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Ion optics of RHIC EBIS[a)*]

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RHIC EBIS has been commissioned to operate as a versatile ion source on RHIC injection facility supplying ion species from He to Au for Booster. Except for light gaseous elements RHIC EBIS employs ion injection from several external primary ion sources. With electrostatic optics fast switching from one ion species to another can be done on a pulse to pulse mode. The design of an ion optical structure and the results of simulations for different ion species are presented. In the choice of optical elements special attention was paid to spherical aberrations for high-current space charge dominated ion beams. The combination of a gridded lens and a magnet lens in LEBT provides flexibility of optical control for a wide range of ion species to satisfy acceptance parameters of RFQ. The results of ion transmission measurements are presented.

I. INTRODUCTION

RHIC EBIS operates on the RHIC accelerating facility with electron current up to 10 A providing a variety of ion species from He to Au [1-3]. The details of RHIC EBIS design can be found elsewhere [4-7]. For most ion species RHIC EBIS operates as a charge breeder: the low charged (1-2) positive ions from one of the outside ion sources are injected into EBIS potential trap where they are confined by the electrostatic fields of the electron beam space charge and the axial potential barriers until these ions reach a required charge state as a result of stepwise ionization in a dense electron beam. At the end of the ionization cycle the multicharged ions from the trap are extracted either for acceleration in RFQ accelerator or for charge state analysis in our Time Of Flight (TOF) mass-spectrometer. The wide range of ion current and energy within one ionization cycle, a limited acceptance of RFQ and the required flexibility of EBIS injector operation determined the complexity of ion optics.

II. STRUCTURE OF ION OPTICS

The structure of RHIC EBIS ion optics with LEBT chamber is presented in Fig. 1. It includes elements, which are an integral part of EBIS (electron collector and ion extractor) and elements inside the LEBT chamber. Almost all optical elements in this schematic are used for both ion injection and ion extraction, except for the spherical benders in LEBT, which are used only for injection into EBIS, and the magnetic lens which is used only for injection of the extracted ion beam into the RFQ. To adjust the Twiss parameters of the ion beam to match the of the RFQ a combination of the electrostatic gridded lens and the solenoidal magnetic lens is used.

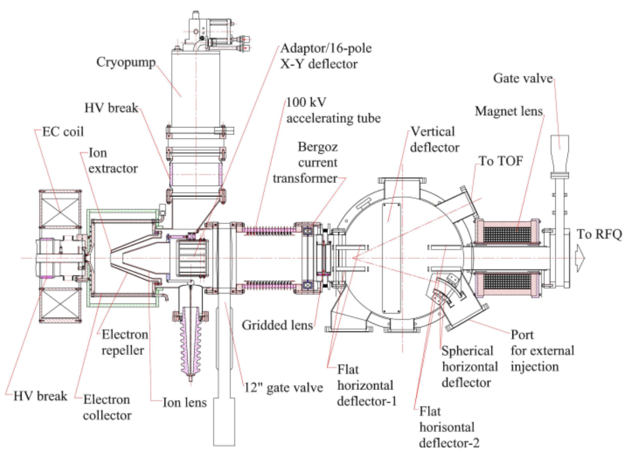

FIG. 1. Schematic of RHIC EBIS ion optics with LEBT.

The pulsed magnetic lens is a single helix solenoidal coil with laminated soft iron shield. The inner diameter of the coil is 140 mm, the total length is 251 mm and inductance is 1.9 mH. The nominal amplitude of the magnetic field pulse for Au^{32+} ion acceleration is 0.98 T. The flattop duration of the half sine pulse with flatness 0.2% is 200 µs, operating frequency is 5 Hz.

With the wide range of charge to mass ratio for the accelerating ions the gridded lens has an advantage of compensating the sometimes overfocusing effect of the accelerating tube by applying positive voltage to the grid, so the lens becomes defocusing. The mesh of the gridded lens has transparency 80% and the cell size is 1x1 mm. According to our trajectory simulations the emittance

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growth of the 8 mA ion beam in this gridded lens does not exceed 5% in a full range of operating voltages for all ion species (see Fig. 2). An area between two dotted lines in this picture is an operating region of the gridded lens. The emittance build up with voltage increase is caused by both spherical aberrations on the periphery of the lens and by the focusing/defocusing effect of individual cells in a mesh.

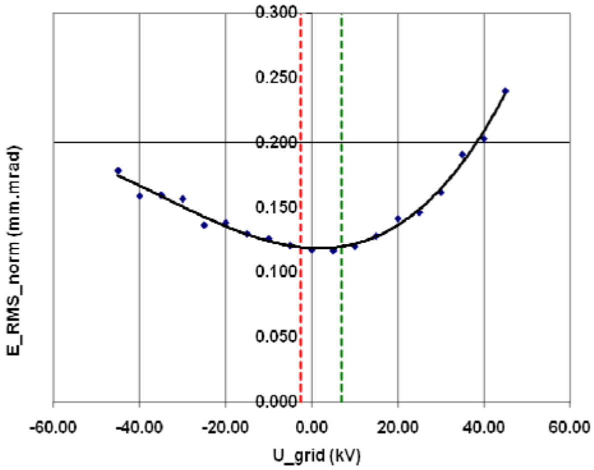

FIG. 2. Simulated ion beam (Au^{32+}) emittance dependence on the voltage of the gridded lens. I_{ion}=8.0 mA, E_{ion}=96 keV/q. Vertical lines define the optimized gridded lens voltages for Au^{32+} (left) and He^{2+} (right).

