A NEW GENERATION OF EBIS: HIGH CURRENT DEVICES FOR ACCELERATORS AND COLLIDERS*

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Abstract

With the advent of heavy ion colliders, such as RHIC at BNL and LHC at CERN, the demand for high charge state ion beam intensities was raised by more than an order of magnitude compared to fixed target operation of existing accelerators.[1] RHIC, for example, requires 3.4×10^9 gold 32+ particles per ion source pulse, or about 85 nC total positive charge yield, assuming a 20% abundance of the selected charge state in the ion source beam. An EBIS is capable of producing the required ion intensities in beams of a low emittance and pulses as short as 10 μs, which is quite advantageous for colliders. However, for the colliders, the EBIS requires electron beam currents on the order of 10 A, about 20 times higher than electron beams utilized in devices at accelerators at Dubna, Saclay, and Stockholm for fixed target and low intensity atomic physics experiments. At BNL, we have constructed a test EBIS, which is now operating at 10 A, the full electron beam power required for RHIC. Electron and ion beam currents in our test EBIS have exceeded values obtained with previous EBIS devices by more than an order of magnitude, in a stable and quiet mode of operation. For operation with gold, ion spectra with dominant charge state of 34+ have been observed; and, even with only half the trap length required by RHIC, 55 nC ion pulses have been obtained at the source exit after a confinement time of only 30 ms. Simple scaling to RHIC requirements now seems well in hand. In addition, with reasonable extrapolations of several parameters of the RHIC EBIS, one should be able to produce Pb^{54+} ions with an intensity which could be of interest for the LHC at CERN. This would eliminate stripping, accumulation, and electron cooling stages from the present LHC injection scheme, which uses an ECR ion source.

1 INTRODUCTION

In order to meet the demands of the heavy ion colliders, renewed, broad research in the development of heavy ion sources such as ECR, laser ion sources, and EBIS has been necessary. A concept of a heavy ion preaccelerator for RHIC based on an EBIS has been developed because an EBIS is capable of producing the required ion intensities in beams of a low emittance ($\varepsilon_{n,\ rms} \sim 0.1\ \pi$ mm mrad) and very short pulses (~10-40μs), which is quite advantageous for colliders. An EBIS based preinjector including an RFQ and short linac would be rather compact and simpler to maintain than the aging Tandem presently used for RHIC. Advantages include:

- more efficient single to few turn injection into the Booster synchrotron
- injection energy into the Booster can be higher than with the present Tandem
- easy production of any ions (solids, gases), and able to quickly switch between species
- stability; no slow variation in beam properties due to changing stripping foil thickness, for example

Previously, the focus for EBIS sources at accelerator facilities at Dubna, Saclay and Stockholm has been to produce very highly charged ions (charge to mass ratio q/m between 0.25 and 0.5). With those sources, the required intensity was within the bounds available with electron beam operation up to 0.5A. For the heavy ion colliders the emphasis is on particle current, and we have in a RHIC EBIS, for example, the benefit of being able to reduce charge state production to intermediate charge states with q/m~0.16. The following sections present experimental results that now demonstrate the viability of using an EBIS to meet heavy ion collider requirements.

2 EBIS MODE OF OPERATION

The electron space charge accumulation in the EBIS trap length L[m] for an electron beam current I[A] and energy E[eV] is given by:

$$C = 1.05 \times 10^{13}\, f{*}I{*}L / \sqrt{(E)} \quad \text{charges}$$

This sets the upper limit on the amount of ion charge that can be confined and extracted from the source. It is possible for the neutralization fraction f = ion charge/electron charge to approach the value of 1. Parameters that are important in determining the time evolution of charge states in the production of highly charged ions are the current density Je [A/cm^2], the confinement period Tc [s] and the electron energy E [eV]. The higher the ionization product, Je*Tc, the faster higher charge states will be generated. The current density Je, depends on the specific nature of the electron beam launching conditions from the electron gun. In the case of the BNL EBIS Test Stand (EBTS), for example, the magnetic field dominates electrostatic effects, and the current density in the main field (ion trap) region, Jm, is given by Jm=Jc* (Bm/Bc), where Jc is the current density at the cathode, Bc is the magnetic field at the cathode and Bm is the field of the main solenoid. A good discussion concerning the traditional mode of EBIS operation, including the evolution of charge states, has been given by Donets [2].

