FIRST TEST OF THE CHARGE STATE BREEDER BRIC

V. Variale , V. Valentino, INFN sezione di Bari, Bari, Italy, A. Boggia, G. Brautti, T. Clauser, A. Rainò, Dipartimento di fisica Universita' di Bari e INFN sezione di Bari, Bari, Italy
P. Bak, Y. Boimelshtein, P. Logatchov, B. Skarbo, M. Tiunov, BINP, Novosibirsk

Abstract

The "charge state breeder" BRIC (BReeding Ion Charge) is based on an EBIS device and it is designed to accept Radioactive Ion Beam (RIB) with charge state +1, in a slow injection mode, to increase their charge state up to +n. BRIC has been developed at the INFN section of Bari (Italy) during these last 3 years. Now, it has been assembled at the LNL (Italy) where are in progress the first tests as stand alone source and where, for the end of the year, it will be tested as charge breeder at ISOL/TS facility of that laboratory.

BRIC could be considered as a solution for the charge state breeder of the SPES project under study also at the LNL.

The new feature of BRIC, with respect to the classical EBIS, is given by the insertion, in the ion drift chamber, of a RF - Quadrupole aiming to filtering the unwanted masses and then making a more efficient containment of the wanted ions. In this paper, the charge breeder BRIC first test will be reported and discussed.

INTRODUCTION

The physics with energetic Radioactive Ion Beams (RIB) represents one of the foremost frontiers in Nuclear Physics. For this reason, many laboratories in the world have start to project and build new facilities for the production of RIB accelerated up to several MeV/u (see for ex. ref. [1]). Among them can be mentioned the SPES project which is in an advanced phase of study at the Legnaro National Laboratory (LNL) (Padua, Italy) [1]. This kind of project is based on the ISOL technique. With this technique, two beam acceleration stages are used. The primary accelerator is intended to provide a proton, or a light ion, beam incident on a target to induce nuclear reactions. Then radioactive species will be produced inside. These radioactive elements need to be ionised for acceleration and then a secondary stage is intended to accelerate the radioactive ions at the desired energy before they reach the experimental area. Since the cost of an accelerator is roughly related to the inverse of the charge state of the beam to be accelerated, a higher ion charge state beam can allow a sensitive lowering of the accelerator cost. This problem can be solved by using, before the post-acceleration of RIB, an appropriate device capable of increase the charge ion state of the radioactive element that must be accelerated. In the framework of the LNL SPES project, our INFN group, in Bari, has been involved in the development and testing of a "*charge state breeder*" device based on an EBIS source type: BRIC. The BRIC features have been presented in a detailed way in ref. [2,3]. The main feature of BRIC is the using of a RF quadrupolar field to obtain a selective containment of the wonted ions. In this way, a more efficient high charge state ion production could be reached. The BRIC device, before to be used as charge breeder, will be tested as stand alone high charge ion source to verify this idea and then study the radio frequency effects in the ion production. In this paper, the test of the selective containment of the BRIC as high charge state ion source will be presented and discussed.

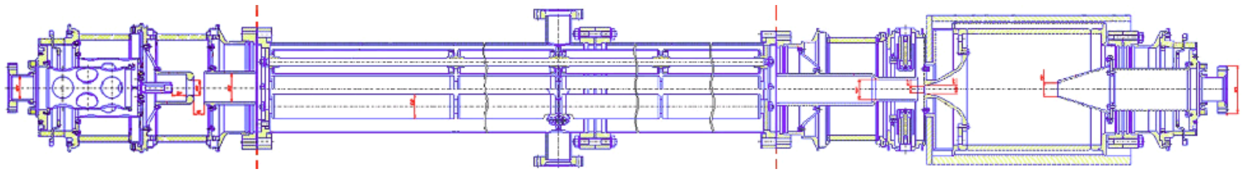
THE CHARGE BREEDER BRIC

As mentioned before, the detailed design of the device has been already presented in ref. [2,3]. However, for sake of clarity, a shortly description of the device here will be done to recall its main features. As can be seen from fig.1, the BRIC experimental set up is practically the same of a classical Electron Beam Ion Source (EBIS). In fact, in that figure, as in an usual EBIS, the electron gun, the ion drift chamber and the typical electron collector with the hole for the ion extraction are shown.

