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THE SUPERHILAC UPGRADE PROJECT*

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Abstract

This project will increase the uranium output of the Bevalac heavy-ion facility from the currently available 10^7 to $5x10^7$ ions/pulse, allowing accurate Lamb shift measurements to be made in U^{90+} and U^{91+} with important applications to the testing of quantum electrodynamics and the development of an x-ray laser. The injected beam intensity will be increased to make better use of the 10emA output space-charge limit of the Wideroe linac. Components will include a new high current MEtal Vapor Vacuum Arc (MEVVA) ion source[1] along with an improved high current, high voltage Cockcroft-Walton power supply to handle the increased beam current. The Low Energy Beam Transport (LEBT) line will be upgraded with additional focusing to manage the increased space-charge forces and with an improved vacuum to reduce charge exchange losses. Finally, the phase matching between the 23MHz Wideroe linac and the 70MHz Alvarez linac will be improved by the addition of the appropriate buncher cavities. Physics design is underway and detailed engineering is scheduled to begin in October 1985, with installation slated for the 1986 summer shutdown.

Introduction

The SuperHILAC serves as an injector for the Bevatron, injecting ions as heavy as uranium at energies up to 8.5 MeV/nucleon. The Bevatron then further accelerates the ions to 2.1 GeV/nucleon for the lighter ions or 1 GeV/nucleon for uranium. This combination of accelerators, called the BEVALAC, is the only facility in the world capable of accelerating the heaviest nuclei to relativistic energies. Continuing upgrades at the SuperHILAC and the Bevatron have allowed the BEVALAC to remain at the forefront of nuclear and atomic physics research, including the production of fully stripped uranium ions in 1982. More recently, fixed-target experiments with intense niobium beams have produced a state of compressed nuclear matter thought to have existed only in the first few microseconds following the Big Bang.

The BEVALAC now produces beams of low-Z ions such as neon at intensities up to 1×10^{10} ions/pulse, and 960 MeV/nucleon uranium beams have been delivered to experimenters at up to 1×10^6 ions/pulse. In addition a new operational mode has been demonstrated in which uranium of somewhat lower energy can be produced at intensities of 1×10^7 ions/pulse. Results show that different conditions can be selected by passing uranium beams through thin targets to produce high yields of either fully stripped uranium (85%), U^{91+}(50%), or U^{90+}(40%).[2]

Increasing the beam intensity by a factor of 5 will open to exploration wide fields of atomic physics research. One notable example would be the measurement of the Lamb shift in H-like and He-like uranium. Such measurements would be of considerable interest to quantum field theorists because one cannot use perturbation theory to accurately calculate the Lamb shift of such high-Z ions. In the case of H-like ions, methods exist for summing perturbation series, but these methods have not yet been checked at high Z. For He-like ions, no theory even exists for calculating radiative corrections. Thus, measuring the Lamb shift of He-like uranium would almost certainly stimulate theoretical activity in nonperturbative quantum field theory.

The recent development of the MEVVA ion source provides the basis for the SuperHILAC upgrade. Transporting this increased beam intensity to the Wideroe linac of the Abel injector will enable better use of the 10emA output capacity of the Wideroe. In addition, improving the longitudinal phase matching between the Wideroe and the Alvarez linacs will further increase the beam intensity. Details of the modifications necessary to transport the high current beam and to match the longitudinal structure are presented below.

Project Overview

Figure 1 shows the SuperHILAC accelerator. This upgrade will focus on the Abel injector, with most of the changes taking place upstream of the Wideroe linac. Since the object of the upgrade is to increase the beam intensity, the chief concerns of the project are the production and transport of low energy, high current, heavy ion beams. The beam is produced by the MEVVA ion source that is capable of delivering more than 100emA of U5+. A detailed description of this ion source appears elsewhere in these proceedings.[1] This beam must be successfully transported to the entrance of the Wideroe to use the full capability of the SuperHILAC. Once the beam has been accelerated by the Wideroe linac, space-charge problems become much simpler. Therefore the upgrade project concentrates on beam transport within the Abel terminal where the beam is extracted from the ion source at a voltage of up to 40kV, and in the Low Energy Beam Transport (LEBT) line upstream of the Wideroe where the beam has an energy of 15.8keV/nucleon.

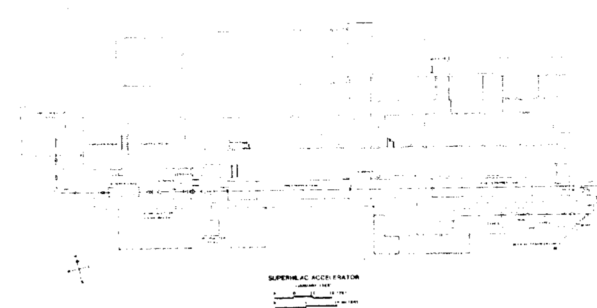

Fig. 1 The SuperHILAC accelerator. The upgrade involves modifications to the Abel injector, both upstream and downstream of the Wideroe linac.

