ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

Struttura
BARI

Ricercatore responsabile locale: Stagno Vincenzo

Rappresentante Nazionale: Vincenzo Stagno

Struttura di appartenenza: BARI

Posizione nell'I.N.F.N.: Incar. di Ric.

INFORMAZIONI GENERALI

Linea di ricerca	Tecnologie degli acceleratori
Laboratorio ove si raccolgono i dati	Bari, Legnaro
Sigla dello esperimento assegnata dal Laboratorio	
Acceleratore usato	CN a Legnaro
Fascio (sigla e caratteristiche)	d 7 Mev 3 microA
Processo fisico studiato	Generatore di alto stato di carica ("charge breeder") per ioni radioattivi, con quadrupolo RF
Apparato strumentale utilizzato	
Sezioni partecipanti all'esperimento	BARI
Istituzioni esterne all'Ente partecipanti	
Durata esperimento	2 anni

Mod. EC. 1

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

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PREVENTIVO LOCALE DI SPESA PER L'ANNO 2001

In ML

VOCI DI SPESA		DESCRIZIONE DELLA SPESA	IMPORTI Parziali	IMPORTI Totale Compet.	A cura della Comm.ne Scientifica Nazionale
Viaggi e missioni	Interno	LNL e contatti ditte. Trasferimento apprecchiature ai LNL (2 settimane x 5 ric x 1.5 Ml) Partecipazione congressi Nazionali	3 15 3	**21**	
	Estero	Contratti gruppo europeo sorgenti EBIS EURISOL (Ganil) Rex-Isolde al CERN - Congr. intern. (PAC) Contatti con BINP di Novosibirsk	 12 5	**17**	
Materiale Consumo		Componenti meccanici, elettrici e materiale da vuoto Passanti isolanti - Piattaforma di isolamento - Gas	 20	**20**	
Trasp.e facch.		trasporto apparecchiature ai LNL	3	**3**	
Spese Calcolo		Consorzio / Ore CPU / Spazio Disco / Cassette / Altro			
Affitti e manutenz. apparecchiat.					
Materiale Inventariabile		Valvola tutto metallo CF35 Pompa di prevuoto turbo "oil free" (RIAL) Trasformatore isolato a 20 KV 220/220 V 500 W	3 15 3	**21**	
Costruzione Apparati		Solenoidi (2x50 cm) per contenimento del fascio Sistema TOF per diagnostica (vedi allegato Mod. EC 2)	50 155	**205**	
			Totale	**287**	

Note:

Mod. EC. 2 (a cura del responsabile locale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

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BARI

ALLEGATO MODELLO EC 2

COSTRUZIONE APPARATI:

Il costo dello spettrometro a tempo di volo, di ML 155, concordato con un fornitore comprende:
- progettazione del sistema (con la partecipazione del gruppo proponente) e sua realizzazione: 100 Ml;
- rivelatore a multichannel plate: 10 Ml;
- elettronica di acquisizione utilizzante un Turbo Multichannel Scaler della EG & G - Mod. T914: 25 Ml;
- alimentazioni: 20 Ml.

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

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PREVISIONE DI SPESA: PIANO FINANZIARIO LOCALE

PER GLI ANNI DELLA DURATA DEL PROGETTO

In ML

ANNI FINANZIARI	Miss. interno	Miss. estero	Mater. di cons.	Trasp.e Facch.	Spese Calcolo	Affitti e manut. appar.	Mat. inventar.	Costruz. apparati	TOTALE Competenza
2001	21	17	20	3			21	205	**287**
TOTALI	**21**	**17**	**20**	**3**			**21**	**205**	**287**

Note:

Osservazioni del Direttore della Struttura in merito alla disponibilità di personale e di attrezzature:

Nessuna annotazione

Mod. EC. 3

(a cura del responsabile locale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

Struttura
BARI

PREVENTIVO GLOBALE PER L'ANNO 2001

In ML

Struttura	A CARICO DELL' I.N.F.N.									A carico di altri Enti
	Miss. interno	Miss. estero	Mater. di cons.	Trasp. e Facch.	Spese Calc.	Affitti e Manut. Appar.	Mater. inventar.	Costruz. appar.	TOTALE Compet.	
BARI	21	17	20	3			21	205	**287**	**0**
TOTALI	**21**	**17**	**20**	**3**			**21**	**205**	**287**	**0**

NB. La colonna A carico di altri Enti deve essere compilata obbligatoriamente

Note:

Mod. EC. 4

(a cura del rappresentante nazionale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

Struttura
BARI

A) ATTIVITA' SVOLTA NELL'ANNO 2000

Vedere Allegato 1

B) ATTIVITA' PREVISTA PER L'ANNO 2001

Vedere report allegato 2

C) FINANZIAMENTI GLOBALI AVUTI NEGLI ANNI PRECEDENTI

In ML

Anno Finanziario	Missioni interno	Missioni estero	Materiale di consumo	Trasp. e Facch.	Spese Calcolo	Affitti e Manut. Apparec.	Materiale inventar.	Costruz. apparati	TOTALE
2000	4	4	10					100	**118**
TOTALE	**4**	**4**	**10**					**100**	**118**

Mod. EC. 5

(a cura del rappresentante nazionale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

Struttura
BARI

PREVISIONE DI SPESA

Piano finanziario globale di spesa

In ML

ANNI FINANZIARI	Miss. interno	Miss. estero	Materiale di cons.	Trasp.e Facch.	Spese Calcolo	Affitti e manut. appar.	Mat. inventar.	Costruz. apparati	TOTALE Competenza
2001	21	17	20	3			21	205	**287**
TOTALI	**21**	**17**	**20**	**3**			**21**	**205**	**287**

Note:

Mod. EC. 6

(a cura del rappresentante nazionale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

Struttura
BARI

COMPOSIZIONE DEL GRUPPO DI RICERCA

N	RICERCATORI Cognome e Nome	Qualifica Dipendenti Ruolo	Art. 23	Incarichi Ricerca	Assoc.	Affer. al Gruppo	Percentuale
1	Brautti Giulio			P.O.		5	30
2	Clauser Tarcisio			P.A.		5	80
3	Raino' Antonio			P.A.		5	70
4	Stagno Vincenzo			R.U.		5	80

Numero totale dei Ricercatori **4,0**

Ricercatori Full Time Equivalent **2,6**

N	TECNOLOGI Cognome e Nome	Qualifica Dipendenti Ruolo	Art. 23	Incarichi Ass. Tecnol.	Percentuale
1	Variale Vincenzo	Tecn			50

Numero totale dei Tecnologi **1,0**

Tecnologi Full Time Equivalent **0,5**

N	TECNICI Cognome e Nome	Qualifica Dipendenti Ruolo	Art. 15	Incarichi Collab. tecnica	Assoc. tecnica	Percentuale
1	Boggia Antonio			Univ		50
2	Valentino Vincenzo	Cter				60

Numero totale dei Tecnici **2,0**

Tecnici Full Time Equivalent **1,1**

Mod. EC/EN 7

(a cura del responsabile locale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

Struttura
BARI

COMPOSIZIONE DEL GRUPPO DI RICERCA (cont.)