The main difference between BRIC and a usual EBIS can be observed from the inside of the ion drift chamber of the fig.1. In that chamber, RF electrodes of cylindrical shape, placed around the symmetry axis in such a way to form a quadrupolar RF field, are shown. This RF field, which is added to the electron beam space charge potential, can give the above mentioned transverse selective containment to the wonted ions. Furthermore, the same cylindrical shaped RF electrodes are used to create the longitudinal trap for the ions before they could be extracted for the acceleration.

As electron beam focusing system two short solenoids made of special coils are used. They are suitable to be mounted together in such a way to form a solenoid [4]. These coils have been designed and built by the BINP institute of Novosibirsk. The construction of these coils has finished at the end of the last year with a very big delay with respect to our experiment schedule. Meanwhile, however, few home made coils have been built to test all the system (e-gun, collector and ion trap) at low power [3]. Furthermore, a TOF system to study the ion charge state of the extracted ion beam, for different RF parameter, has been designed and built [4]. The home made coils have been also used to test the TOF system. For this test the vacuum measured was 3.5 x 10-8 Torr, the electron beam current, used to produce ions, measured on the collector was 13 mA (practically all the electron current has been recovered at the collector). The ion pulse measured at the end of the TOF is shown in fig. 2.

0-7803-7739-9



|--------- E-gun -------------|------ Ion drift chamber with rf electrodes ------|----------- Collector --------------------------|

Figure1: BRIC mechanical design without electron focusing solenoid.

From that figure it can be seen that the extracted ion pulse length is of about 350 µs and the signal amplitude, of 3 V, correspond to an ion current of 3 µA. Since the charge contained in our trap for this test can be evaluated as about 1 nC ($\Delta Q=I_e\Delta l/v_e$ where Δl=0.8m is the trap length) and the area inside the pulse signal (in 2a)) gives a higher charge value, the reason why an extra charge has been measured needed to be explained. In order to clarify this effect, the width of the voltage extraction pulse has been increased, as shown in fig. 2b) (yellow line). From that figure, it can be seen that the ion pulse, extracted from the source, was composed by two signals, as shown by the dashed lines. The first signal is given by the ion pulse trapped in the source and then released when the trap potential is down and this pulse must have total charge less then the trap capacity (1 nC). The latter is given by the starting of new ionisations after the pulse has been extracted and the extracted voltage level remains down allowing also to the new ions to go towards the TOF system.

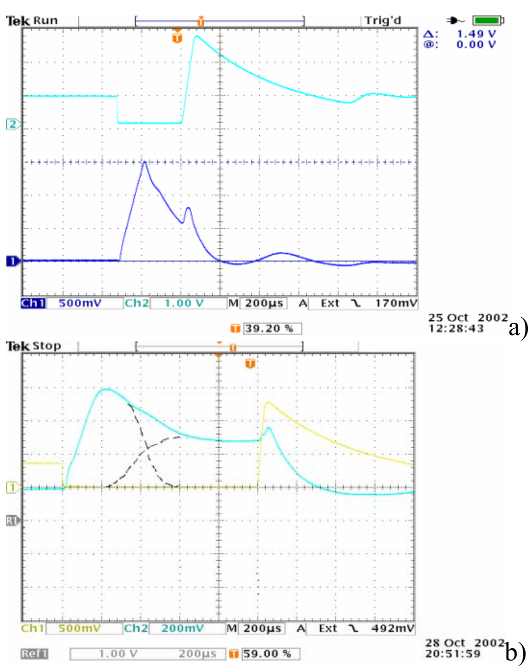


Figure 2: ion pulse measured on the FC at the end of the TOF system. a) cyan line is the voltage pulse for ion extraction with V_{ex}=-80 V and τ_{ex}=320 µs and blue line indicates the ion pulse. b) yellow line: pulse voltage with V_{ex}=-80 V and τ_{ex}=1 ms, cyan line indicates the ion beam pulse.