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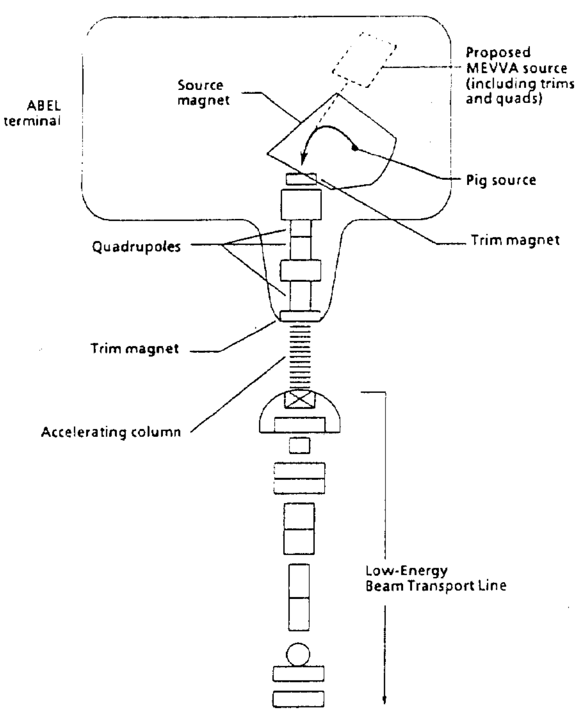
The only component of the project downstream of the Wideroe is the addition of a buncher to enhance the longitudinal phase matching of the beam entering the prestripper. Bunching the 23MHz structure of the beam leaving the Wideroe into the 70MHz bunches needed by the prestripper will greatly increase the fraction of beam within the acceptance of the prestripper.

Terminal Modifications

Figure 2 shows the Abel terminal and the beginning of the LEBT line. At present the ions are produced in the source magnet using a PIG source. This source is capable of producing about 5emA of U^{6+} at the entrance of the accelerating column. The MEVVA source will be mounted outside of the source magnet as indicated in the figure, since it operates with a small axial field produced by its own solenoid and cannot operate within the strong magnetic field of the source magnet.[1] Note that the installation of the MEVVA source in no way interferes with the operation of the PIG source, so that either source can be used as required. In between the ion source and the source magnet a set of quadrupoles and a pair of steering magnets will provide the necessary optical elements to transport the beam into the magnet. The source magnet will then be used to separate the charge states produced by the MEVVA source, making use of 69° of analysis. An existing quadrupole triplet will transport the analyzed beam to the entrance of the existing medium gradient column.



ABEL Injector, showing proposed MEVVA source

Fig. 2 The Abel terminal and the beginning of the LEBT line. Note the MEVVA ion source placement upstream of the source magnet.

Computer calculations using a beam envelope code show that up to 50emA of U^{5+} can be transported through the present column, assuming that the optics can be matched at the column entrance and exit. Since it is anticipated that this column will continue to be used, only minor modifications are needed to the Cockcroft-Walton power supply to handle the increased current of the MEVVA beam. The main modification will involve the installation of a small bouncer or de-rippler to maintain the voltage regulation of the terminal at $\pm 0.1\%$ under the increased loading of the high current beam.

Low Energy Beam Transport Modifications

Substantial modifications of the LEBT line are anticipated to manage the increased space-charge forces of the intense MEVVA beam. In addition the vacuum will be improved by the addition of extra pumps and the use of metal vacuum seals wherever practical.

Transporting the low energy, high current beam means that additional focusing will be required to counteract the larger space-charge forces. At present there are four quadrupole doublets in the LEBT line, two upstream of the 90° isotope analysis magnet and two downstream of the magnet. These quadrupole magnets will be augmented by a third doublet upstream and another downstream of the analysis magnet, resulting in a total of six quadrupole doublets. Calculations show that this combination should be able to transport up to 15emA of U^{5+} under the assumption of no space-charge neutralization. Other experiments have shown that under similar conditions the beam should be about 50% neutralized by electrons.[3] This implies that about 30emA of U^{5+} would be transported to the Wideroe. The 10emA space-charge limit of the Wideroe is the maximum beam that can be accelerated through the linac. To reach this limit about 100emA should be transported to the buncher upstream of the Wideroe. Since the saturation of the Wideroe output is nonlinear, transporting 30emA to the buncher would allow the Wideroe to operate near its space-charge limit.

Vacuum improvements will be made to decrease the residual gas pressure from the present 5×10^{-7} Torr to 1×10^{-7} Torr. For a beam of U^{5+} this decrease in pressure should result in a 20% increase in transmission. Since we now transport U^{6+} this means that transmission should increase from 70% to greater than 95% using the planned U^{5+}. The vacuum will be improved by adding four liquid nitrogen cryotraps to the beamline, along with three helium refrigerator cryopumps. In addition, all new beamline components will be outfitted with metal-to-metal vacuum seals to reduce outgassing and to allow at least partial vacuum baking. These improvements are expected to result in the desired decrease in background pressure.

