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DISCLAIMER

STATUS OF THE EBIS PROJECT AT BROOKHAVEN*

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Abstract

The EBIS Project at Brookhaven National Laboratory will replace the Tandem Van de Graaff accelerators with an Electron Beam Ion Source, an RFQ, and short linac, as the heavy ion preinjector for RHIC. This project, jointly funded by DOE and NASA, will provide a modern preinjector which will have increased flexibility in providing beams to the various programs running simultaneously, will be capable of providing beams not presently available for RHIC and the NASA Space Radiation Laboratory, and will be simpler and less costly to operate. Presently in the first year of the four-year project, the detailed design is nearly complete, and some major procurements have been placed. The overall status of the project is presented, as well as some unique features in the design, and discussion of the R&D using the prototype EBIS.

INTRODUCTION

The present preinjector for heavy ions for RHIC uses the Tandem Van de Graaff accelerator, built around 1970. BNL will construct a new heavy ion pre-injector for RHIC, the EBIS, which will lead to more reliable, cost-effective operations and new capabilities important for planned future upgrades of the facility. The EBIS will also provide for a major enhancement in capability for the NASA Space Radiation Laboratory (NSRL), which utilizes heavy-ion beams from the RHIC complex. EBIS will allow for the acceleration of all important ion species for the NASA radiobiology program, such as, helium, argon, and neon that are unavailable with the present Tandem injector. In addition, the new system will allow for rapid switching of ion species, reducing delays due to interference between RHIC injection and NSRL operations.

The project includes the fabrication of an Electron Beam Ion Source for the production of mA-level currents of high charge state heavy ions (ex. Au^{32+}) in ~10-20 μs pulses, plus the procurement of an RFQ and heavy ion Linac to accelerate ions from EBIS to a final energy of 2 MeV/amu. A transport line will be fabricated to transport the beam from the output of the Linac to the existing Booster heavy ion injection point, as show in Figure 1.

DESIGN FEATURES

The technical objectives of the new preinjector need to meet requirements of both the RHIC and NASA experimental programs. Performance requirements for the preinjector are given in Table 1. Pulse width is chosen to allow 1-4 turn injection in to Booster. The need to supply beams to multiple users "simultaneously" determines the requirement for species switching in 1 second.

Table 1: Performance Requirements of the Preinjector

Species	He to U
Intensity (examples)	2.7×10^9 Au^{32+} / pulse 4×10^9 Fe^{20+} / pulse 5×10^{10} He^{2+} / pulse
Q/m	≥ 0.16, depending on ion species
Repetition rate	5 Hz
Pulse width	10-40 μs
Switching time between species	1 second
Output energy	2 MeV/amu

An example of how the preinjector may operate illustrates the requirements on beam switching. For RHIC, one may be asked to provide 1.7 emA of Au^{32+}, 10 μs pulse width, for 4 pulses at a 5 Hz repetition rate. In addition, a second, interleaved beam might be required for NSRL, which could be any one of the following: He^{2+}, C^{5+}, O^{8+}, Si^{13+}, Ti^{18+}, Fe^{20+} at ~2-3 emA, ~10 μs pulse width. The present control system allows the setpoints of all devices to be changed pulse-to-pulse, depending on the "user". It will now be required from the new preinjector that within 1 second the EBIS will change species, the RFQ and linac will change gradient, and the transport line elements will switch to new field values.

EBIS

An EBIS is ideally suited for meeting the requirements of producing short pulses of highly charged heavy ions at high currents, along with fast switching of species without any deleterious "memory" effects. Other than a straightforward scaling of the length of the ion trap, the parameters chosen for the RHIC EBIS do not deviate in any significant way from those demonstrated in the very successful prototype EBIS developed at BNL [1].

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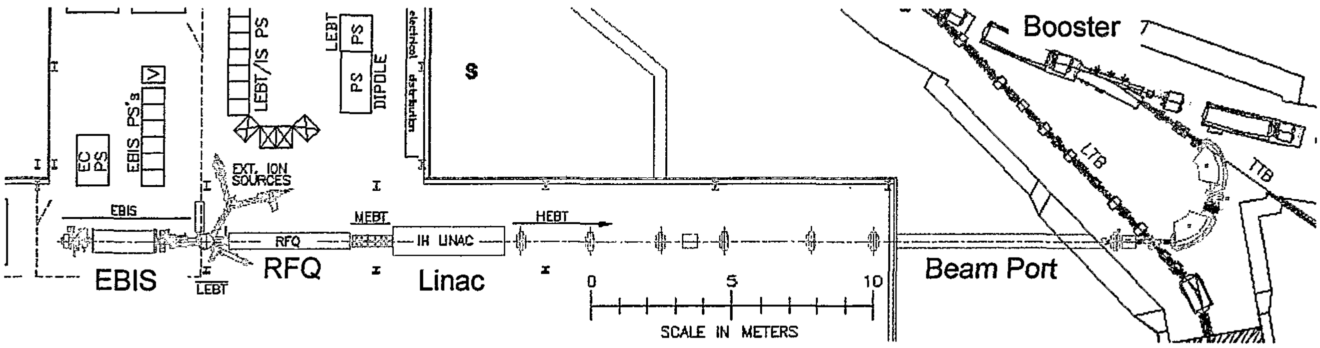