LAUREANDI Cognome e Nome	Associazione SI	Associazione NO	Titolo della Tesi
Morea Annarita Relatore A. Rainò	O SI	◉ NO	Trasporto di un fascio di elettroni in una sorgente di ioni intrappolati
Relatore	O SI	O NO	
Relatore	O SI	O NO	
Relatore	O SI	O NO	
Relatore	O SI	O NO	
Relatore	O SI	O NO	
Relatore	O SI	O NO	
Relatore	O SI	O NO	

SERVIZI TECNICI

	Denominazione	mesi-uomo
1	Elettronica	1
2	Officina Meccanica	3

Annotazioni

INTERAZIONI CON LE INDUSTRIE (COMMESSE HIGH TECH)

DENOMINAZIONE	DESCRIZIONE PRODOTTO O COMMESSA

Mod. EC/EN 7a

(a cura del responsabile locale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

Struttura
BARI

REFEREES DEL PROGETTO

Cognome e Nome	Argomento
Vaccaro Vittorio	
Gammino Santo	

MILESTONES PROPOSTE PER IL 2001

Data completamento	Descrizione
Giugno 2001	assemblaggio apparato
Dicembre 2001	test del sistema come sorgente di ioni

COMPETITIVITA' INTERNAZIONALE

LEADERSHIPS NEL PROGETTO

Cognome e Nome	Funzioni svolte

Mod. EC/EN 8

(a cura del responsabile nazionale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

Struttura
BARI

Consuntivo anno 1999/2000

LAUREATI

Cognome e Nome	Titolo della Tesi	Sbocco professionale
Laurea in		
Laurea in		
Laurea in		
Laurea in		
Laurea in		

DOTTORI di RICERCA

Dott in		
Dott in		
Dott in		
Dott in		

PRESENTAZIONI A CONFERENZE SU INVITO E SEMINARI SIGNIFICATIVI

Relatore	Titolo	Conferenza o luogo
V. Variale	BRIC Project	TWIST II: GANIL - CAEN

(a cura del responsabile locale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

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BARI

Consuntivo anno 1999/2000

SIGNIFICATIVE VARIAZIONI DI BILANCIO

Capitolo	Variazione (ML)	Motivazione
Missioni Interne		
Missioni Estere		
Consumo		
Traporti e Facchinaggio		
Spese Calcolo		
Affitti e Manutenzioni		
Materiale Inventariabile		
Costruzione Apparati		
Totale storni		

CONFERENZE, WORKSHOP e SCUOLE ORGANIZZATE in ITALIA

Data	Titolo	Luogo

SIGNIFICATIVE COMMESSE E RELATIVO IMPORTO

ANAGRAFICA FORNITORE	DESCRIZIONE PRODOTTO O COMMESSA	IMPORTO (ML)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

Struttura
BARI

Consuntivo anno 1999/2000

MILESTONES RAGGIUNTE

Data completamento	Descrizione
Settembre 2000	costruzione e test: e-gun + collettore
Dicembre 2000	costruzione camera di ionizzazione

Commento al conseguimento delle milestones

Le milestones sono state ritardate perchè, a causa del sub-judice, il finanziamento dell'apparato é stato ottenuto in ritardo e quindi gli ordini sono partiti in ritardo.

SVILUPPO DI STRUMENTAZIONE INNOVATIVA

Ricadute su altri gruppi, sul sistema industriale e su altre discipline

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
1277	BRIC	5

Struttura
BARI

Elenco delle pubblicazioni anno 1999/2000

Mod. EC 11a (a cura del responsabile nazionale)

Esperimento BRIC
Attivita' svolta nel periodo gennaio - giugno 2000

Durante i primi sei mesi del 2000 l' attivita' di BRIC si e' svolta nelle due direzioni:

- Disegno e progettazione dell'apparato: è stato definito completamente il disegno di progetto dell'intero apparato: sorgente di elettroni (Pierce gun da 1.0 ampere con catodo 'reserve' con Φ = 10 mm); camera di deriva degli ioni con quadrupolo RF (L = 110 cm, Φ = 150 mm) completamente immersa in due solenoidi (L = 50 cm) separati tra loro di d = 10 cm; collettore degli elettroni monostadio con quadrupolo elettrostatico di focheggiamento per gli ioni al foro di ingresso/uscita praticato sulla parete di fondo del collettore. Tutte le varie componenti sono anche state ordinate al Budker Institute of Nuclear Physics (BINP) di Novosibirsk, escusi i due solenoidi.

- Simulazione numerica della dinamica del fascio di elettroni e di quello degli ioni: la propagazione del fascio di elettroni dal catodo al collettore di raccolta attraverso tutto il breeder è stato simulato con il noto codice: EGUN,. Tale codice prende in considerazione anche la carica spaziale, ma non e' possibile valutare l' azione del campo del quadrupolo RF. Tale valutazione e' pero' stata fatta con il nostro codice, BRICTEST, appositamente sviluppato e di cui si parlera' piu' diffusamente in seguito. La simulazione della dinamica degli ioni nel quadrupolo RF è stata fatta acquisendo il noto codice SIMION. Con tale codice e' stato anche possibile introdurre il campo magnetico longitudinale dei solenoidi dimostrandone l' effetto destabilizzante in combinazione con il campo quadrupolare. Ma SIMION non tiene in conto della carica spaziale del fascio di elettroni. Il codice da noi sviluppato invece, BRICTEST assicura la valutazione contemporanea dell'effetto del campo quadrupolare, del campo magnetico longitudinale e della carica spaziale degli elettroni. Con tale codice e' stato possibile dimostrare la stabilità del fascio di elettroni nel quadrupolo RF (impossibile con EGUN).
  Il risultato piu' interessante di queste prime simulazioni con BRICTEST , ci sembra di poter affermare che sia stato quello della conferma dell'azione di filtro di massa esercitata dal quadrupolo RF. Variando infatti opportunamente i valori della componente DC e di quella AC della RadioFrequenza, e' possibile selezionare uno stretto range di masse con dato stato di carica che risultano stabili e quindi possono essere estratte dal breeder, mentre le altre sono eliminate. L' azione di filtro risulta potenziata a stati di carica maggiori (*).

(*) Report BRIC, allegato

The BRIC Experiment: Project Study and Simulations

G. Brautti, T. Clauser, A. Rainò, V. Stagno,
Dipartimento di Fisica dell'Università and INFN - Sezione di Bari, Italy
V. Variale,
Istituto Nazionale di Fisica Nucleare (INFN) - Sezione di Bari, Italy
P. Logatchov,
Bunker Institute of Nuclear Physics (BINP), Novosibirsk, Russia

Abstract

This work deals with the "charge state breeder" that will be tested at INFN Laboratory of Bari (Italy). The breeder, based on the Electron Beam Ion Source (EBIS) scheme, is designed for applications in Radioactive Ion Beam (RIB) production facilities based on the Isotope Separation On-Line (ISOL) method in the framework of the SPES project of the INFN LNL laboratory (Legnaro). Some improvements with respect to the classical EBIS have been foreseen and numerically simulated. The insertion in the ion chamber of a RF - Quadrupole , aiming to filtering the unwanted masses, is the most relevant change with respect to the classical EBIS. The breeder design and numerical simulation results of the electron and ion beam propagation are reported.

1 INTRODUCTION

The SPES Project at the LNL-INFN of Legnaro (Padua) [1] aims to assembling an advanced facility for Radioactive Ion Beam (RIB) production based on the Isotope Separation On-Line (ISOL) method. In the framework of the SPES project, our INFN group in Bari is involved in the development and testing of a "*charge state breeder*" of the EBIS (Electron Beam Ion Source) type: BRIC. The accelerated radioactive atoms will have probably a mass lying in the range 80-200 a.m.u. A facility of this type, has two acceleration stages (see Fig. 1).

