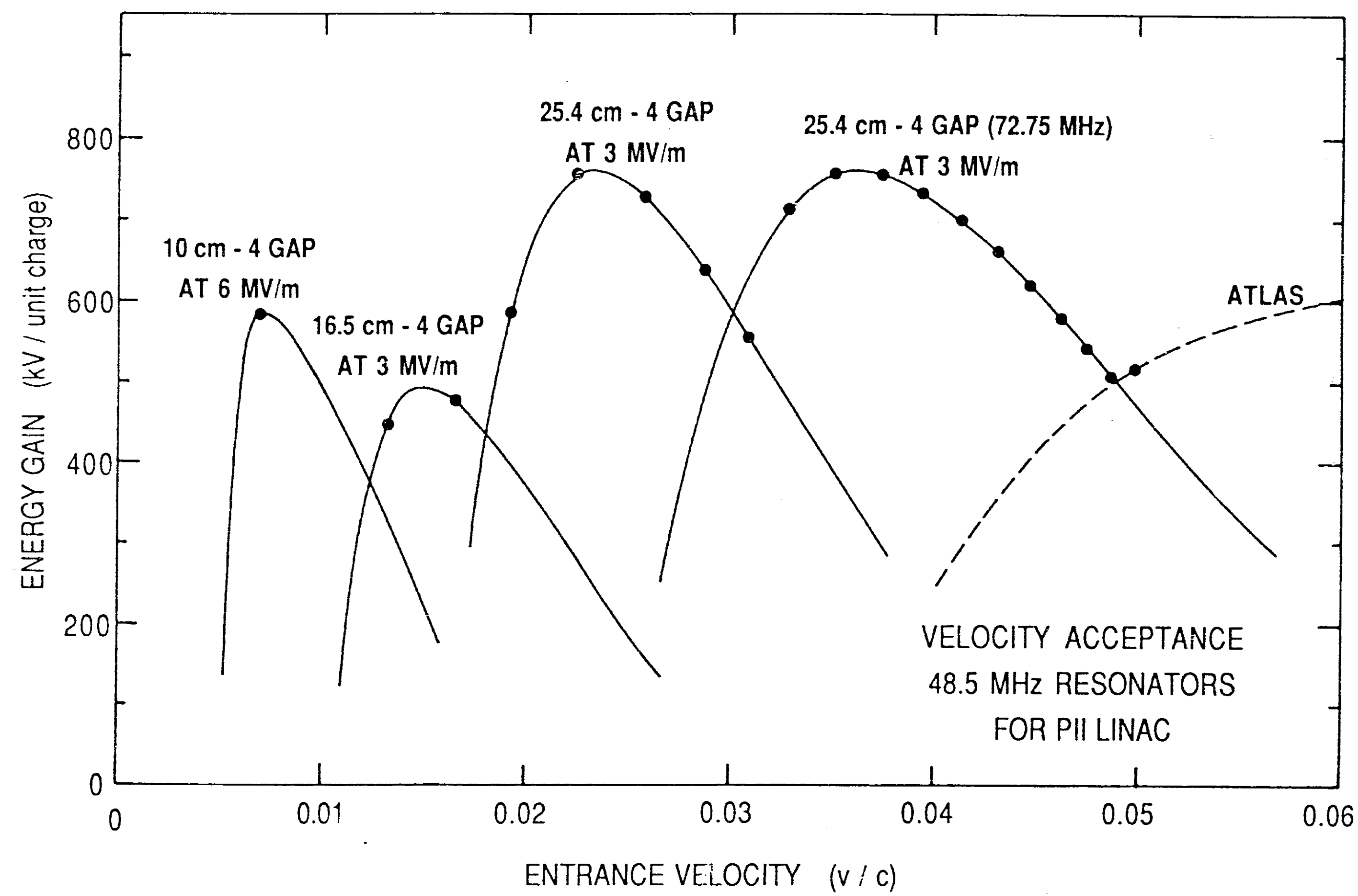

POSITIVE-ION INJECTOR
ATOMIC PHYSICS BEAM LINE
ECR ION SOURCE (10 GHz)
ANALYZER #1
ANALYZER #2
OBJECT SLITS
BEAM DIAGNOSTICS
350 KV ACCELERATOR TUBE
BUNCHER #1
MOMENTUM SLITS
QUADRUPOLE SINGLET
BUNCHER #2
BEAM DIAGNOSTICS
IMAGE SLITS
CHOPPER
CHOPPER SLITS
INJECTOR LINAC (12 MV)
0
5
10
SCALE (meters)

RESONATORS FOR POSITIVE-ION INJECTOR



β	0.009	0.016	0.025	0.037
L_a (cm)	10.2	16.5	25.4	25.4
f (MHz)	48.5	48.5	48.5	72.75



10 cm - 4 GAP
AT 6 MV/m
16.5 cm - 4 GAP
AT 3 MV/m
25.4 cm - 4 GAP
AT 3 MV/m
25.4 cm - 4 GAP (72.75 MHz)
AT 3 MV/m
ATLAS
VELOCITY ACCEPTANCE
48.5 MHz RESONATORS
FOR PII LINAC
ENERGY GAIN (kV / unit charge)
ENTRANCE VELOCITY (v / c)
0
200
400
600
800
0.01
0.02
0.03
0.04
0.05
0.06

END

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