Fig. 1: Layout of the EBIS Preinjector

An electron beam current of 10 A and trap length of 1.5 m are sufficient to produce the required total extracted ion charge of 5.5 x 10^{11}. The extraction energy of 17 keV/amu is chosen high enough to minimize space charge effects in the LEBT line, without being excessive, such that voltage holding becomes more difficult, and the RFQ length increases.

The superconducting solenoid is a major component of the EBIS. The solenoid will have a coil length of 1.9 m, a warm bore diameter of 204 mm, and a peak field of 6 T. This solenoid (NASA-funded) is being fabricated by ACCEL, and is scheduled for delivery in November, 2006.

We will rely on external ion injection to provide most ion species. In this manner, the EBIS functions purely as a charge state multiplier. The advantages of an EBIS working with ion injection are many: once the proper ion optics configurations are set up and stored, one can easily change species and charge state on a pulse to pulse basis, there is virtually no contamination or memory effect, and several relatively low cost external sources can be connected by gate valves and maintained independently of the EBIS. To date, we have operated the EBIS successfully with external ion injection from a Metal Vapor Vacuum Arc Source [2], a Hollow Cathode Ion Source [3], and a Liquid Metal Ion Source [4]. In addition, for beams such as helium, we have used standard gas injection.

Low Energy Beam Transport

High beam transmission and minimal emittance growth under high space charge are required in Low Energy Beam Transport (LEBT) beamline. In addition, one must allow space for injection of the singly charged ions into the EBIS trap, and for beam instrumentation required for fast beam setups. A prototype of this beamline, as shown in Fig. 2, is being built as part of the R&D program.

After exiting the EBIS accelerating column, the first focusing element is a gridded electrostatic lens. While the use of a grid results in a loss in current, it was chosen because it can provide focusing or defocusing as required by the particular beam species. This can be switched within ~1 ms, to allow different focusing for the incoming, singly charged ions, and the extracted, highly charged ions. A magnetic solenoid lens focuses beam into the RFQ, and gives the strong focusing required without introducing any additional loss in intensity from a grid. The distance between the two lenses is kept as short as possible, in order to minimize space charge blowup of the high perveance extracted ion beam. The LEBT includes pulsed electrostatic deflectors for injection of singly charged ions into the EBIS trap, deflection of highly charged ions into a diagnostic line (time-of-flight spectrometer), and a deflector which allows ions to be injected directly in to the RFQ from an auxiliary source on a spur line, if desired. Figure 3 shows a calculation of the beam optics for a Au^{32+} through the electron collector, 100 kV accelerating column, and then the matching lenses into the RFQ.

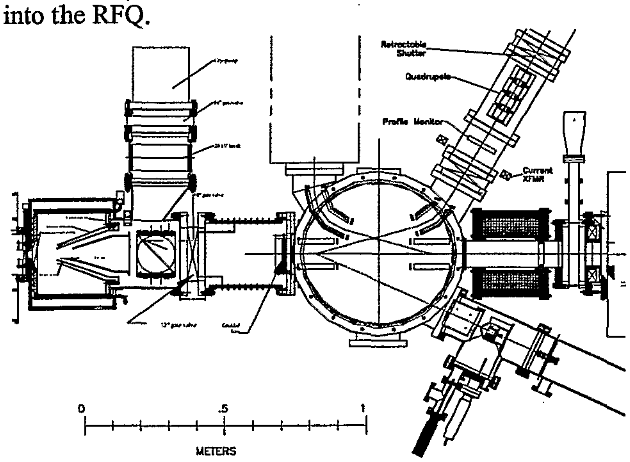

Figure 2: LEBT, matching between the EBIS (left) and the RFQ entrance (right)

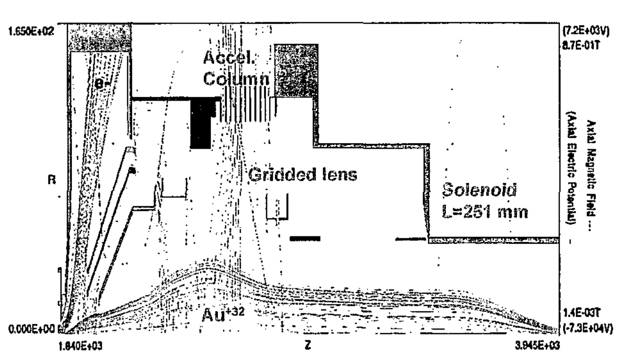

Figure 3: TRAK simulation for an 8 mA Au^{32+} beam. The distance from the electron collector entrance (left) to the RFQ entrance (right) is 2.1 m.