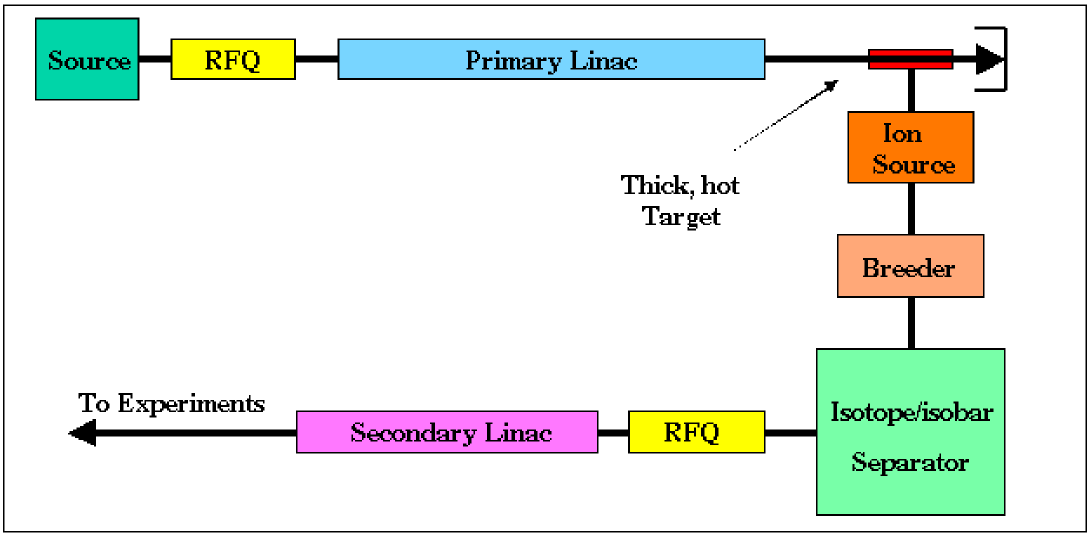


Fig. 1: ISOL-Facility Scheme

The primary accelerator is intended to provide the ion beam incident on the target. The produced radioactive species have to be ionized, elevated in charge state and mass separated. The secondary stage is intended to accelerate the radioactive ions at the desired energy before they reach the experimental area. After the production, the radioactive species enter the ion source to be ionised. Then the singly charged ion beam is injected into a charge state breeder device to enhance the ion charge state at high level. This allows to increase the total efficiency of the beam transmission and to lower the cost of the secondary accelerator. For efficient acceleration by compact LINAC's, charge over mass ratios greater than 1/10 are required and a value between 1/9 and 1/4 seems to be a good choice [2]. At the present state of art, other than the usual stripping tecnique, two sources type seems useful for charge state breeding: the Electron Cyclotron Resonance Ion Source (ECRIS) and the Electron Beam Ion Source (EBIS). A comparison between the performances of this two ion sources have been reported by several authors (see for example [2,3]).

In an EBIS source, the ion charge state enhancement is obtained through the interaction with an external electron beam. In a typical scheme of the source the electron gun, the ion chamber and the collector are coaxial and the ions are injected and extracted from the same side of the set up. The injected ions are trapped in a longitudinal potential well where they remain until the extraction. Two injection mode for the ion beam have been considered up to now [2]:

- fast injection mode:
  where the ions are decelerated before the injection, enter the breeder through the collector and are finally trapped by raising the potential barrier on the collector side. The ions must be injected in a pulse whose length has to be shorter than the round trip time in the potential well.

- slow injection mode:
  where the ions have an energy higher than the potential barrier on the collector side and enter continuously the chamber during the confinement time. They reach a higher charge state during one round trip time and then remain trapped in the confinement area.

For the fast injection mode the continuous ion beam must be pre-bunched, so a trap for accumulation, cooling and bunching is requested (as in REX-ISOLDE (CERN)). However the number of particles that can be accumulated in a Penning source is limited. On the contrary for the slow injection or accu-EBIS mode no trap is required, but the electron space charge force can be directly to transverse contain the ions during the charge state breeding. The number of ions that can be contained in an EBIS depends on the electron beam current I_e and energy U_e, on the confinement length ℓ and on the reachable fraction of space charge compensation k which is ˜ 50%. This number is given by:

(1)
$$N_q^+ \leq k \sqrt{\frac{m_e}{2e^3}} \frac{\ell}{q} \frac{I_e}{\sqrt{U_e}}$$

2 BRIC EXPERIMENT

2.1 Set-Up Assembly

The BRIC experimental set up is, in the test assembling, the same as the classical one just described before in the introduction. The general scheme of the breeder is shown in Fig. 2.

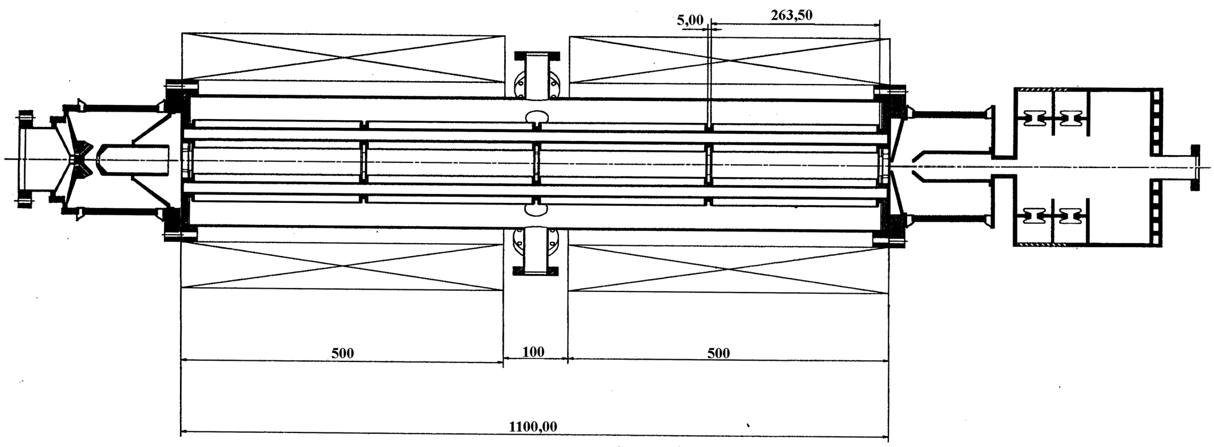


Fig. 2: BRIC Set-Up Assembly

In this configuration, the input and the output of the radioactive ions are on the same side of the device: the hole aperture on the right side of the collector. In this way, the alignment of the electron gun and the electron beam collector with the ion drift chamber results in a more compact device and can aids to reduce same geometrical problems.

This choice cannot be the better choice from the point of view of the whole ISOL facility line and different breeder configurations are in order for the future studies. A possible new assembling where the electron gun and collector axis will have an angle with respect to the ion chamber axis is shown in Fig. 3.

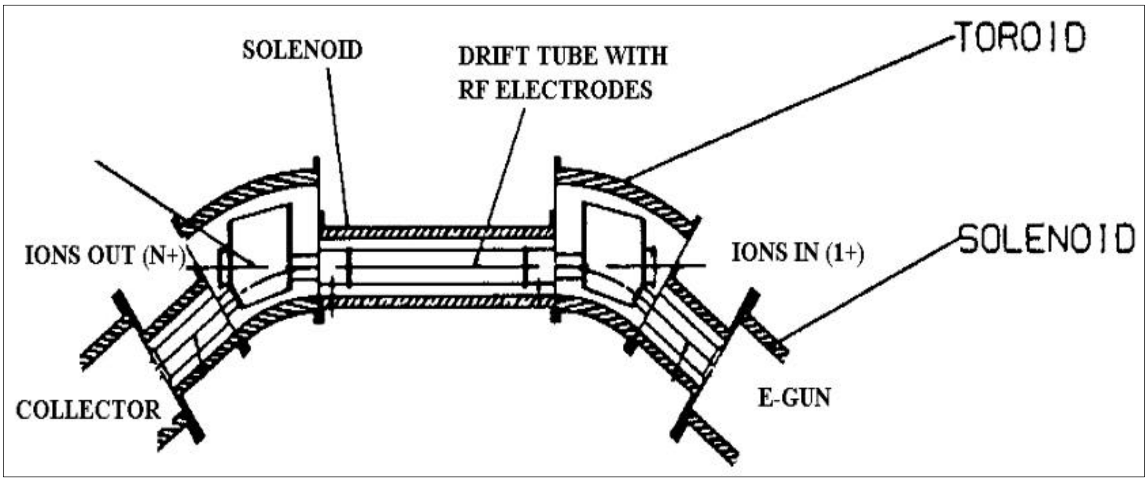


Fig. 3: A possible future BRIC configuration

This configuration, just adopted in the our pioneer experiment TIS (Trapped Ion Source) [3], has the advantage to inject and extract the ions on the opposite sides of the breeder by leaving the radioactive ion drift axis unchanged.

2.2 Electron Gun and Collector

The BRIC electron gun (Fig. 4) has been chosen having in mind the device major commercial qualities together with the minor cost. So a classical Pierce gun supporting a dispenser cathode with Æ ˜ 10 mm providing a current up to 1.5 A has been selected.

