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Status Report on the Positive Ion Injector (PII) for ATLAS

at Argonne National Laboratory

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Abstract

The Positive Ion Injector (PII) is part of the Uranium upgrade for ATLAS accelerator at Argonne National Laboratory. This paper will include a technical discussion of the Positive Ion Injector (PII) accelerator with its superconducting, niobium, very low-velocity accelerating structures. It will also discuss the current construction schedule of PII, and review an upgrade of the fast-tuning system.

I. Introduction

The ATLAS facility at Argonne consists of a 9-MV tandem electrostatic accelerator with a superconducting post accelerator composed of 47 niobium split-ring resonant cavities. Performance of the ATLAS facility has been limited by the characteristics of the 9-MV tandem injector to mass $A < 127$ and to beam currents of typically a few particle nanoamperes for the heavier ions.

Several years ago, the PII project was initiated with the goal of replacing the tandem portion of ATLAS. The PII injector will provide greatly increased beam currents, and extend the mass range of ATLAS to uranium.[1,2]

PII consists of an ECR ion source on a 350-kV platform injecting into a very low-velocity superconducting linac. The linac is composed of an independently-phased array of superconducting four-gap interdigital resonators which will accelerate ions over a velocity range of .007 to .06 c. The technical goal of PII is to combine the good transverse and longitudinal emittance, highly-positively-charged ion beams of the ECR source with the superconducting linac injector. This union will maintain and exceed tandem-like beam quality, while matching the beam velocity into ATLAS.

II. Elements of PII

The elements and layout of PII are shown in Fig. 1. The primary features are:

1) An ECR source on an open air 350-kV platform, designed to produce beams in mass up to uranium at velocities of .008 c.

2) A two-stage harmonic bunching system which produces bunches of less than 300 psec time width at the linac entrance.

3) A very low-velocity superconducting linac, which accelerates ions over the range of .007 < B < .06, and which produces limited emittance growth.

III. Beam Bunching

The two-stage bunching system in PII is similar to that used in ATLAS. The first stage is a gridded gap structure using fourth harmonic approximation to a saw-tooth voltage at a fundamental frequency of 12.125 MHz. The amplitude of the first stage forms a time-waist focus about 35 m downstream, at the second-stage buncher. The second stage is a two-gap, normally-conducting spiral-loaded resonator, which forms a time waist at the entrance to the linac.

With the significantly increased beam currents and the large mass range available from the ECR source, a suitable RF timing diagnostic device was needed. A stripline Faraday cup of exceptional bandwidth (DC to 6.1 gigahertz)[3] has been developed (Fig. 2). An electrostatic shield in the ground-plane geometry prevents electric-field coupling of incoming ions so that the time distribution of low-velocity (b > .01 c) particles can be measured. Beam bunch widths of 400 psec. have been measured using 3.9 MeV $^{84}Kr^{15+}$ beam (200 namps average). Bunch widths down to 100 psec should be observable with a sampling oscilloscope. Beam-bunch shapes have been monitored at beam current levels of 1.0 nanoampere to 10 microampere average.

A low-velocity version of this Faraday cup, along with a four-segmented aperture, and a two-wire beam-shape monitor have been mounted directly on the output of the first resonator of PII. These devices operate at 4.5 K and are able to be moved in or out of the beam path from outside the cryostat vessel. With the stripline Faraday cup directly on the output of the first accelerating structure, this enables us to measure the beam-bunch width as close as possible to the desired time focus.

IV. The Injector Linac

The injector linac is formed from four types of independently-phased, four-gap accelerating structures as shown in Fig. 3. The linac is based on the fact that short, high-gradient superconducting accelerating structures can be closely interspersed with short, powerfully focusing superconducting solenoids. The rapid alternation of radial and longitudinal focusing elements maintains the beam quality through the machine. The velocity acceptance characteristics of the four resonator types of PII are shown in Fig. 4. The discrete points represent the single-resonator velocity increments for a $^{238}U^{+24}$ beam. The whole string of points shows the passage of such a beam through the 18 resonant cavities that will be the final configuration of the PII linac.

V. Construction Schedule

The construction of PII has proceeded in several steps. In 1987, the technology for a very low-velocity superconducting linac was beginning to be 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 the first cryostat (3.5 MV) of the linac were completed and tested with beam early in 1989.[9] Construction of the second cryostat proceeded through the summer, and in early spring of 1990, the system operated with two cryostats (7 MV) on line. Accelerating fields in the off-line tests averaged above 4 MV/m, but in these early tests the average on-line field level was 3 MV/m, which is the original design goal. This lower average was being limited by the fast-tuner cryogenic electronics.[10] In September 1991, an upgrade of the electronics at the cryogenic end of the fast-tuning system demonstrated that the power handling capabilities of the fast-tuner circuit is no longer a limitation. This upgrade is presently being installed in 12 of the 18 PII cavities and will be used in the on-line tests scheduled for December 1991.