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3 BNL EBTS DESIGN CHOICES

Operation of the BNL EBTS has resulted in ion current improvement from 10’s of μA’s to several mA’s and total charge output has gone from a few nC to over 55nC, operating with an electron beam current of 10A rather than the typical ~0.5 A. Several important choices have been made in the EBTS design and operation that have resulted in the large jump in overall EBIS performance. The basic guidelines followed have been to separate the function of various EBIS components and remove them as much as possible from the EBIS trap region. Some important features of the BNL EBIS are as follows:

•Unshielded warm bore (5 Tesla) superconducting main solenoid to provide the main magnetic field for electron beam propagation and compression. The pumping in the (warm) ionization region is independent of the cryosystem and is less sensitive to beam loss or beam induced desorption than a cold bore EBIS. This also eliminates “memory effects”, and allows faster turn around times if maintenance is needed.

•Unusual magnet structure which makes use of two auxiliary (warm) solenoids, one at the electron gun and one in the transition region at the entrance of the electron collector. This allows the gun and collector, which are both sources of vacuum degradation, to be located far from the ionization region, thereby accommodating differential pumping stages. This rather open magnetic geometry also allows additional control of the electron beam launching , compression, and collection, as well as allowing easy introduction of transverse steering coils not typical to EBIS designs.

•The electron gun, designed in Novosibirsk [3], is very different than that used in previous EBIS’s. It uses a convex cathode, and the resultant beam, with low rotational velocity, is less sensitive to acceleration and deceleration common in an EBIS. Its perfomance has been excellent and has been a large factor in the propagation of very low loss multiampere electron beams.

•Large diameter (32mm) drift tubes have been used, compared to the 3-9mm tubes typical for an EBIS. This helps with pumping near the electron beam in the warm bore and reduces loading (desorption) effects. It also reduces the requirement on alignment precision, and having the electron beam far from drift tube gaps lessens RF coupling. The large diameter also results in a favorable aspect ratio of diameter to length, which is beneficial to ion trap manipulation and allows fast ion extraction without special drift structure design.

4 SUMMARY OF EBTS RESULTS

The performance of the EBTS, with its unusual magnetic configuration and novel electron gun, has been excellent. Very stable operation has been achieved over a wide range of gun operating parameters. One can consistently extract a total ion charge corresponding to 60-85% of the electron beam space charge.

Figure 1 shows measured Au ion yields for electron beam currents up to 8A. A TOF spectrum measured at 7.2A and 50ms ion confinement time showed a most abundant charge state of Au^{34+}. By using spectra and neutralization data obtained with 7-8A electron beams, it is conservatively estimated that the EBTS is presently producing $>10^9$ Au^{32+} ions per pulse.

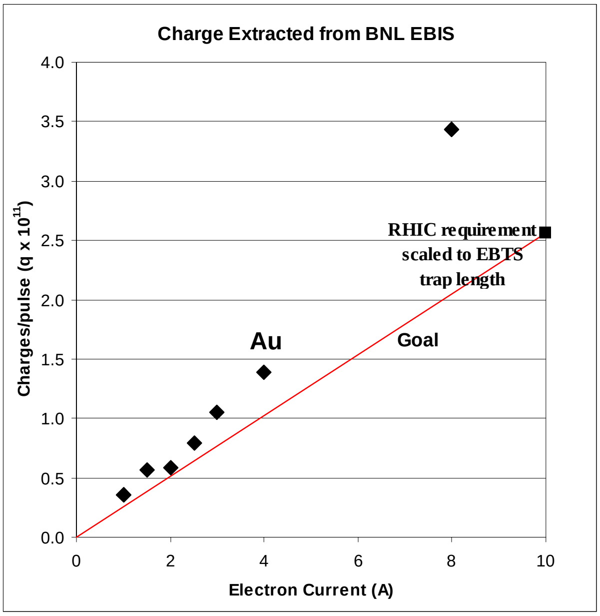

Figure 1: Au ion yield from EBTS vs. electron current

A 3.2mA, 12μs FWHM, (40nC) ion pulse was obtained at the source exit toroid using a 6.8A e-beam and Au external ion injection, after a 15ms confinement period, as shown in Fig. 2. Faster extraction has been reported earlier by applying a gradient to the well floor during extraction. In the future, the pulse shape will be tailored by applying an appropriate voltage pulse to the well. More details on the EBTS results can be found in [4].