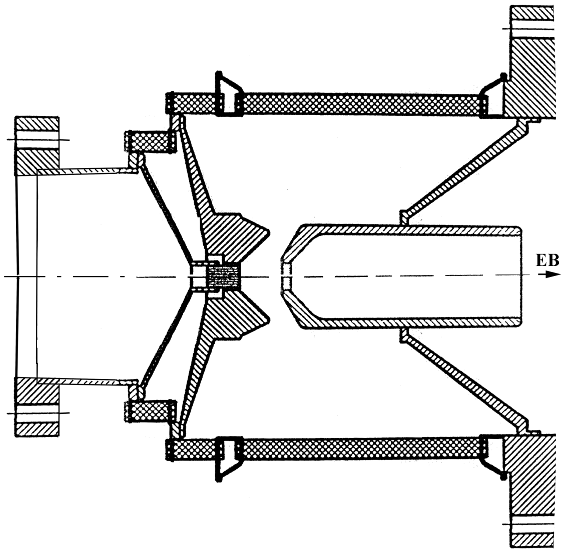


Fig. 4: Electron Gun

The beam can be focused and modulated by controlling the voltage of the Pierce electrode. The output energy can be raised up to 10 keV. The transverse dimensions of the beam are reduced to about 4 mm by the increasing magnetic field of the solenoid on the ion chamber. Actually the gun will be placed at the inflexion point of the solenoid magnetic field (semi-immersed flow configuration). These dimensions are maintained throughout the ion drift chamber by neglecting the whole beam oscillations (beam scallop).

The collector (Fig. 5) allocates two static quadrupoles to focus the ions at the exit hole.

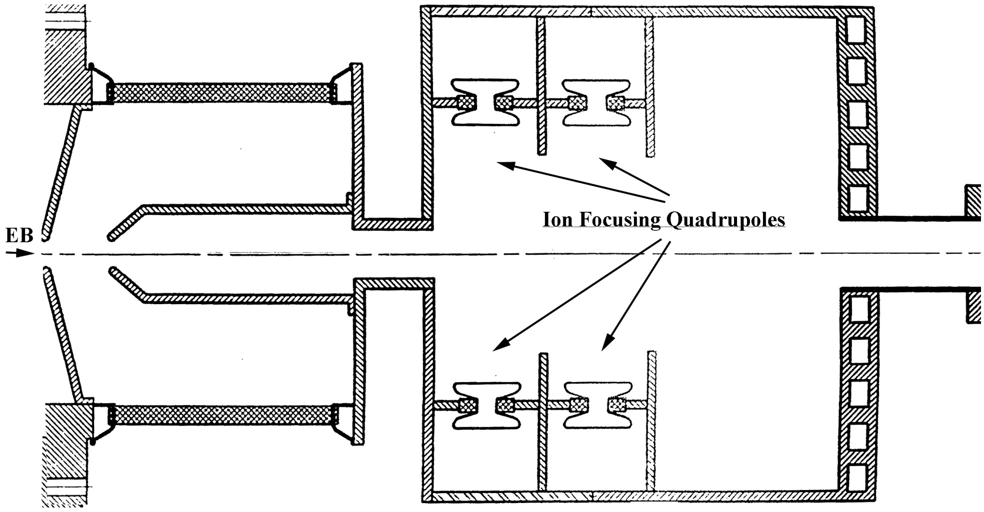


Fig. 5: Electron Collector

The tail of the solenoid field have to be cut on the collector zone in order to increase the efficiency of the electron beam collection and to avoid the electrons to come back towards the ion chamber and towards the gun. The static quadrupoles aid to focus the ions at the exit hole.

2.3 The Ion Chamber

The ion chamber (Fig. 6) has been designed to allocate the drift tubes, the barrier electrodes for the longitudinal ion trapping and the RF-Quadrupole. All the feed troughs for DC voltage and RF power supply, diagnostics and so on, have been inserted in the central zone of the chamber.

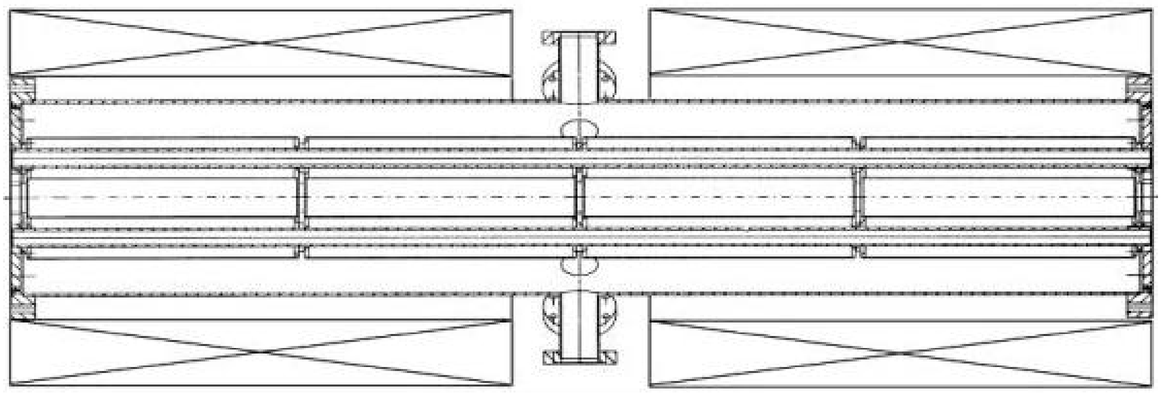


Fig. 6: Ion Chamber

The overall chamber (110 cm length) is immersed in the longitudinal magnetic field of two solenoid (50 cm long, 10 cm apart). The current in the windings has been chosen to reach a maximum field on the axis of ˜ 2 kGauss. The magnetic field is important to ensure the highest possible electron beam current density J thus reducing the ion-beam containment time τ_c to reach the required charge state; so a much higher magnetic field intensity should be required (around 1 T). However this can be obtained with corresponding major cooling problems and cost. The chosen field value on the axis permits to reduce the beam diameter to ˜ 4 mm and to reach (with the maximum of the electron beam current of 1.5 A) a value of J ˜ 10 A/cm^2.

BRIC Charge Breeding Parameters:

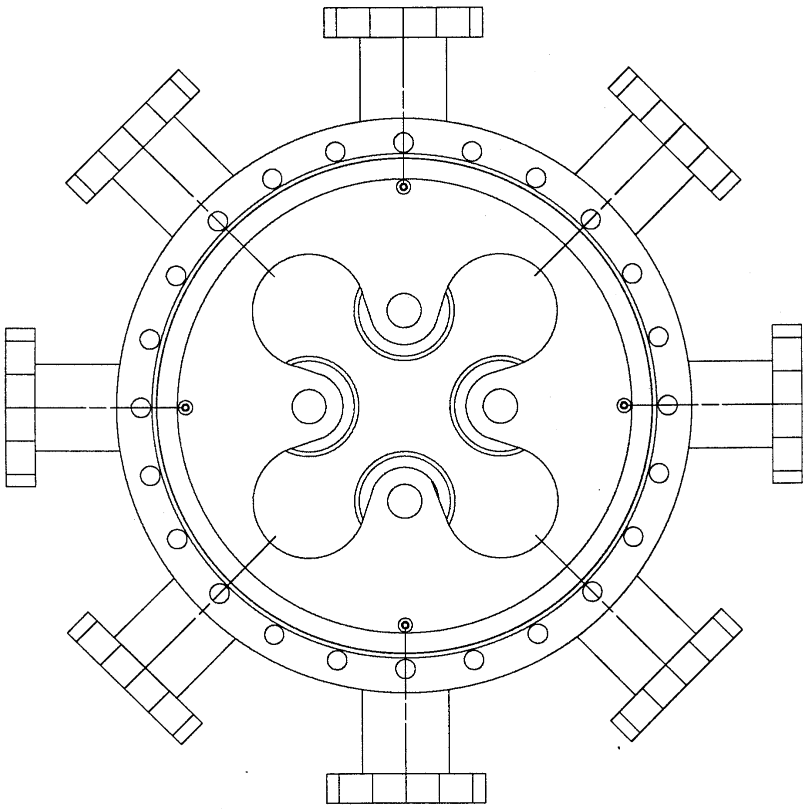
Following the SPES project requirements, if an ion mass of about 100 a.m.u. and a charge state of 10 (charge over mass ratio = 1/10) is considered, from the condition [4]:

$$J \cdot \tau_c \sim 3 \div 4 \ [A \cdot sec/cm^2]$$

the resulting containment time τ_c , for electron beam current density J of the order of tens A/ cm^2, is in the range: 100 ÷ 300 msec.