The sizes of the opened apertures of RHIC EBIS ion optical elements are determined primarily by the high space charge of the extracted beam of multicharged ions. The RHIC EBIS ion current can reach 10 – 15 mA for extraction time about 10 µs. At the extraction energy 15 – 20 keV/charge this effect determines fast expansion of the ion beam after decoupling from the electron beam inside the electron collector. To reduce the beam loss on the first extracting diaphragm and the ion beam expansion caused by the space charge after extracting the ion beam from the electron beam the inner diameter (ID) of the ion extractor is made as large as reasonably possible (40 mm) and the ion extractor itself is positioned close to the entrance aperture of the electron collector. The ion lens, which is located next to the ion extractor, has high negative potential (40-50 kV). It accelerates and provides a focusing action to the ion beam. The accelerating tube for 100 kV is equipped with internal electrodes, which have inner diameter of 195 mm. A 12" gate valve between the electron collector chamber and the accelerating tube has axial dimension 100 mm; it reduces useful penetration of the accelerating field into the critical low-energy region, but serves an important maintenance function.

The space between the ion lens and the accelerating tube contains an adaptor/deflector, consisting of 16 isolated electrodes, which are connected to eight bi-polar power supplies (±3.0 kV) floating on a common potential (±20.0 kV). This combined unit is 136 mm long and has inner diameter of 142 mm. It provides both focusing and 2-dimentional transverse deflection of the ion beam. The transverse electric field is quite uniform within the ion beam radius and its vector can be arbitrarily rotated. The view of adaptor/deflector and potential distribution of such structure simulated with 2D version of TREK is presented in Fig.3.

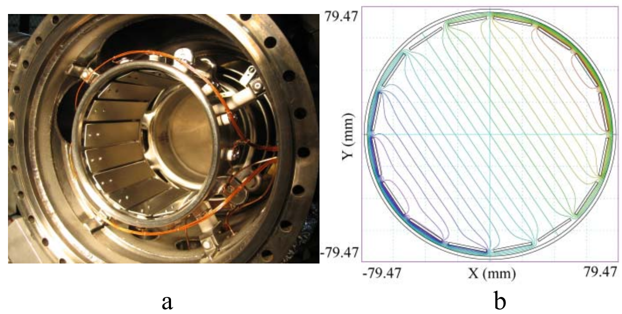

FIG. 3. Assembly of the 16-pole adaptor/deflector (a) and simulated equipotential lines inside its electrode structure (b).

According to this simulation the maximum variation of the electric field within 70% of the inscribed radius of the electrode structure is 2.3%.

A trajectory simulation for injection of Au^{32+} ion beam from a 10A electron beam into RFQ is presented in Fig. 4.

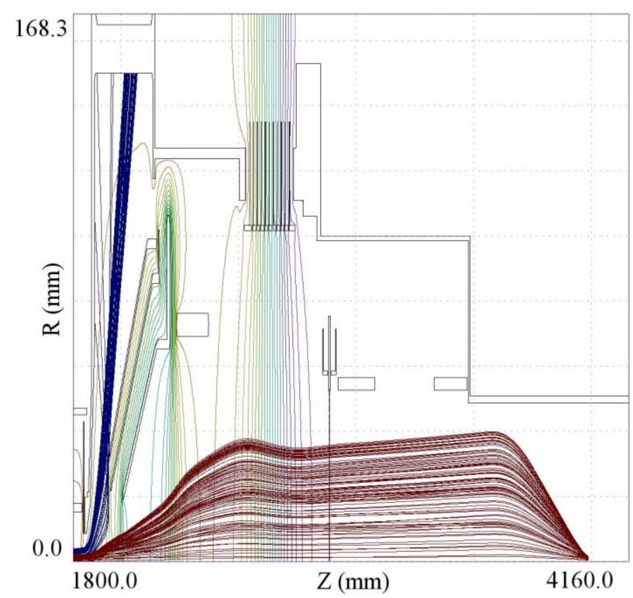

FIG. 4. Simulated electron and ion trajectories for extraction of Au^{32+} ion beam with parameters of optical elements tuned in experiment for optimum injection into RFQ.

The simulation shows that for the optimum tune the emittance of ion beam increases by 10-15% from the initial value at the entrance into the electron collector and is caused primarily by spherical aberrations.

There are two flat horizontal deflectors with distance between plates 100 mm and one flat vertical deflector with distance between plates 117 mm in the LEBT chamber. With the 16-pole deflector at the EBIS exit this set of deflectors is sufficient for the needed ion beam displacement and tilt.