Our present schedule is to have the complete 12-MV injector, as shown in Fig. 1, installed and ready for initial beam tests by late December 1991. Construction of all 18 cavities has been completed. Fifteen of the cavities have been tested and are ready for operation, while 3 cavities are being prepared to be tested and will be ready for operation soon.

VI. Beam Tests and Operation

Because of the versatility of independently controlled, modular elements used in the PII accelerator construction, a linac ca' be configured to provide a useful capability with as few as five resonant cavities. The cryostat design permits the spacing and sequence of focusing and accelerating structures to be easily changed. This capability has permitted a series of beam tests to be performed as the construction of the low-velocity linac has proceeded.

First beam through the PII/ATLAS system was obtained in February 1989, with a 3.5-MV configuration of the PII linac. A one-microamp beam of $^{40}Ar^{12+}$ was accelerated to as much as 36 MeV. During these tests the beam was injected into ATLAS, accelerated to 173 MeV, and used for a brief (6 hr.) beam-quality test. In the spring of 1990, with a 10-resonator, 7-MV configuration of the PII linac, another series of PII/ATLAS tests were performed. A variety of beams were accelerated including, $^{3}He^{1+}$, $^{13}C^{4+}$, $^{16}O^{6+}$, $^{40}Ar^{12+,13+}$, $^{86}Kr^{15+}$, and $^{92}Mo^{16+}$. The PII system was used as an injector into ATLAS and delivered beam for test measurements for a period of more than four weeks. In addition to these tests there was time for PII systems shakedown and development.

VII. Conclusions

Operation of the PII systems have been characterized by excellent reliability and stability. Even in these early tests the system ran for extended periods, several weeks, with little or no operator intervention. Tests of the partially completed system have demonstrated 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 increased beam quality and increased beam current.

Our construction schedule for the completion of the PII linac, in its 12-MV configuration, is proceeding smoothly and should be ready for initial tests in December 1991.

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References

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Figure Captions

Fig. 1 Layout and major elements of the Positive Ion Injector (PII).

Fig. 2 Low beta fast Faraday cup system in PII α cryostat.

Fig. 3 Four resonant geometries used for the injector linac.

Fig. 4 Velocity acceptance profile for the resonators forming the low-velocity linac. The discrete points show the single-resonator velocity increments for a $^{238}U^{24+}$ beam.