2.4 The RF- Quadrupole

The Fig. 7 reports the transverse section of the BRIC ion chamber together with the RF-Quadrupole. The design parameters have been chosen accordingly to the parameter $\eta = r/r_o$ where r is the cylinder radius and r_o is the distance of the cylinder from the axis). Currently the value of the η parameter is fixed as the "magic number" η = 1.145. However the best approximation has been recently demonstrated to be η = 1.1 [5]. So we designed our quadrupole with this last assumption.



3 TRANSVERSE PARTICLE DYNAMICS IN THE RF QUADRUPOLE

3.1 Pure RF Quadrupole

The theory of the RF Quadrupole has been completely developed (see for example [6,7]). Here only some important results are reported. In general the electrode applied signal has two components: a DC component U, sometime called equalizing voltage, and a RF component V. The particle motion equations, can be expressed, in both the transverse coordinate planes, through two Mathieu equations:

$$\begin{cases} \dfrac{d^2x}{d\tau^2} + \left(a_x - 2q_x \cos 2(\tau - \tau_o)\right)x = 0 \\ \dfrac{d^2y}{d\tau^2} - \left(a_y - 2q_y \cos 2(\tau - \tau_o)\right)y = 0 \end{cases} \tag{2}$$

where: $\tau = \frac{1}{2}\omega t$; $a_x = a_y = \dfrac{4q_i U}{m_i \omega^2 r_o^2}$; $q_x = q_y = \dfrac{2 q_i V}{m_i \omega^2 r_o^2}$;

Here q_i and m_i are the ion charge and mass respectively, r_o is the quadrupole bore radius, ω is RF angular frequency and τ_o is the initial phase of the RF with respect to the particle. It can be shown that the maximum displacement of the particle does not depend on the initial coordinates and velocity but on the phase τ_o. The theoretical results on the Mathieu equations show that the motion is stable only when the coefficients a_x and q_x are chosen within same "stability regions" for both the transverse planes. In the mass filter theory the stability region of interest is restricted to a small quasi-triangular zone in the positive (a, q) plane. Owing to the symmetry around both axes x an y, often only the positive (a, q) quadrant of the stability diagram of base q ˜ 0 ÷ 0.9 and vertex: a = 0.2334, q = 0.706 is considered, as shown in Fig. 8. The major filtering is obtained for values of a near the vertex a_o = 0.2334 corresponding to q_o = 0.706. The ratio: u = a / q = 2U/V is only dependent on the DC and AC components of the Radio-Frequency. For a fixed charge state, the points corresponding to the given masses are all on the working line corresponding to the chosen U and V RF components. The intersection of this line with the stability region determines the stable masse range. The slope of the line, and consequently the range of the stable masses, can be changed by varying the value of U and V.

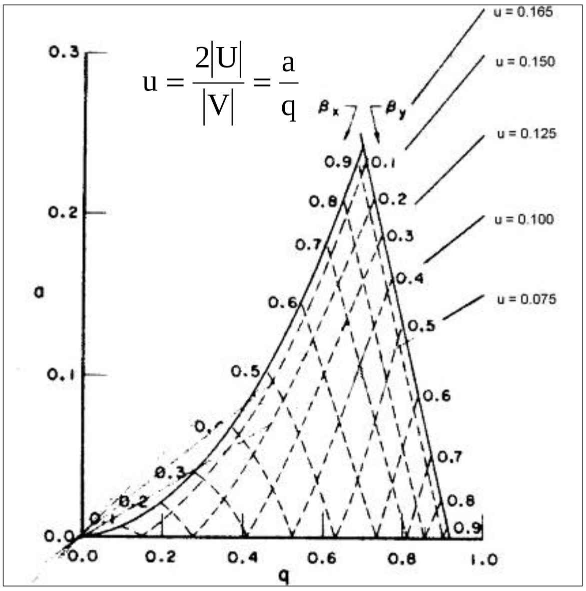


Fig. 8: Mathieu first stability zone

3.2 Solenoid Magnetic Field and Electron Beam Space Charge Effects

When the longitudinal field of the solenoid and the electron beam space charge force are taken into account, the stability diagram is quite modified. Namely the new equations of the ion motion in the plane (x, y) depend also on two other coefficients accounting for the magnetic field and the electron beam space charge. A simple model can be assumed to evaluate the space charge effect since within the ion chamber the electron beam can be roughly assumed cylindrical of constant radius r_b owing to the solenoid containment and by neglecting the small scallop effect. Thus the new trajectory equations can be written as:

$$(3) \qquad r < r_b \quad \Rightarrow \quad \begin{cases} \dfrac{d^2x}{d\tau^2} - b\dfrac{dy}{d\tau} + \left(a_x + c - 2q_x \cos 2(\tau-\tau_o)\right)x = 0 \\ \dfrac{d^2y}{d\tau^2} - b\dfrac{dx}{d\tau} + \left(a_y + c - 2q_y \cos 2(\tau-\tau_o)\right)y = 0 \end{cases}$$

if the ion is in the electron beam, and:

$$(3') \qquad r \geq r_b \quad \Rightarrow \quad \begin{cases} \dfrac{d^2x}{d\tau^2} - b\dfrac{dy}{d\tau} + \left(a_x + c\left(\dfrac{r_b^2}{r^2}\right) - 2q_x \cos 2(\tau-\tau_o)\right)x = 0 \\ \dfrac{d^2y}{d\tau^2} - b\dfrac{dx}{d\tau} + \left(a_y + c\left(\dfrac{r_b^2}{r^2}\right) - 2q_y \cos 2(\tau-\tau_o)\right)y = 0 \end{cases}$$

if the ion is out of the electron beam.

In Eqs. (3) the new parameters: $b = \dfrac{2q_i B}{m_i \omega}$ and $c = \left(\dfrac{1}{4\pi\varepsilon_o}\right)\dfrac{8q_i}{m_i \omega^2 r_b^2}\dfrac{I_e}{v_e}$ are been introduced. The fist one is related to the solenoid field B, whereas the second one take into account the electron beam space charge force: I_e is the beam current intensity and v_e the electron velocity.

Nevertheless also in this case, new stability regions can be identified [9]. The magnetic field and the electron beam space charge act in opposite way: the first one reshapes and reduce the stability region area, whereas the second one increases the stability area, due to the enhancement of the transverse containment of the ions.

4 BRIC NUMERICAL SIMULATIONS

4.1 Electron Beam Simulation

The electron beam propagation from the gun to the collector has been numerically simulated by the well known EGUN code [10]. Several possible experimental conditions and configurations have been tested. The example shown in Fig. 9 refers to an electron energy of 10 keV and electron beam current 1 A. The solenoid magnetic field is B =1.8 kGauss and the gun is in semi-immersed flow configuration. Evident from the figure is the shrinking of the beam up to the ion chamber input due to the semi-immersed flow configuration. Evident in the figure are the whole beam small oscillations (scallop), and the deep in the central zone of the ion chamber due to the gap (10 cm) between the two solenoids.

