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First Operation of ATLAS Using the PII Linac and a Comparison to Tandem Injection

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Abstract

The ATLAS Positive Ion Injector (PII) is designed to replace the tandem injector for the ATLAS heavy-ion facility. When the PII project is complete, ATLAS will be able to accelerate all ions through uranium to energies above the Coulomb barrier. PII consists of an ECR ion source on a 350 kV platform and a very low-velocity superconducting linac. The PII project is nearing completion. First beam from the complete system is expected in early 1992. Beam tests and experiments using a partially completed PII linac have demonstrated that the technical design goals are being met. The results of the early beam tests and first experiments will be discussed and compared to the performance of ATLAS with tandem injection.

Introduction

The ATLAS superconducting linac [1] is the largest heavy-ion post-accelerator. The range of ion species which may be accelerated by ATLAS is limited to mass $A < 127$ by characteristics of the 9-MV tandem injector and to beam currents of typically a few particle nanoamperes for the heavier ions. The Positive Ion Injector (PII) project [2,3] replaces the ATLAS tandem electrostatic injector with a new injector which will greatly increase the beam current for all ions and extend the mass range of ATLAS to include uranium.

The Positive Ion Injector project combines an ECR source and pre-linac bunching system with a superconducting linac to produce a new class of low-velocity accelerator. The elements of PII are shown in figure 1.

Construction has proceeded in several phases. First, the technology for a very low-velocity superconducting linac was developed [4,5,6]. At the same time an ECR source was designed and built on a high-voltage platform [7,8]. The source, beam transport and bunching system, and a small (3.5 MV) portion of the linac were completed and beam tested in early 1989 [9]. In the first half of 1990, the system was operated with 7 MV of linac installed. PII will be completed in late 1991 when the linac is enlarged to 12 MV. This final injector will accelerate uranium ions up to more than 1 MeV/A, enough for ATLAS to accept the beam and further accelerate it to ≈ 8 MeV/A.

Design studies indicated that such a low-velocity injector would provide sufficient velocity to match the remainder of the ATLAS linac for ions of all masses. The performance of the complete PII injector linac as a function of mass is shown in Figure 2. The different curves result from differing assumptions on charge states from the ECR ion source and, therefore, different beam currents.

These calculations also predict a high quality beam for all ion species, especially for longitudinal optics. Both longitudinal and transverse beam emittance is expected to be similar to that of the lighter ions from the present ATLAS tandem injector. This results from restricted use of stripping to achieve the desired ion charge state.

The highly adaptable nature of the linac has permitted a series of beam tests as construction of the low-velocity linac has proceeded. This has included several periods of actual operation of ATLAS injected with the PII system. early beam tests, with only a portion of the linac complete, have confirmed these calculations.

Beam Tests and Operation

The development of the Positive Ion Injector has extended the ATLAS technology into a new regime of operation which has not been previously attempted. First, the need for efficient highly precise beam bunching developed for the original ATLAS accelerator at velocities of $\beta \approx 0.06$ now must be extended to velocities of approximately $\beta \approx 0.01$. Second, the use of independently phased resonators at such low velocities has never been attempted before. Deciding to adopt this approach had the benefits of the widest possible species acceptance (q/m range), the most efficient use of the available accelerating voltage, and the lowest emittance beams possible. The early results described in this paper give us renewed confidence that the final system will achieve all our design goals.

The two-stage bunching system is similar to that used for tandem injection of ATLAS except that the first stage is located on the high-voltage platform (fig. 1). The first stage is a gridded-gap four-harmonic buncher with a fundamental frequency of 12.125 MHz. The amplitude of the first stage is adjusted to form a time waist about 35 m downstream, near the second stage buncher. The second buncher is a two-gap normal-conducting spiral-loaded resonator operating at 24.25 Mhz, which forms a time waist ≈ 1.5 m downstream, near the first resonator in PII. After bunching 60-70% of the DC beam, the remaining unbunched portion of the beam is removed by a sine-wave vertical-deflecting chopper.

Development of new detection techniques[10] was necessary in order to study bunching of these low velocity ions. To date, the best bunching result is a measured FWHM of 1.2-nsec for a 2.0-MeV $^{40}Ar^{12+}$ beam with the first stage buncher. The second stage buncher then formed a 130-psec bunch at a detector 55 cm downstream. This time spread is remarkably small for such a low velocity beam ($\beta = 0.01$).

Model calculations of this portion of the bunching process predict that an additional 30% improvement may be possible. The limitations at that level are fairly equally distributed between the harmonic components of the first stage buncher, the stability of the high voltage platform power supply, and the isochronism of the beam transport system.

First beam through PII was obtained in February 1989, with a 3.5 MV configuration of the linac. A 1μA beam of $^{40}Ar^{12+}$ was accelerated to as much as 36 MeV. In the course of these tests the beam was injected into ATLAS, accelerated to 173 MeV, and used for a brief (6 hr) experiment. Another series of tests were performed in 1990, with a 10-resonator, 7 MV configuration of the PII linac. The total running time of ATLAS using tne positive ion injector is now in excess of four weeks.