The voltages on the optical elements, which are used for both ion injection and ion extraction, can be changed from one regime to another within 1 ms. Also, these voltages can be changed for different ion species on a pulse-to-pulse basis. With currently two external hollow cathode ion sources operating on separate beam lines with a common switching chamber one can quickly switch the extracted ion beam between at least 2 ion species.

The existing optical elements in EBIS, LEBT and ion injection transport lines with optimum tuning provide sufficient conditions for injection of low-charged ions from the external ion sources into EBIS ion trap. An example of ion injection simulations with emittance of injecting ion beam taken from measurements with the pepper-pot emittance meter is presented in Fig. 5. Currently, the ions are injected into the EBIS trap at ground potential on the EBIS platform.

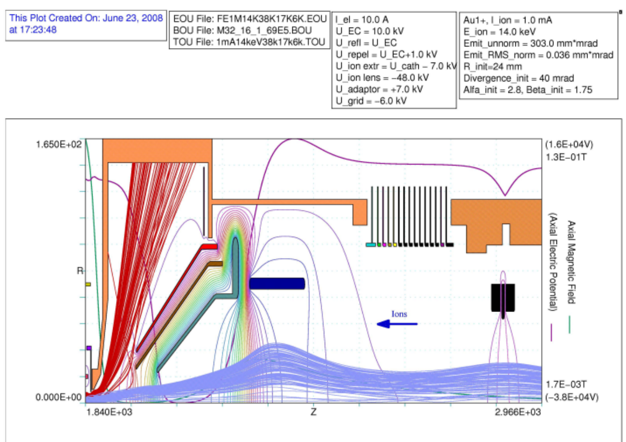

FIG. 5. Simulation of ion injection (Au^{1+}) into a 10 A electron beam.

This simulation shows that the ion beam has radius 2.1 mm inside the aperture of the electron collector, which is approximately 35% of the electron beam radius. Other simulations of the ion injection into the trap show that the 10A electron beam with EBIS parameters has normalized RMS acceptance 0.65 mm*mrad for injection into the trap space limited by the electron beam radius. This value of acceptance is larger than emittances of our existing external primary ion sources, which normally does not exceed 0.04 mm*mrad. RHIC EBIS ion optics, which was originally designed for optimum ion extraction, allows flexible control of the radius and the entrance angle of the injected ion beam into the electron beam, matching the emittance of the primary ion beam with the acceptance of the electron beam. The results of experiments on measurements the efficiency of ion injection into Test EBIS, which has the same ion optics as RHIC EBIS, with electron current 1.0 A and 1.5 A are presented in [8].

III. EXPERIMENTAL RESULTS

With the complex composition of the ion beam extracted from EBIS and different focusing properties of the magnetic lens for different ion species and charge states it is difficult to measure the efficiency of ion transmission from EBIS to the entrance of the RFQ and of acceleration through the RFQ. To date, for routine operation at up to 5A and total peak currents out of EBIS of up to 5 mA, the transmission from the EBIS output to a 2 cm diameter Faraday cup right at the RFQ entrance is ~80% when running Au^{32+} to Booster, and ~100% when running He^{2+}.

IV. CONCLUSION

An efficient ion extraction/injection low-energy beam line for RHIC EBIS has been built, tested and used during EBIS runs for NASA applications with different ion species.

V. REFERENCES

[1]J.G. Alessi, et.al., *Commissioning of the EBIS-based heavy ion preinjector at Brookhaven*, proceedings of Linac10, FR103, (2010) http://accelconf.web.cern.ch/AccelConf/LINAC2010/papers/fr103.pdf

[2]A. Pikin, J.G. Alessi, E.N. Beebe, A. Kponou, R. Lambiase, R. Lockey, D. Raparia, J. Ritter, L. Snydstrup, Y. Tan, *RHIC EBIS: basics of design and status of commissioning*, JINST 5, C09003 (2010) .

[3]J. G. Alessi et. al. *Performance of the new EBIS preinjector*, Proceedings of PAC-2011, WEP261 (2011)

[4]J. G. Alessi et. al., *The Brookhaven National Laboratory electron beam ion source for RHIC*, Rev. Sci. Instrum., 81, 02A509 (2010).

5E. N. Beebe et.al. *Test EBIS operation and component development for the RHIC EBIS*, Journal of Physics: Conf. Ser. 2 164 (2004).

6A. Pikin, J. Alessi, E. Beebe, A. Kponou, K. Prelec, G. Kuznetsov, M. Tiunov, *EBTS: design and experimental study*, Proceedings of 8-th International Symposium EBIS/T 2000, AIP Conference proceedings, 572, p. 3 (2001).

[7]A. Pikin, J. G. Alessi, E. N. Beebe, A. Kponou, and K. Prelec, *Experimental study of electron- and ion-beam properties on the BNL electron beam ion source and comparison with theoretical models*, Rev. Sci. Instrum., 77, 03A910 (2006).

[8]S. Kondrashev, J. G. Alessi, E. N. Beebe, C. Dickerson, P. N. Ostroumov, A. Pikin, G. Savard, *Measurements of charge state breading efficiency at BNL test EBIS*, Nuclear Instrum. Meth. A 642 (2011).