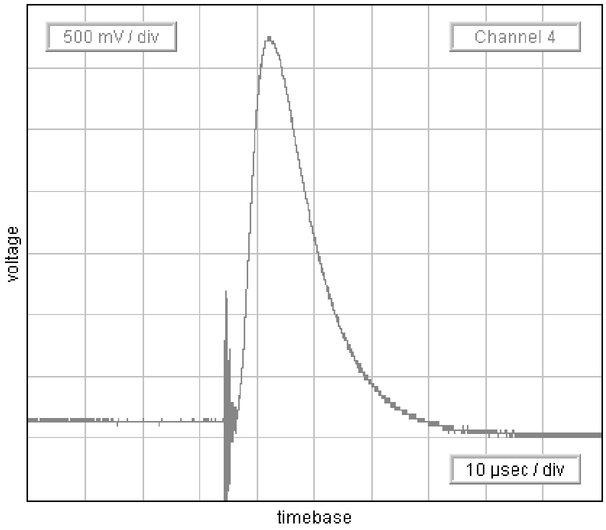

Figure 2: Total extracted current of 3.2mA, in 12μs FWHM, with Ie=6.8A, Au injection, and 15ms confinement time.

Table 1

	Achieved (EBTS)	**Proposed - RHIC**	**Proposed - LHC**
Ion	Au^{32+}	Au^{32+}	Pb^{54+}
I_e	10 A	10 A	20 A
J_e	500 A/cm^2	500 A/cm^2	3000 A/cm^2
$t_{confinement}$	35 ms	35 ms	150 ms
L_{trap}	0.7 m	1.5 m	2.0 m
Capacity	0.51 x 10^{12} charges	1.1 x 10^{12} charges	2.4 x 10^{12} charges
% extracted ions	> 75%	50%	20%
% in desired Q	20%	20%	20%
Extracted charge	> 55 nC	85 nC	77 nC
Ions/pulse	> 10^9 (Au^{32+})	3.3 x 10^9 (Au^{32+})	1.8 x 10^9 (Pb^{54+})
Pulse width	10-20 µs	10-40 µs	5-10 µs

5 RHIC EBIS DESIGN AND LHC EBIS OPTION

The RHIC EBIS requires a yield of 5 x 10^{11} positive charges/pulse, in order to produce the desired 3.3 x 10^9 ions/pulse of Au^{32+}. Table 1 shows the parameters for an EBIS meeting RHIC requirements, as well as parameters already achieved on EBTS. As can be seen, what is required for RHIC is the straightforward doubling of the trap length by installing a longer superconducting solenoid. We have verified the linear scaling with trap length on EBTS over a range of ~35-107 cm.

There will be continued component optimization on EBTS, as well as systematic studies of the emittance of the extracted beam, and beam transport line design. Future funding to build a new RHIC preinjector is anticipated.

Also shown in Table 1 are suggested parameters for an EBIS which could meet the requirements for LHC at CERN. As has been pointed out previously [1,5], the use of Pb^{54+} directly from an EBIS would have several advantages:

- elimination of the first stripping stage required by a lower charge state source such as an ECR
- elimination of the need to use LEIR for ion accumulation and electron cooling
- 10 Hz linac operation would not be required
- single turn injecton into the PSB
- any ion species, with fast switching, becomes possible

The increase in current density could come primarily from the use of an IrCe cathode, which could boost Jc by a factor of 4 relative to EBTS. The remaining increase in Je is gained from increased magnetic compression.

6 SUMMARY

With EBTS, one has achieved more than an order of magnitude improvement in EBIS performance. All that is needed to meet requirements for RHIC and LHC are now more modest increases in well understood parameters. The progress at BNL on the EBIS development gives confidence that a high current EBIS source injecting into a Linac-based preinjector can reach the pulsed Au beam intensity required for RHIC. Such a system offers significant advantages in meeting long-term requirements for performance and reliability for the RHIC program.

7 REFERENCES

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