POSITIVE - ION INJECTOR

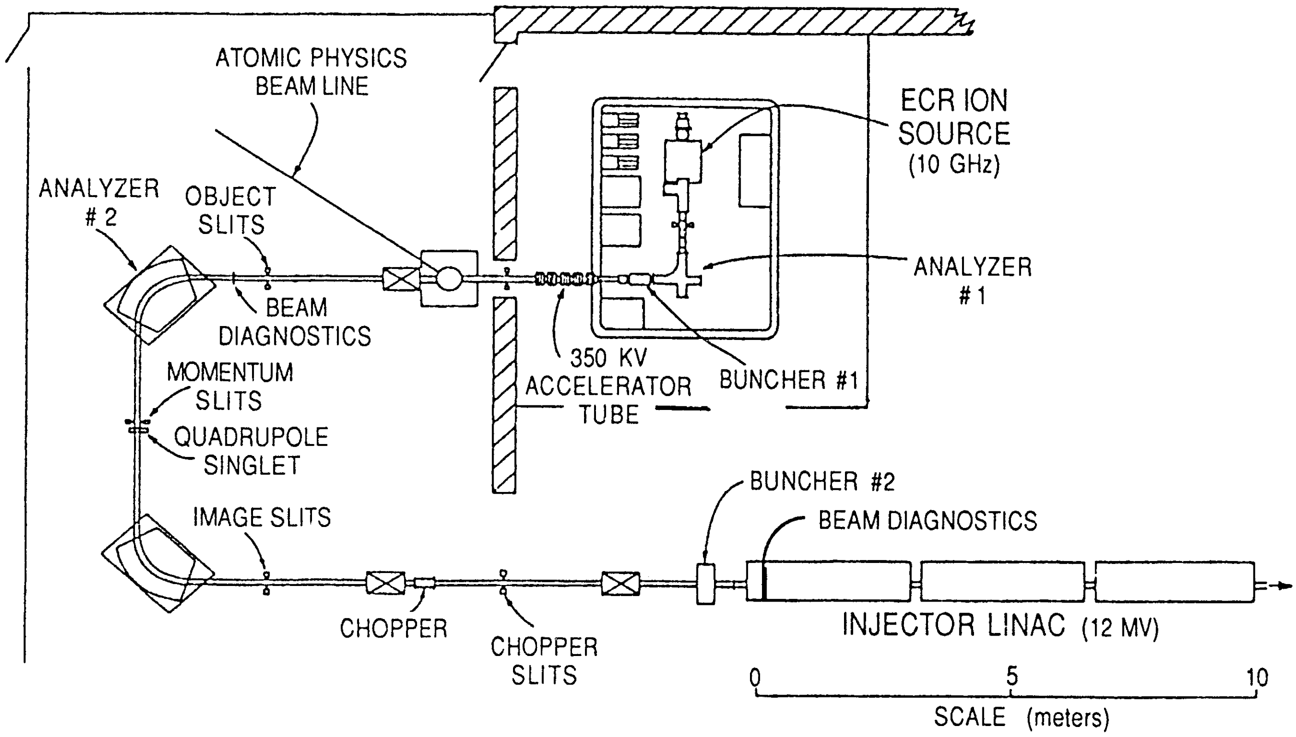
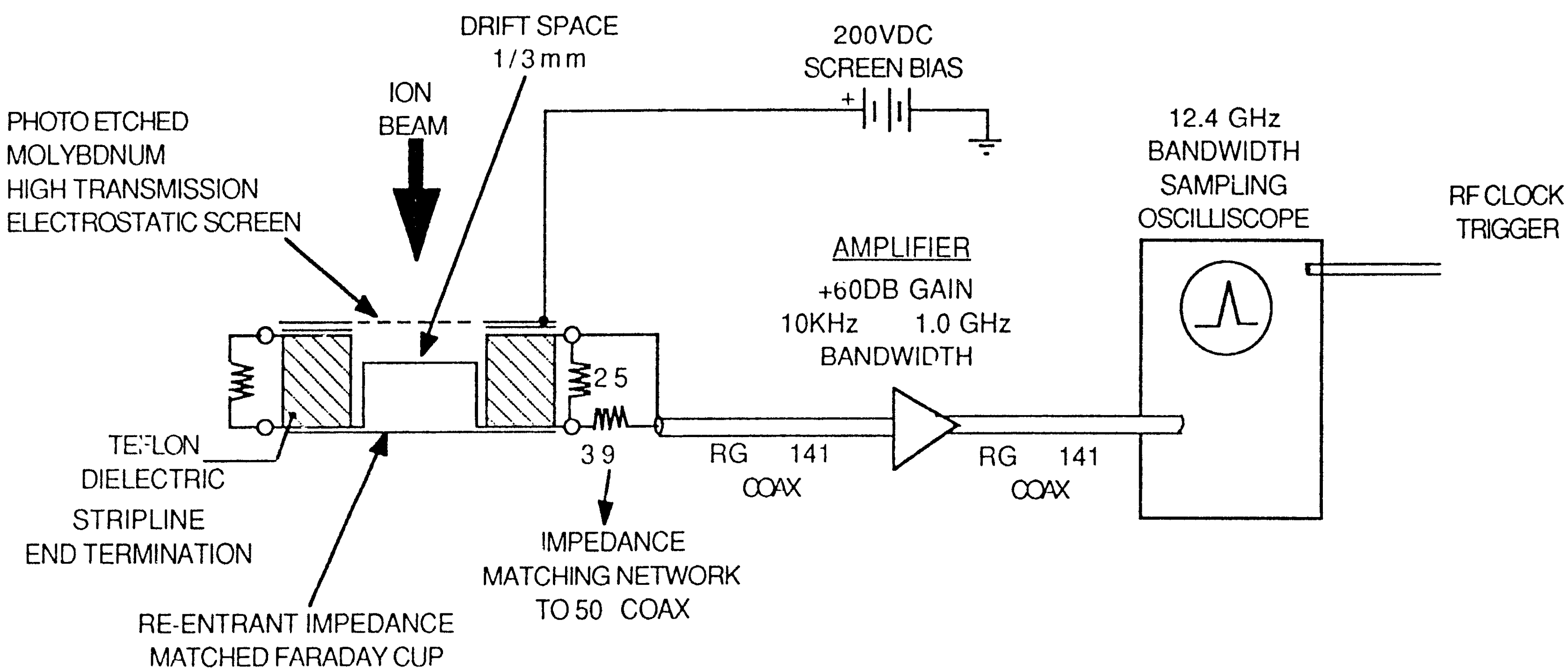