RFQ and Linac

Requirements for the RFQ are given in Table 2. The input energy is determined by space charge considerations in the injection line. The general frequency range was driven by space charge considerations at the RFQ entrance, and within that range, the exact frequency was chosen to be one half the frequency of the present 200 MeV H^- linac. The RFQ is very similar to several existing and well proven RFQs, and will be provided by Dr. A. Schempp of the IAP, University of Frankfurt.

Requirements for the linac are also given in Table 2. The design is chosen based on proven technology and closely matches several existing linacs.

Table 2: RFQ and Linac Design Specifications

Parameter	RFQ	Linac	Units
Type	4-rod	IH	
Operating Frequency	100.625		MHz
Design Beam Current	10	5	mA
Maximum Beam Current	>20	>10	mA
Q/m	0.16 – 1.0		
Repetition Rate, Max	5		Hz
Pulse Width	≤ 1.0		ms
Input Energy	17.0	300	keV/u
Input Emittance (rms, normalized, Au^{32+})	0.09	0.11	π mm mrad
Input Emittance, longitudinal (90%)	-	172	π keV/u-deg
Acceptance (normalized)	≥ 1.7	≥ 4.3	π mm mrad
Output Energy	300	2000	keV/u
Emittance Growth	≤ 20		%
Output Emittance, longitudinal (90%)	≤ 172		π keV/u-deg
ΔE (90%) for Au^{+32}		< ±10	keV/u
Transmission Efficiency	> 90		%

High Energy Beam Transport

The High Energy Beam Transport (HEBT) matches beam transversely from the Linac to Booster injection. A beamline penetration through the Linac shielding provides a short, direct path into the Booster allowing injection using the existing heavy ion inflector. Since the RFQ and Linac will not eliminate all unwanted charge states, the line has been designed for charge discrimination. Booster matching is sensitive to input energy spread, so two debuncher cavities will be used in HEBT to rotate the longitudinal phase space, producing a momentum spread at Booster injection of < ±0.1%.. The two 73 degree dipoles in the HEBT line will be laminated to allow rapid field changes for the 1 second species switching.

R&D USING THE TEST-EBIS

A goal of the present R&D program using the existing Test EBIS [1] is to develop the hardware to operate the EBIS on a 100 kV platform. In addition, a prototype LEBT is being built. This will allow us to characterize the EBIS emittance at full energy, at the RFQ location. A second part of the EBIS R&D is to build and test the RHIC EBIS electron collector, first thermal testing with full current electron beam, and then when installed on the Test EBIS.

The Test EBIS has now been installed on a platform isolated for 100 kV. The EBIS only has to be at high voltage during the < 50 μs ion extraction time, so pulsing of the high voltage will reduce the likelihood of breakdowns, and allow the external ion sources and injection lines to reside at laboratory potential. A 100 kV pulsed power supply has been designed and fabricated.

The electron collector for the EBIS is presently being fabricated, with delivery scheduled for the fall of 2006. It is required to handle a ~50 ms, 5 Hz pulsed electron beam with current up to 20 A and collection energy up to 15 keV. Detailed simulations have been done of simultaneous electron beam and ion beam transmission through the electron collector under various conditions. Hydraulic, thermal and stress analyses of the electron collector for different conditions of power load from the electron beam have been performed. The electron optics, cooling structure and material of the electron collector were optimized to reduce both the average temperature of the inner surface and amplitude of its variations during the operation cycle. The maximum heat load on the inner surface is ~350 W/cm^2 during the pulse, and averaged over the area being hit, is ~ 200 W/cm^2 during the pulse. The collector material will be Hycon 3 HP (Brush-Wellman). This high conductivity BeCu, was chosen since it results in low stresses in the material.

PROJECT STATUS AND SCHEDULE

Construction of the EBIS-based heavy ion preinjector at BNL has begun, jointly finded by NASA and DOE. The procurements of the superconducting solenoid and RFQ have been placed with NASA funds. The electron collector for the EBIS is being fabricated. The beam port through the ~25' shielding wall between the Linac and Booster has been installed. Detailed design of the entire preinjector is nearly complete, and fabrication of the rest of the EBIS components is scheduled to begin by the end of 2006. DOE approval for CD2 (Performance Baseline) and CD3 (Start of Construction) is expected by the end of the calendar year. The present schedule shows a staged installation and testing, starting with EBIS installation in the fall of 2007. Final testing of the entire beamline is scheduled to begin the summer of 2009.

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