Notice that this signal after a while reach a saturation, given by the ionisation rate, and then it remains at constant value up to the closing of the trap.

In these last months, after the arrival of the coils for the solenoid from Novosibirsk, it is started the test of the source at nominal power, which is with an electron current of I_e=0.5A and a kinetic energy of E_k=5 keV. Since, for this test, a solenoid magnetic field of 1.6 kG will be used a water cooling system has been prepared at LNL where the test is underway. All the coils have been mounted together to form the solenoids and then aligned as shown in fig.3 where the system to measure the axial magnetic field is also exposed. The solenoid has been aligned in the vertical plane by tilting the single coils around the vertical axis by acting on the special wings placed on the coil sides (see fig.3) in such a way to minimize the transverse magnetic field read on the 3D Hall probe.

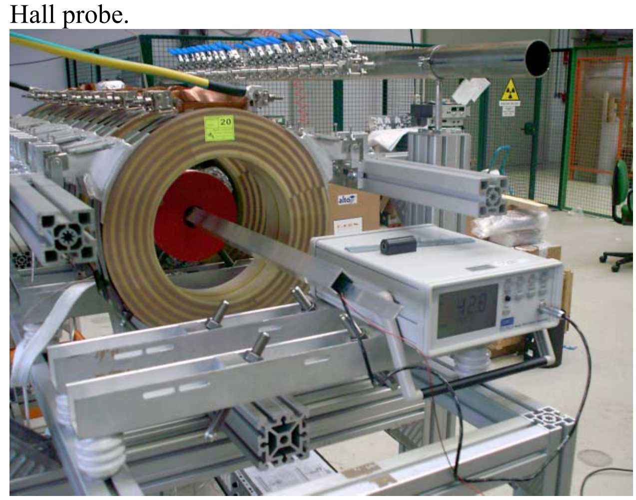


Figure 3: Coils mounted on BRIC to form the suitable solenoid for electron beam focusing. The axial magnetic field measurement system for the coils alignment is also shown.

The magnetic field precision reached with this system has been of about 5×10^{-4}. furthermore, although the water cooling system was still not ready during the magnetic measurement, we measured the maximum axial magnetic field reachable with our solenoid and obtained a value of about 1.2 kG. However, we hope that when the coils water cooling will be operating (at the beginning of May) B_{max} will reach 1.6 kG as foreseen. In conclusion, for the end of the month of May, the first test measurement at nominal power to produce ions of Ar with high charge states, taking into account the effect of the RF quadrupole containment, will start.

TEST AS HIGH CHARGE STATE ION SOURCE

To find out what are the RF parameters that give stable motion condition for the wanted ions with the aim of improve the containment efficiency a code package, called BRIC-code, have been developed [5]. As described in the ref. [5], once fixed the element of interest, one of the codes can be used to find the stability region in the plane (*q,a*).

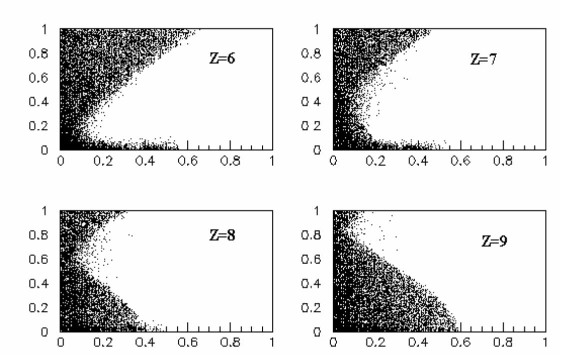


Figure 4: Stability zones (dotted regions) for different charge states of Ar ions in the plane (*q,a*).