Fig. 1

LOW BETA FAST FARADAY CUP SYSTEM IN PII α CRYOSTAT



FARADAY CUP SPECIFICATIONS :

- DC 9.1 GHz BANDWIDTH
- 38.5 picosecond RESPONSE TIME
- ELECTROSTATIC SHIELD TO FARADAY CUP DRIFT SPACE (1/3mm)
- E-FIELD PRE-PULSE BROADENING FOR IONS OF = 0.01 IS LIMITED TO 100 picoseconds
- BEAM CURRENT OUTPUT EFFICIENCY IS 0.10 (10%)

Fig. 2

RESONATORS FOR POSITIVE-ION INJECTOR

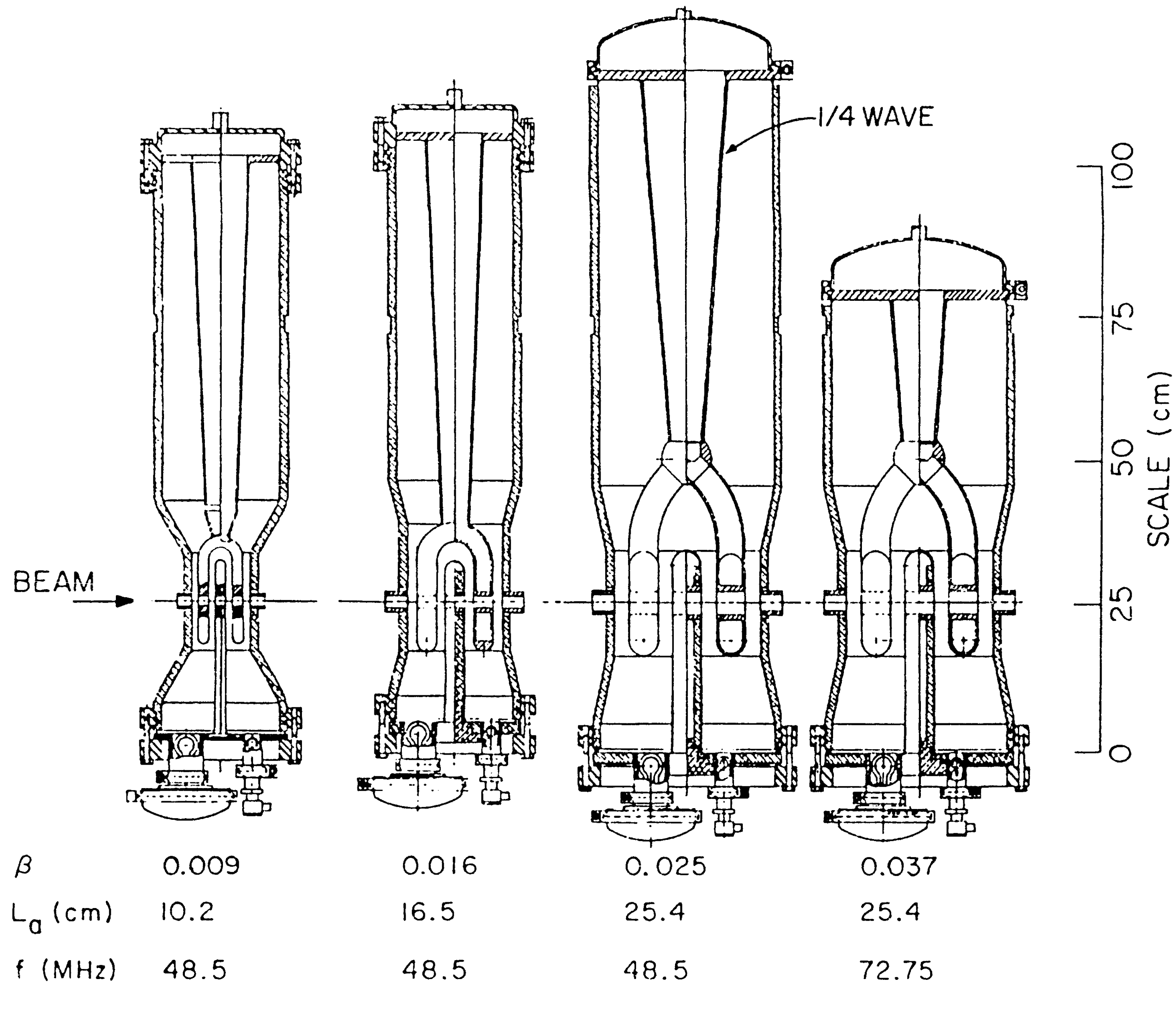