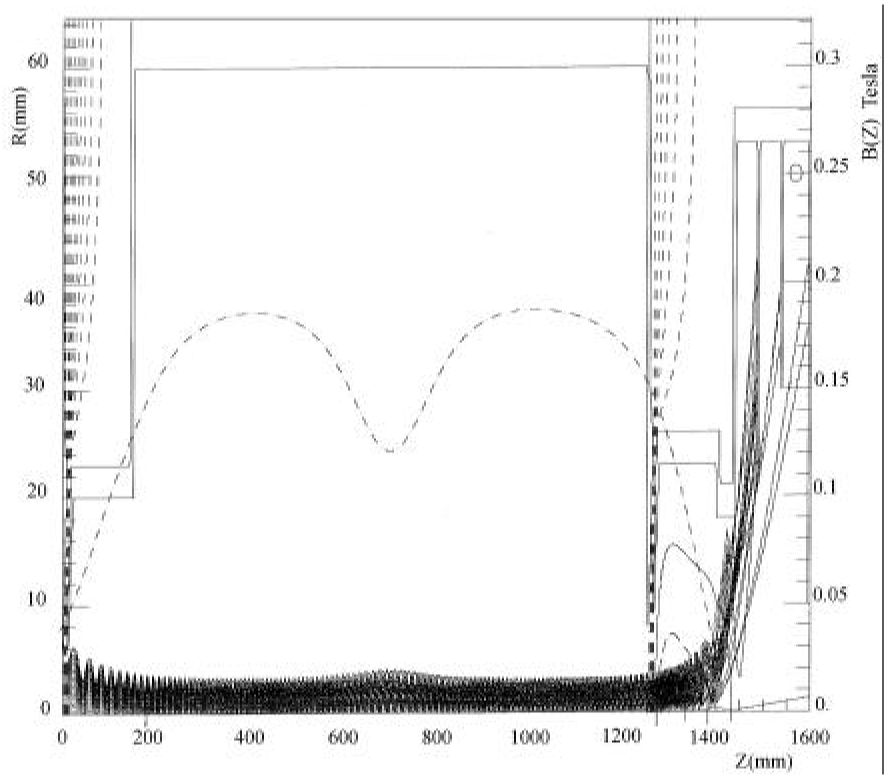


Fig. 9: BRIC Electron Beam Simulation

4.2 Ion Motion in the RF – Quadrupole (SIMION Code)

To simulate the ion motion in the drift chamber, the code SIMION has been used [9]. Several experimental conditions have been simulated and the effect of the solenoid field has been evaluated. An example of ion stable trajectories without magnetic field is shown in Fig. 10.

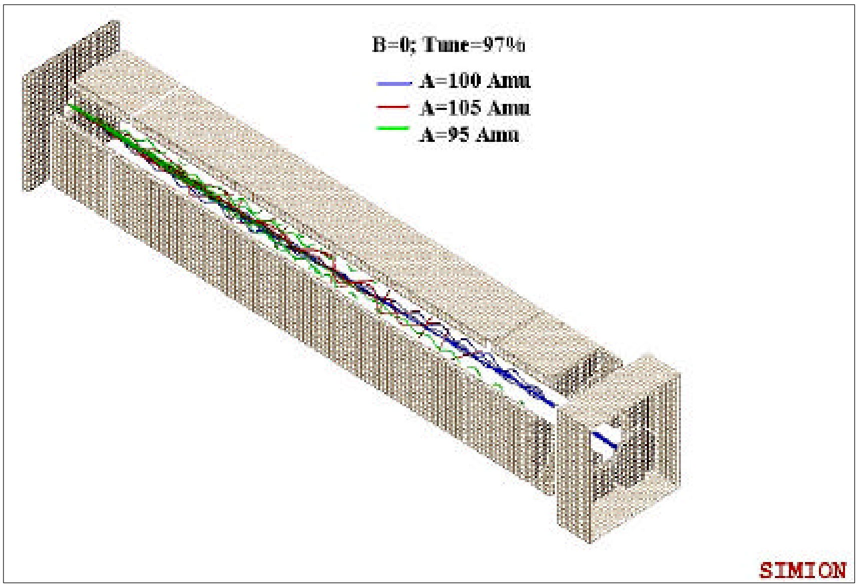


Fig. 10: RF - Quadrupole Ion trajectories

The tune in SIMION is defined by fixing the q value to 0.706 and by decreasing the a value from the maximum 0.2334 (Tune = 100%) down to zero.

The effect of the solenoid magnetic field (generating instability) can be observed in the example reported in Fig. 11 (same tune 97 % as in Fig. 10, longitudinal section view). By lowering the tune value (77 %), new stable trajectories can be observed for the same magnetic field (see Fig. 12).

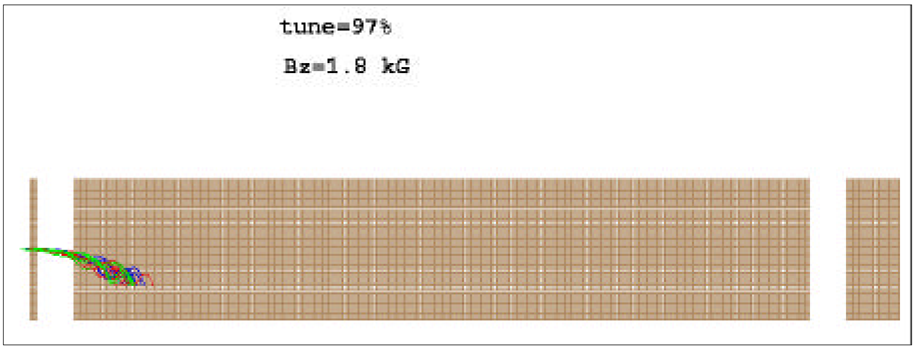


Fig. 11: Instability Effect of the Solenoid Field on the Ion Trajectories

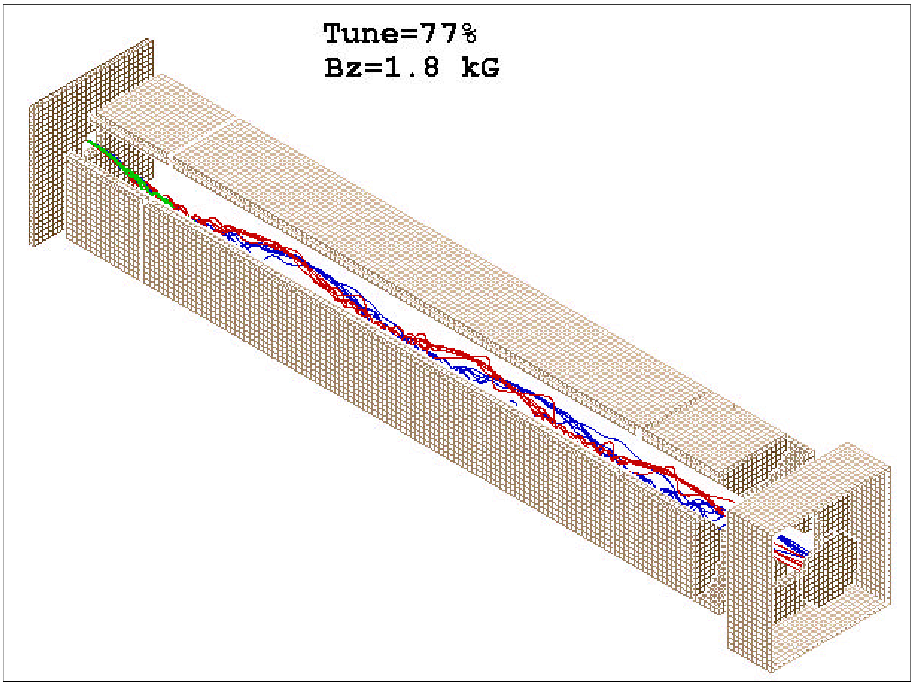


Fig. 12: Stable Ion Trajectories for a Lower Tune Value

4.3 BRICTEST Code Ion Simulation

The EGUN Code is not useful for quadrupole analysis. The SIMION Code cannot evaluate the electron beam space charge forces and the charge state evolution of the ions during the interaction with the electron beam. Thus we are developing an appropriate numerical package (BRICTEST) to take into account all the physical problems involved. The routines already working allow to evaluate both the solenoid and electron beam space charge effect, whereas work is in progress to include all the physical processes involved in the ion-electron interaction to fix the requested time to reach the desired ion charge state level. In Fig. 13 some well known results, reproduced with BRICTEST, are shown. Here, a ˜ 0.23 and q = 0.706 (vertex of the first stability region). The ion motion is stable.