The parameter *q* and *a* are typically used in the theory of the RF quadrupole spectrometry and are defined as:

$$a = a_x = -a_y = \frac{4eU}{m\varpi^2 r_0^2}$$

$$q = q_x = -q_y = \frac{2eV}{m\varpi^2 r_0^2}$$

here ω is the RF signal used and V its amplitude, U is the DC component, r_0 is the distance from the axis to the RF electrodes and *e/m* is the charge over mass ratio of the element considered. The simulation results of figure 4 show stable regions for different charge states Z of Ar.

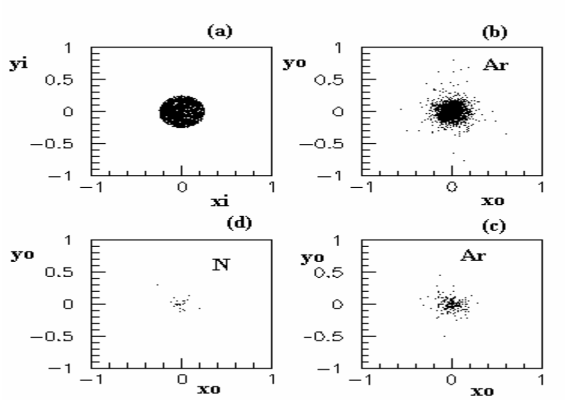


Figure 5: Ion beam spots of (a) initial conditions, (b) final results for Ar with stable value of (q,a) at Ar^{+8}, (d) final results for Ar with instable point, (c) final results for N with the same (q,a) of (b) case.

From the ion charge state evolution during the electron beam bombardment (see for ex.[6]), it can be seen that the charge state distribution of one element has, at a certain confinement time ,τ_c, the simultaneous presence of very different charge state ions. However, for a value of $j_e\tau_c$ of about 2 the main fraction of charge state of Ar are Z=7, Z=8, Z=9. By looking at the stable regions in the plane (*q,a*) shown in figure 4, a working point, stable for the ions Ar^{+8} and instable for the other charge state ions, can be chosen. In our case, the point (0.3,0.2) has been chosen as RF parameters for the simulations of the Ar ion motion in BRIC. In the code that simulates that motion it is also taken into account Ar ion charge state evolution and the space charge compensation [5]. The results shown in fig. 5 (b) show the beam spot of the Ar ions after a $j_e\tau_c$ of about 2 corresponding at a charge state distribution with a maximum pick for Ar^{+8}[6]. In the fig. 5 (c) it is shown also a beam spot of the N (typical residual gas element) ions after the same value $j_e\tau_c$. Notice that from the simulation results shown in fig. 5, it seems that, for the chosen stable point, a large fraction of the initial Ar ions is preserved only in the case (b). The residual gas elements, as N, are expelled as seen in 5(c). In fig. 5(d) it is shown the case of Ar ions but for a working point, (*q,a*) = (0.6,0.4), which is external to all the stability regions shown in fig. 4. In that case a very small fraction of Ar ions remain stable up to the end of simulation.

In conclusion we can say that the simulation results seem to confirm the hypothesis of a selective containment effect. However, the simulation codes make several approximations [5] and then an experimental test is needed to be sure of this effect. That experiment is underway at LNL (PD, Italy).

REFERENCES

[1] SPES Project study, LNL-INFN (REP), 145/99.

[2] G. Brautti et al.,'BRIC: An EBIS design for charge state Breeding in RIB', EBIS/T 2000, Upton, New York.

[3] V. Variale, G. Brautti, T. Clauser, A. Rainò, V. Stagno, G. La manna, V. Valentino, A. Boggia, Y. Boilmelshtein, P. Logatchov, B. Skarbo and M. Tiunov, " An EBIS for charge state breeding in the SPES project", PRAMANA- journal of physics, Vol. 59 (2002) 765.

[4] V. Variale et al. "The Charge State Breeder BRIC: Status Report", Conference Proceedings of LINAC2002, Gyeongju August 2002, Sud Korea.

[5] V. Variale et al., 'BRICTEST: A Code For charge Breeding Simulations', EPAC2002, Paris, June2002.

[6] Handbook of ION SOURCES, ed. B. Wolf, CRC Press, (1995) 12.