Fig. 3

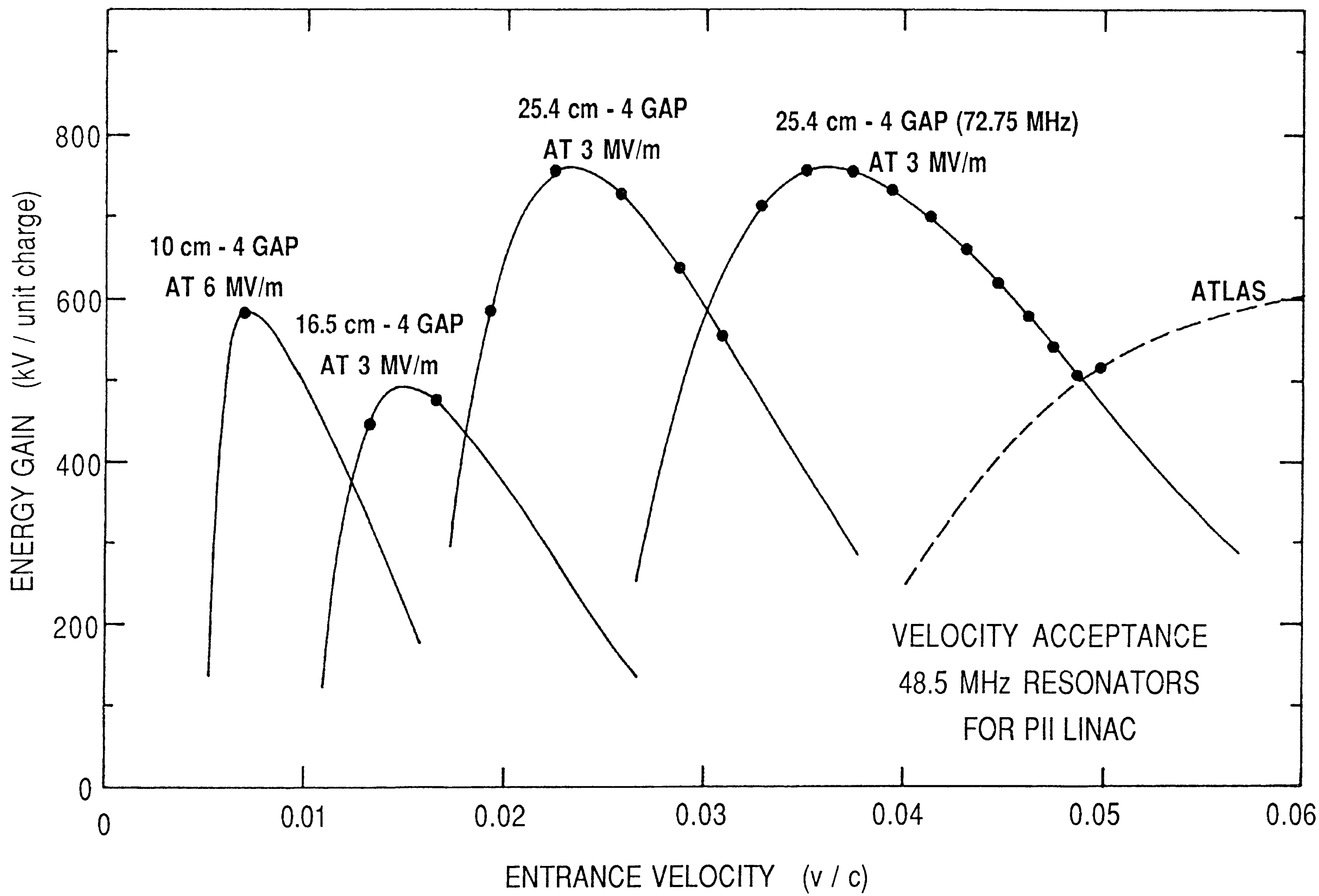

10 cm - 4 GAP
AT 6 MV/m
16.5 cm - 4 GAP
AT 3 MV/m
25.4 cm - 4 GAP
AT 3 MV/m
25.4 cm - 4 GAP (72.75 MHz)
AT 3 MV/m
ATLAS
VELOCITY ACCEPTANCE
48.5 MHz RESONATORS
FOR PII LINAC
ENERGY GAIN (kV / unit charge)
ENTRANCE VELOCITY (v / c)
0
200
400
600
800
0.01
0.02
0.03
0.04
0.05
0.06

Fig. 4

END

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