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BNL-79626-2007-CP

High performance EBIS for RHIC

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Presented at the 22nd Particle Accelerator Conference (PAC'07)
Albuquerque, New Mexico
June 25-29, 2007

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DISCLAIMER

HIGH PERFORMANCE EBIS FOR RHIC*

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Abstract

An Electron Beam Ion Source (EBIS), capable of producing high charge states and high beam currents of any heavy ion species in short pulses, is ideally suited for injection into a synchrotron. An EBIS-based, high current, heavy ion preinjector is now being built at Brookhaven to provide increased capabilities for the Relativistic Heavy Ion Collider (RHIC), and the NASA Space Radiation Laboratory (NSRL). Benefits of the new preinjector include the ability to produce ions of any species, fast switching between species to serve the simultaneous needs of multiple programs, and lower operating and maintenance costs. A state-of-the-art EBIS, operating with an electron beam current of up to 10 A, and producing multi-milliamperes of high charge state heavy ions, has been developed at Brookhaven, and has been operating very successfully on a test bench for several years. The present performance of this high-current EBIS is presented, along with details of the design of the scaled-up EBIS for RHIC, and the status of its construction. Other aspects of the project, including design and construction of the heavy ion RFQ, Linac, and matching beamlines, are also mentioned.

INTRODUCTION

At BNL a new heavy ion preinjector, based on an EBIS source, is being constructed. There are considerable advantages to the use of an EBIS+linac-based preinjector instead of the present Tandem Van de Graaffs for injection of beams into the Booster synchrotron for RHIC and the NASA Space Radiation Laboratory (NSRL). The replacement of the 35 year old Tandems by a modern injector will be simpler and less costly to operate. Booster injection will become easier and more efficient since one will only need to inject over 1-4 turns, rather than the present 30-60 turn injection. While ion species from the Tandems are limited to those starting as negative ions, the EBIS can provide any ion species, thus allowing 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. Since the desired final charge state can be produced directly in the EBIS, two stripping stages are eliminated, resulting in more stable beam operation,. Finally, this preinjector, coupled to the Booster via a short transport line, will be able to rapidly switch beam species (1 second) to meet the needs of both RHIC and NSRL simultaneously.

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 ~10-40 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.

Performance requirements for the preinjector, including the RFQ and Linac, are given in Table 1.

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

The EBIS has many advantages over other type sources in meeting the requirements of the above applications. An EBIS can produce any type ions - from gas, metals, etc., and is easy to switch species, even pulse-to-pulse, when feeding the trap by injection of singly charged ions from external sources. One has precise control over the charge state produced, and it is easy to produce a distribution peaked at intermediate charge states such as Au^{32+} or U^{45+}. One has control over pulse width, extracting a fixed charge, so one can better match synchrotron requirements. EBIS produces a narrow charge state distribution ($\geq 20\%$ in the desired charge state), so there is less of a space charge problem in the extraction and transport of the total current. Finally, the source is reliable, and has excellent pulse-to-pulse stability, and long lifetime.

Requirements for the RHIC EBIS are the following:

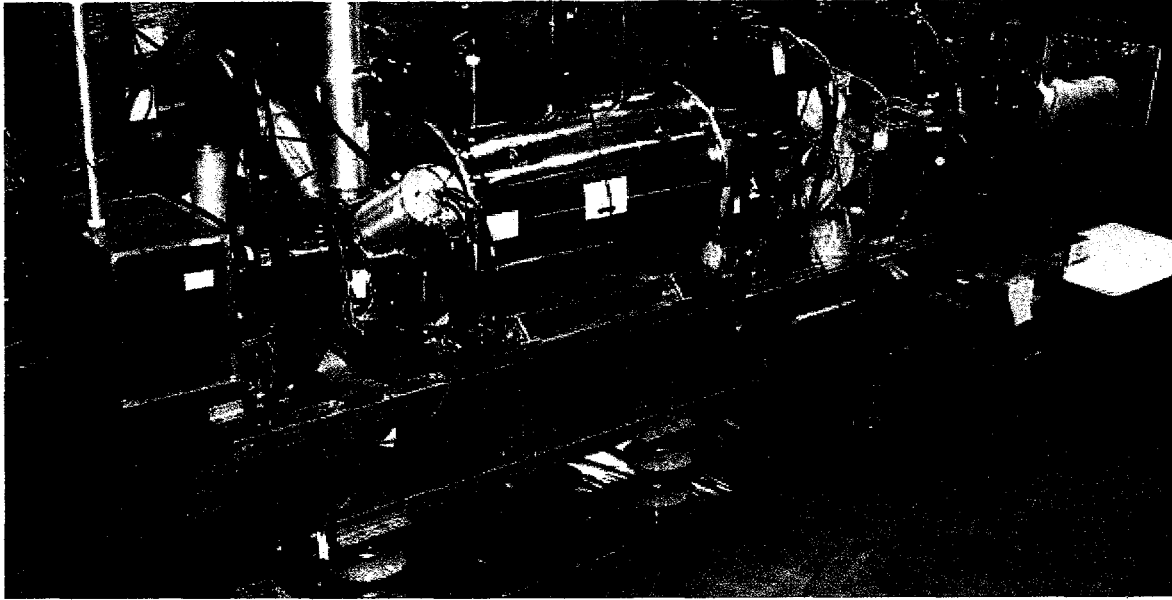| Output Charge (single charge state):	$\geq 1.1 \times 10^{11}$ charges
Ion output (Au^{32+}):	3.4×10^9 particles/pulse
Q/m	≥ 0.16, depending on ion species
Beam current (single charge state):	1.7-0.42 mA Pulsed, 10 - 40 μS, 5 Hz
Output energy:	17 keV/amu
Emittance (Au):	~0.35 π mm mrad (norm, 90%)
Switching times: Injection-Extraction Between species	 $\leq$1ms 1 second

Figure 1: Photo showing the Test EBIS on the high voltage platform, and extraction to time-of-flight diagnostic .

PERFORMANCE OF THE TEST-EBIS

The Test EBIS, built to demonstrate all essential features of an EBIS meeting RHIC requirements, is shown in Figure 1. This half-trap length (72 cm, half-yield), full power electron beam prototype is described in detail in [1]. The following are some key features and results.

Electron Beam

An IrCe cathode, from BINP, Novosibirsk [2], is now routinely used on the Test EBIS, and electron beams up to 10A, and 100kW peak power dissipation on the electron collector have been propagated with losses less than 1mA. The gun perveance is 1.3×10^{-6} A/V$^{3/2}$. At our design electron current of 10A, the IrCe cathodes have expected lifetimes of ~20,000 hours, several times longer than the LaB$_6$ cathodes previously used.

Ion Output

Au^{32+} has been produced in less than 35ms, Ne^{8+} in 18ms, N^{5+} in 4ms, and Cu^{15+} in 15ms. Charge state vs. confinement time agrees with calculations. With external ion injection, 3.5×10^{11} charges/pulse of Au ions, and $\geq 2 \times 10^{11}$ charges/pulse of Ne, N, and Cu have been achieved. In all cases our goal of extracting charge of 50% of the trap capacity has been exceeded. The above yields can be extracted in pulses of 10-20µs FWHM, resulting in extracted currents for these ions of several mA's. Examples of ion pulses and charge state distributions are shown in Figures 2 and 3.
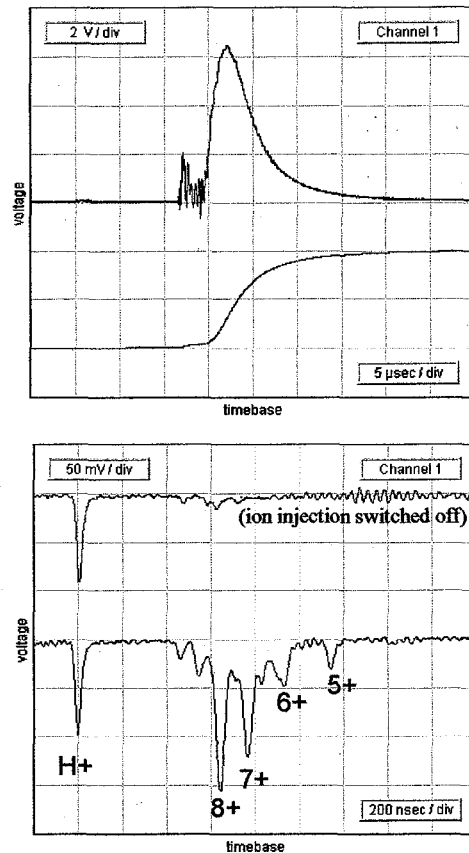