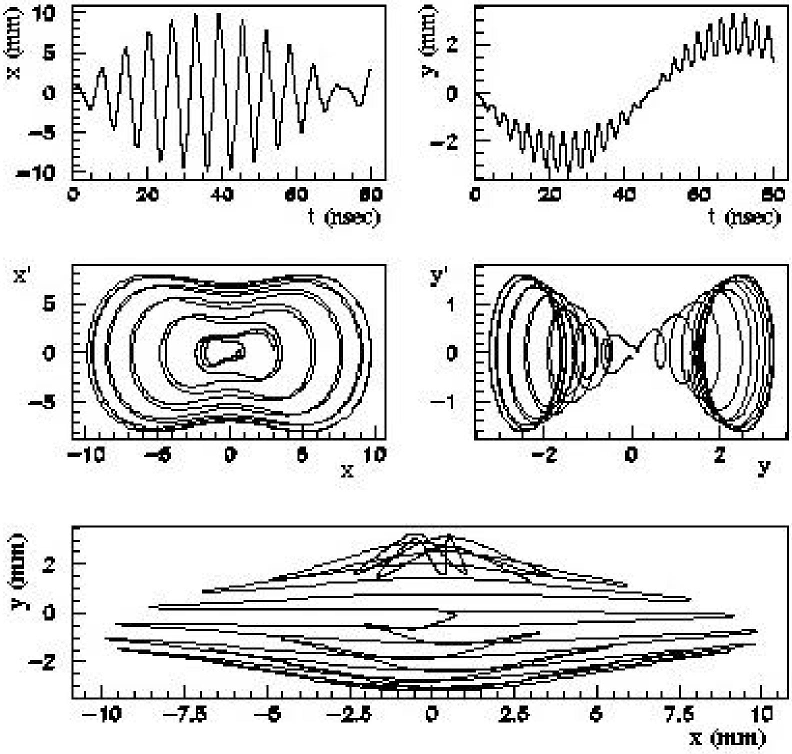


Fig. 13: RF – Quadrupole Ion Trajectories. <u>top</u>: x(t) and y(t); <u>center</u>: (x,x’) and (y, y’); <u>bottom</u>: transverse (x, y) plane

In Fig. 14 a longitudinal magnetic field B = 1.8 kGauss has been inserted with the same values of the a and q parameters. The generation of instability is evident as deduced from the SIMION simulations.

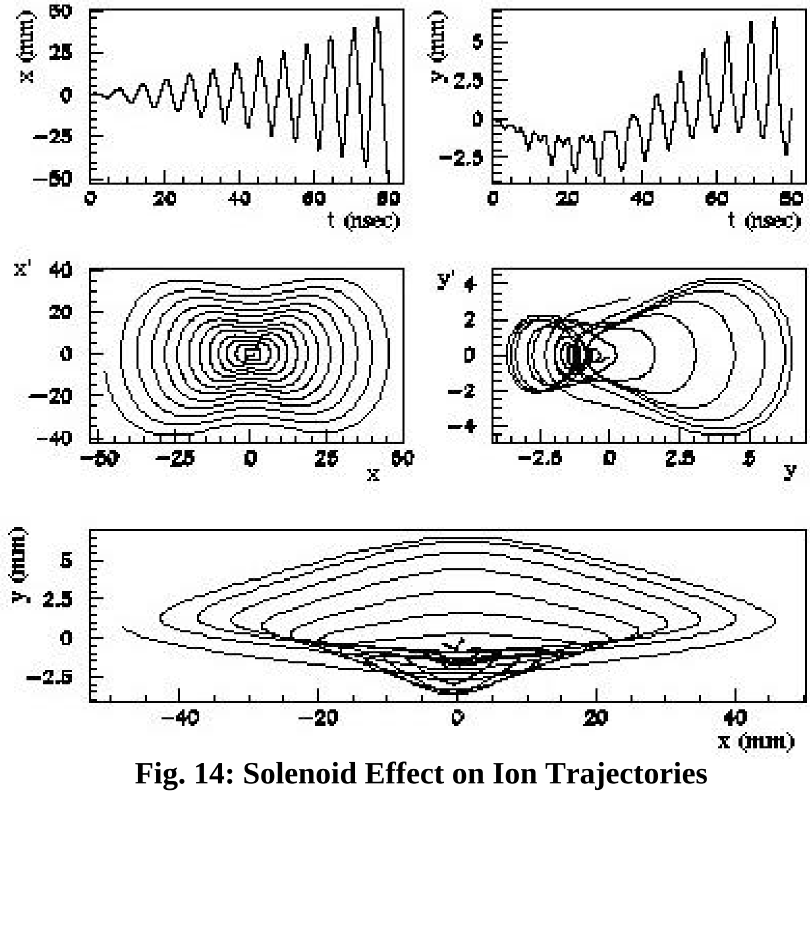


Fig. 14: Solenoid Effect on Ion Trajectories

Finally the space charge force due to the electron beam has been added. In the preceding conditions we observe that a beam of 5 keV and 100 mA is sufficient to obtain again the ion motion stability. The results are shown in Fig. 15.

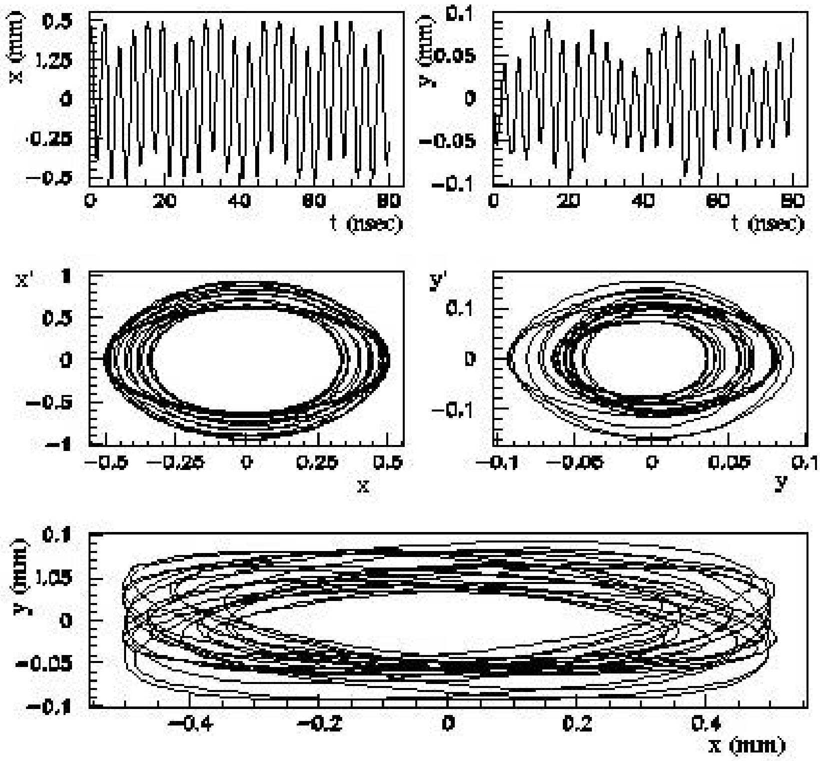


Fig. 15: RF – Quadrupole + Solenoid + E-beam Space Charge

5 RF – QUADRUPOLE MASS FILTERING

From the simulation results obtained up to now, the filtering action of the RF-quadrupole resulted evident. By plotting the mass range versus the AC component of the quadrupolar field, for fixed DC component value, stability and instability regions can be enlighten. This shows the possibility to select the mass range of interest with a good resolution by varying the amplitude of the RF DC and AC components. A particularly intersting example for zero DC component, RF frequency of 1 MHz and mass range 80÷200 (as probably will be the case of the SPES project) is reported in Fig. 16. Here, the chosen parameter values are: electron beam current Ie = 100mA; electron energy We = 5 keV; solenoid magnetic field on the axis B = 1.8 kGauss. In Fig. 16 a), b), and c) the effect of the increasing charge state level can be observed.

Although the analysis of the example reported and of all the other tests, shows that the mass separation is possible, however the complexity of the parameter connections needs still a lot of work. Namely the evolution of the charge state level in the breeder must be analyzed in a deeper way to understand how the masses of interest can be elevated at the highest charge state without instability generating.