A variety of beams have been accelerated with PII, including $^{3}He^{2+}$, $^{13}C^{4+}$, $^{16}O^{6+}$, $^{40}Ar^{11+,12+}$, $^{41}K^{9+}$, $^{83}Kr^{17+}$, $^{86}Kr^{15+}$, and $^{92}Mo^{16+}$. In addition to beam tests of PII, the system has delivered beam to the ATLAS linac for tests and for several experiments totaling more than four weeks.

Operation of the PII system has been characterized by excellent reliability and stability. Even in these early tests, all elements of the system typically ran for extended periods, several days, with little or no operator intervention. Of course, many problems with details of the system arose in these early tests. The most serious of these problems were the transmission through the PII linac (which did not exceed 75% and was more typically 40-50%) and the poor performance of the chopper. We believe the transmission problem is due to the imperfect injection beamline optics required during these tests. Further studies concerning the chopper performance indicate that it is highly sensitive to the beam bunch-width at the chopper. These calculations indicate that a simple change in the details of the bunching configuration may improve the chopper performance.

A primary goal for the new injector has been to achieve beam quality competitive with that of the tandem, especially in longitudinal phase space. Measured longitudinal emittance, ϵ_z, of several beams is shown in Table I. These tests demonstrate that the beams from PII have substantially smaller longitudinal emittance than similar tandem beams, and that PII sets a new standard of quality for heavy-ion beams.

Conclusion

The results of beam tests to date indicate that all design goals for the PII system will be met. Tests of the partially completed system already 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 cost-effective, but can also provide improved beam quality and increased beam current.

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TABLE I
Measured Longitudinal Emittance at ATLAS

Ion	Injector Energy (MeV)	Stripping Post-Injector	ϵ_z(keV-nsec) Tandem	PII
$^{3}He^{2+}$	3.5	no		$<1\pi$
$^{16}O^{6+}$	1.1	no		15π
$^{16}O^{8+}$	59.5	yes	20π	
$^{40}Ar^{12+}$	37.0	no		5π
$^{58}Ni^{10+}$	93.5	no	30π	
$^{58}Ni^{19+}$	93.5	yes	40π	
$^{86}Kr^{15+}$	88.0	no		19π