Medium Energy Beam Transport Modifications

The longitudinal bunch structure in the Medium Energy Beam Transport (MEBT) line has been measured to determine the best way to improve the matching of the 23MHz beam bunches produced by the Wideroe into the 70MHz buckets of the prestripper. Measurements of the bunch width were made at three positions along the MEBT line using crystal detectors in a fast timing mode. The transport system was originally designed with a long drift space to allow the beam to debunch fully between the Wideroe and the prestripper. Measurements indicate, however, that the beam has not fully debunched.

Figure 3 shows a calculation of the bunch shape expected at the entrance of the prestripper based on some of the bunch width measurements in the MEBT line.[4] The upright ellipses represent the theoretical acceptance of the prestripper. This figure shows that the simplest means of improving the amount of beam captured in the prestripper would be to bunch the beam at 70MHz with a buncher upstream of the prestripper, filling one out of every three prestripper buckets. Figure 4 shows the expected bunch structure using this single buncher. Comparing the two figures shows the quantity of beam accepted in the prestripper increasing by more than a factor of three in this case. Calculations based on measurements of many different beams have shown at least a factor of two improvement. Therefore a 70MHz buncher, similar to that in use in our other two injector lines, will be installed upstream of the prestripper.

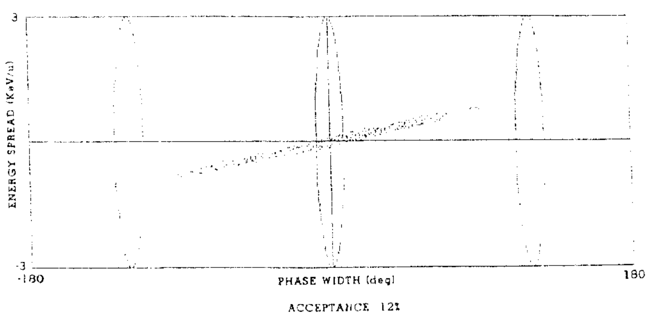


Fig. 3 Calculated longitudinal bunch shape at the prestripper entrance. The horizontal axis represents time or phase relative to the Wideroe RF at 23MHz, while the vertical axis represents energy spread. The three ellipses represent three buckets of the prestripper that operates at 70MHz.

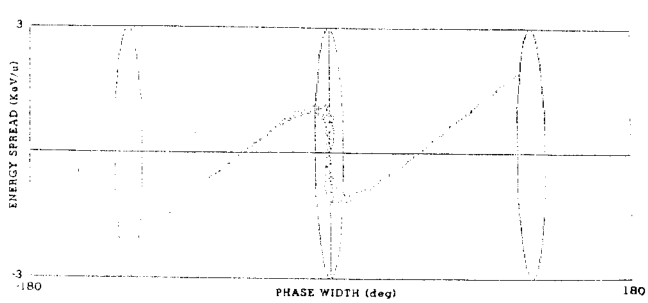


Fig. 4 Calculated longitudinal bunch shape at the prestripper entrance. In comparison with Fig. 3, a 70MHz buncher has been added to the MEBT line upstream of the prestripper.

Conclusions

The SuperHILAC Upgrade Project will increase the uranium output of the BEVALAC heavy-ion facility from the currently available 10^7 to $5x10^7$ ions/pulse. This upgrade will open to exploration wide fields of atomic physics research, such as enabling detailed Lamb shift measurements to be made in H-like and He-like uranium with important applications to nonperturbative quantum electrodynamics field theory and to the development of an x-ray laser.

This increase in ion intensity will be accomplished by the addition of a MEVVA source to the Abel terminal along with the appropriate focusing elements and by increasing the current handling capability of the Cockcroft-Walton power supply to accelerate at least 50emA of beam through the existing medium gradient column. The LEBT line will be modified to improve the vacuum and additional focusing elements will be included to counteract the space-charge forces of the low energy, high current beam. Finally, the phase matching between the beam exiting the 23MHz Wideroe and the acceptance of the 70MHz prestripper will be improved by the addition of a 70MHz buncher upstream of the prestripper. These improvements should result in a factor of 5 improvement of beam intensity for the heaviest beams, such as uranium. Detailed component engineering will begin in October 1985, and installation is scheduled to take place during the 1986 summer shutdown.

Acknowledgments

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[2] H. Gould et al., "Electron Capture by U91+ and U92+ and Ionization of U90+ and U91+," Phys. Rev. Lett., vol. 52, pp.180-183, January 1984.

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[4] Computer code courtesy of J. Staples, Lawrence Berkeley Lab, private communication.