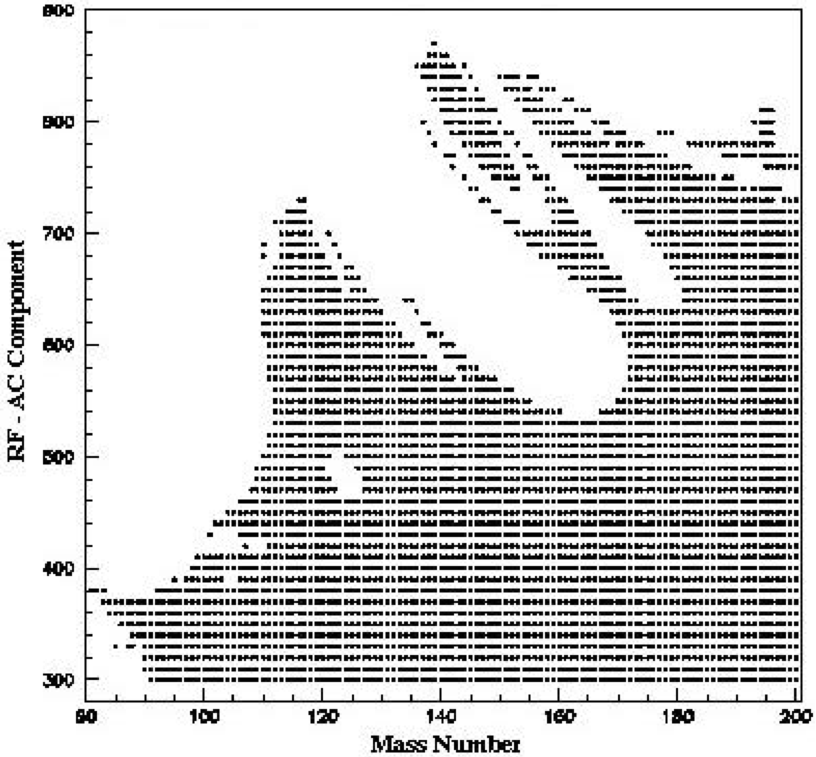


Fig. 16 a) Charge State Number Z = 4

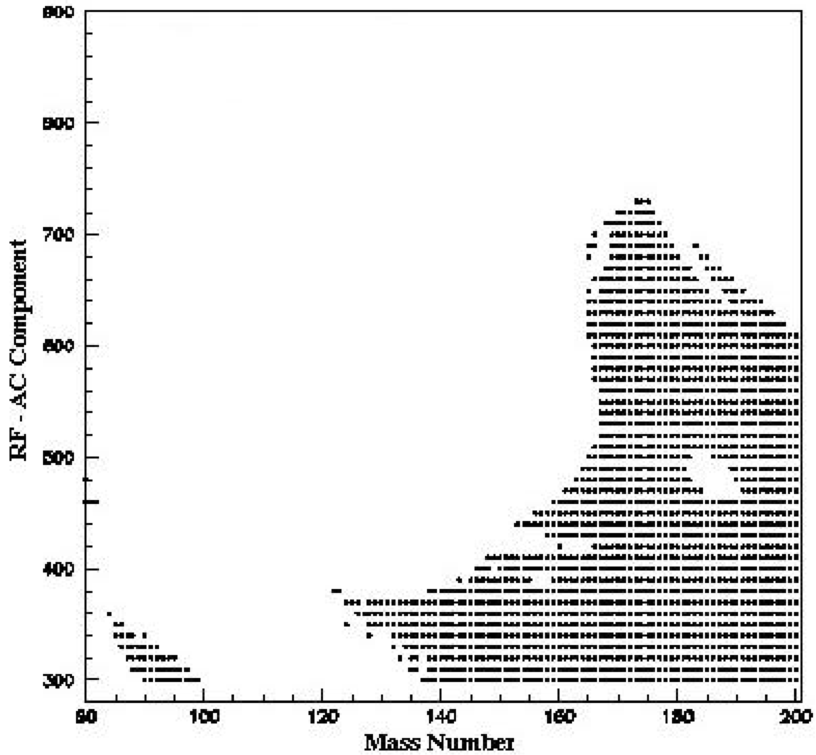


Fig. 16 b): Charge Number Z = 6

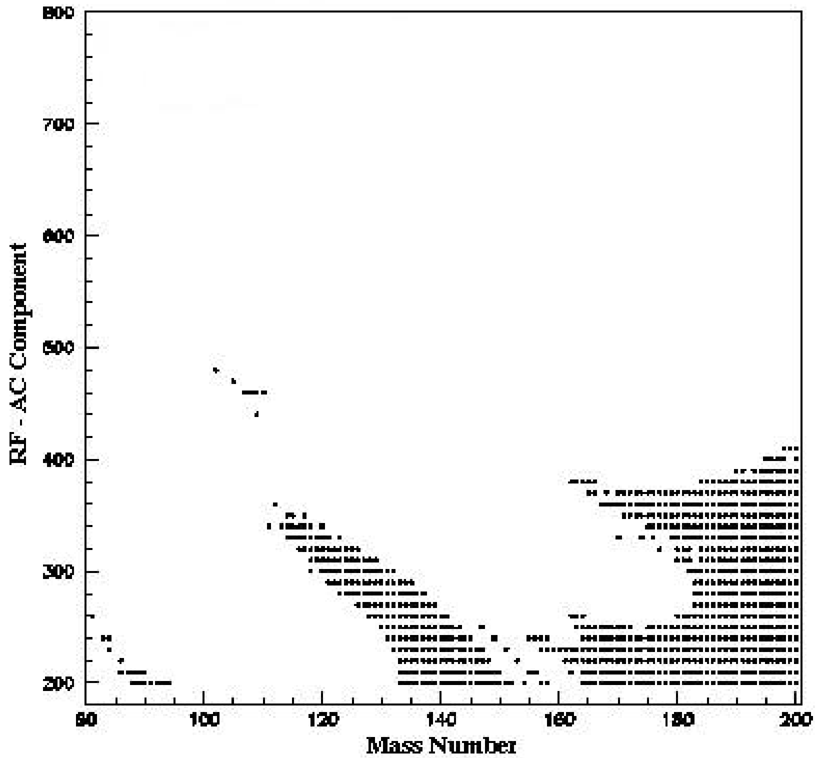


Fig. 16 c): Charge State Number Z = 8

6 CONCLUSIONS

The numerical simulation of the charge state breeder BRIC show that it is possible to obtain an increase of the mass separation through the insertion of an RF-quadrupole into the ion chamber. The mass filtering action depends on a complex way on several parameters that can be varied to match the best experimental conditions, and to increase the containment of the desired ion masses with the required charge state level of ionization. The strong instability of the light masses obtained through the quadrupole at lower charge states can help to increase the chamber vacuum by eliminating the residual gas masses.

A lot of work is necessary to understand the problems related to the ion containment and the stability conditions during the charge state enhancement.

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Esperimento	gruppo	Rappresentante nazionale	Struttura res_naz	nuovo_continua
BRIC	5	Vincenzo Stagno	BARI	continua

STR.	ESPERIM.	Missioni interno	Inviti ospiti stran.	Missioni estero	Mater. di Cons.	Spes Sem	Tras. e Fac.	Pub. Scien.	Spese Calc	Aff. e Manut. App.	Mater. invent.	Costruz. apparati	TOTALE
BARI	BRIC	21		17	20		3				21	205	**287**
	di cui sj												
	Totali	21		17	20		3				21	205	**287**
	di cui sj												

Personale

Ricercatori	4,0	Tecnologi	1,0	Tecnici	2,0	Servizi mesi uomo
FTE	2,6	FTE	0,5	FTE	1,1	4,0

Rapporti (FTE/numero) Ricercatori 0,65 **Ricercatori+Tecnologi** 0,62

Richieste/(FTE ricercatori+tecnologi) 92,58

TOTALI

	Missioni interno	Inviti ospiti stran.	Missioni estero	Mater. di Cons.	Spes Sem	Tras. e Fac.	Pub. Scien.	Spese Calc	Aff. e Manut. App.	Mater. invent.	Costruz. apparati	TOTALE
Totali	21		17	20		3				21	205	**287**
di cui sj												

Confronto con il modello EC4

	Missioni interno	Inviti ospiti stran.	Missioni estero	Mater. di Cons.	Spes Sem	Tras. e Fac.	Pub. Scien.	Spese Calc	Aff. e Manut. App.	Mater. invent.	Costruz. apparati	TOTALE
Mod. EC4 dati	21		17	20		3				21	205	**287**
Totali-Dati EC4												

Personale

Ricercatori	4,0	Tecnologi	1,0	Tecnici	2,0	Servizi mesi uomo
FTE	2,6	FTE	0,5	FTE	1,1	4,0

Rapporti (FTE/numero) Ricercatori 0,65 **Ricercatori+Tecnologi** 0,62

Richieste/(FTE ricercatori+tecnologi) 92,58