Figure 2: Neon ions produced with a 6.8 A electron beam and 18 ms confinement, 6.3 mA peak ; 2.4 x 10^{11} charges/pulse.
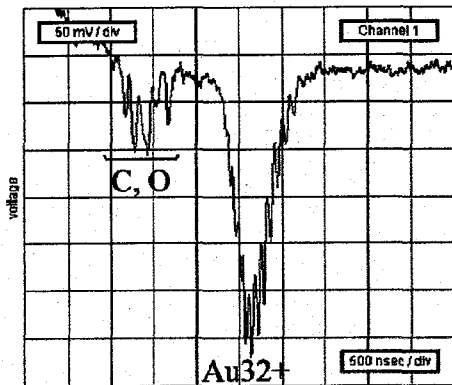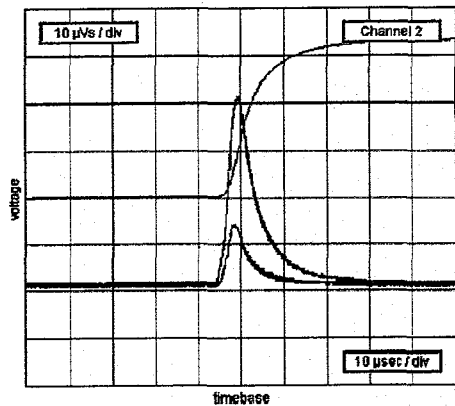
10 µVs / div   Channel 2

voltage

10 µsec / div

timebase

50 mV / div   Channel 1

voltage

C, O

Au32+   500 nsec / div

Figure 3: Au ions produced with a 6.8 A electron beam and 36 ms confinement, 4.0 mA peak ; 2.0 x 10^{11} charges/pulse. Charge state distribution peaked around Au^{32+}

High Voltage Operation

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 reduces the likelihood of breakdowns, and allows the external ion sources and injection lines to reside at laboratory potential. A 100 kV pulsed power supply has been fabricated. Operation of the Test EBIS at the maximum required 80 kV extraction has been very successful. There is no change in performance observed when the platform voltage is pulsing, and no voltage breakdowns are observed.

Emittance

A normalized, rms emittance of 0.1 π mm mrad has been measured for a 1.7 mA Au beam extracted from the EBIS. For lighter ion species and higher currents, emittances increase to ~0.3 π mm mrad. (Since there is no separation of beam components, the emittance of all charge states were measured; individual charge state emittance could be

smaller). Normalized rms emittances were constant whether measured with the platform at ground potential, or with up to 80 kV acceleration (i.e. 18 to 98 keV).

Seeding the EBIS trap

We rely on external ion injection to provide most ion species. In this manner, the EBIS functions purely as a charge state multiplier. One can easily change species and charge state on a pulse to pulse basis, and there is virtually no contamination or memory effect. To date, we have operated the EBIS successfully with external ion injection from a Metal Vapor Vacuum Arc Source [3], a Hollow Cathode Ion Source [4], and a Liquid Metal Ion Source [5]. In addition, for beams such as helium, we have used standard gas injection.

STATUS OF RHIC EBIS HARDWARE

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 Test EBIS described above. 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}. A schematic of the RHIC EBIS is shown in Figure 4.