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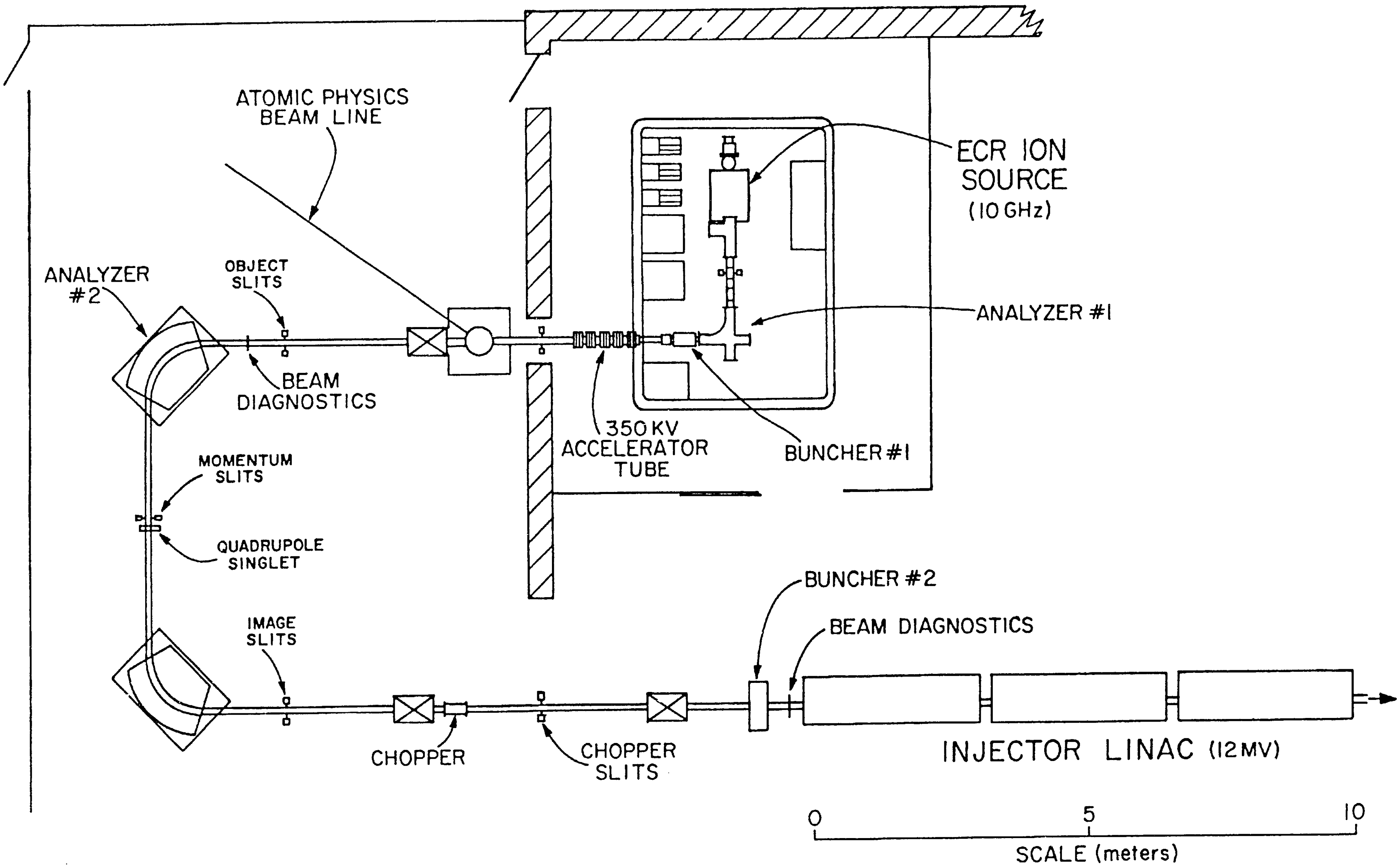
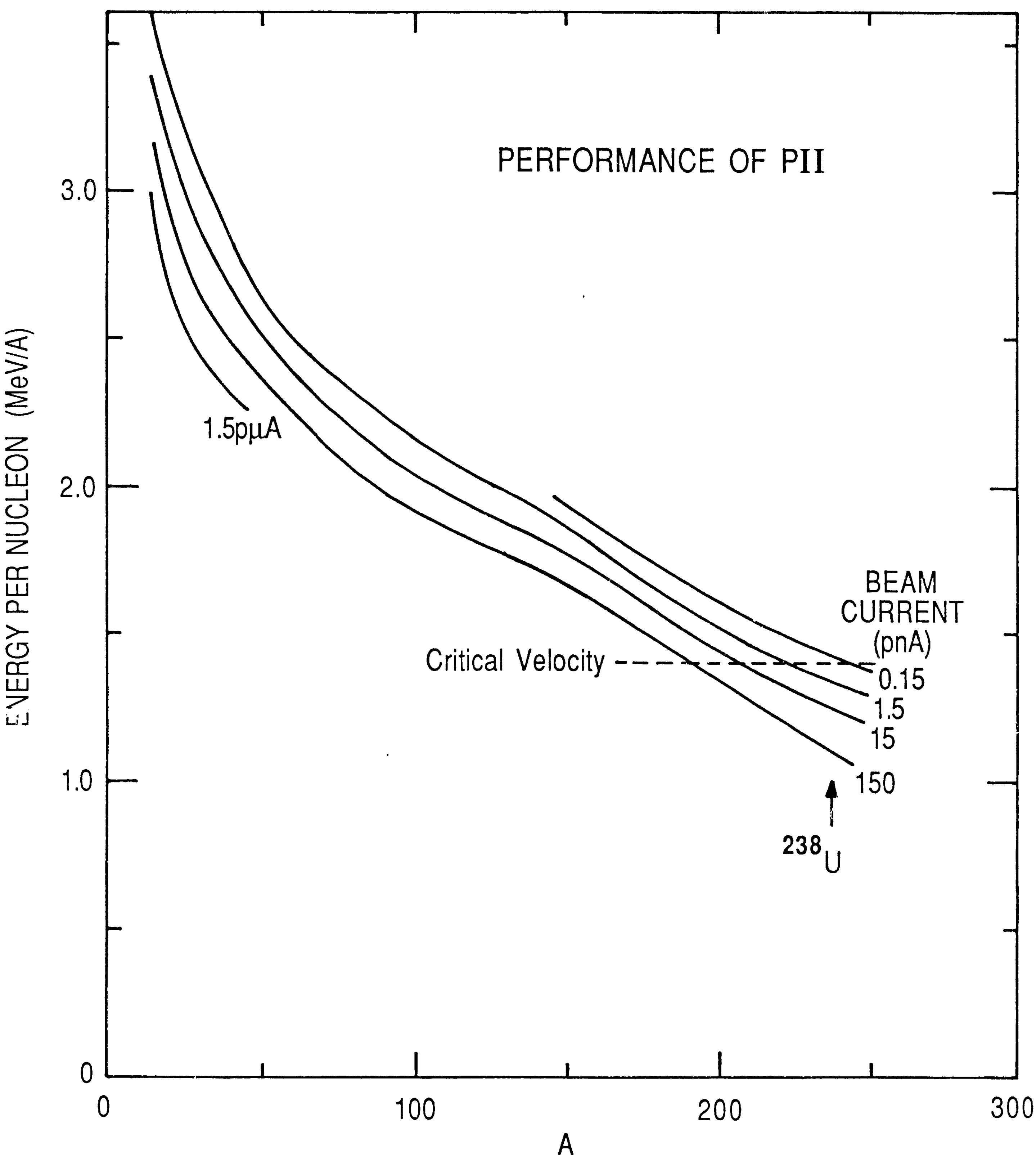
POSITIVE-ION INJECTOR





PERFORMANCE OF PII
ENERGY PER NUCLEON (MeV/A)
A
0
1.0
2.0
3.0
0
100
200
300
1.5pμA
Critical Velocity
BEAM
CURRENT
(pnA)
0.15
1.5
15
150
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