Electron Gun

The performance required for the RHIC EBIS can be achieved with the 10 A electron gun already in use. Nevertheless it is desirable to have a safety margin with electron beam current for EBIS operation at 10 A and some prospects for increase of output ion intensity in the future, and indeed, with this IrCe cathode one has the possibility of increasing emission and producing an electron current up to 20A. We have such a design of the electron gun and collector which would allow a possible future increase of electron current in RHIC EBIS to 20 A. To reach electron current of I_{el}=20 A with existing 40 kV anode power supplies the perveance of the gun is doubled relative to our present gun. The IrCe cathode can provide emission current density 40 A/cm^2, with an expected lifetime at this density of several thousand hours [2]. The design is based on the inverted magnetron geometry of our existing electron gun of Novosibirsk design, which produces a laminar electron beam, allowing operation in a wide range of electron current, potential and magnet field distributions. It also allows substantial deceleration of the electron beam in the ion trap and electron collector regions. The cathode is immersed in a magnetic field of approximately 0.14 T. The perveance of this gun is ~$2.5 \cdot 10^{-6}$ A/V$^{3/2}$.
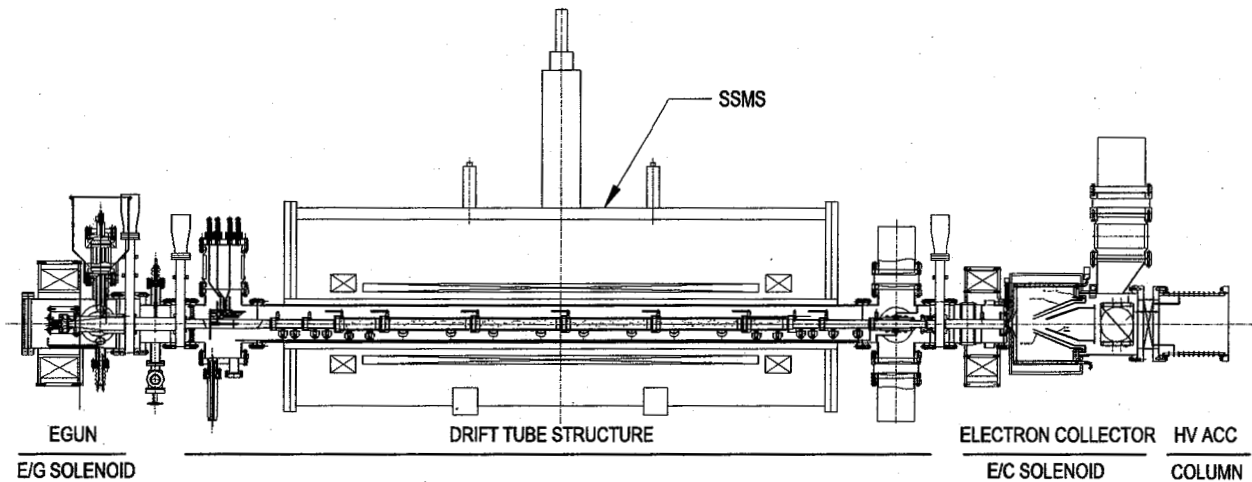
Electron Collector

Figure 4: Schematic of the EBIS for RHIC.

The electron collector for the EBIS, shown schematically in Fig. 5, is presently being fabricated. 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. 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 for electron beam current 20 A 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 is Hycon 3 HP (Brush-Wellman). This high conductivity BeCu, was chosen since it provides longer fatigue lifetime. However, due to difficulties this material is presenting during electron beam welding, we are also beginning the fabrication of a second collector using a zirconium chromium copper alloy.
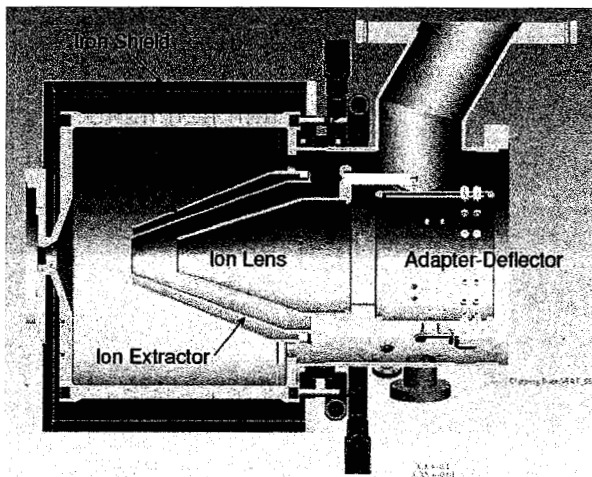

Figure 5: Electron collector for the RHIC EBIS.

Superconducting Solenoid

The superconducting solenoid is a major component of the EBIS. For RHIC, the straightforward doubling of the trap length by installing a longer superconducting solenoid is required. 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 is being fabricated by ACCEL [6], and delivery is now expected in July, 2007.

PROJECT STATUS

Components for the RHIC EBIS are now being fabricated. A prototype of the low energy beam transport section, matching beam from the EBIS into the RFQ, has been fabricated and is now being tested [ref these proceedings].

A 100 MHz, 4-rod RFQ will accelerate the beam from an input energy of 17 keV/amu, to 300 keV/amu. This will be followed by a 100 MHz IH linac for acceleration to the final energy of 2 MeV/amu. The RFQ and linac are both being designed and fabricated by the Institute of Applied Physics, Frankfurt [7]. The 400 kW rf amplifiers for these structures are being manufactured by Continental Electronics [8].

Testing of the RFQ with beam from the Test EBIS is scheduled for early in 2008. First testing of the RHIC EBIS source is presently planned for the spring of 2008.

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