ECRIS and EBIS charge state breeders

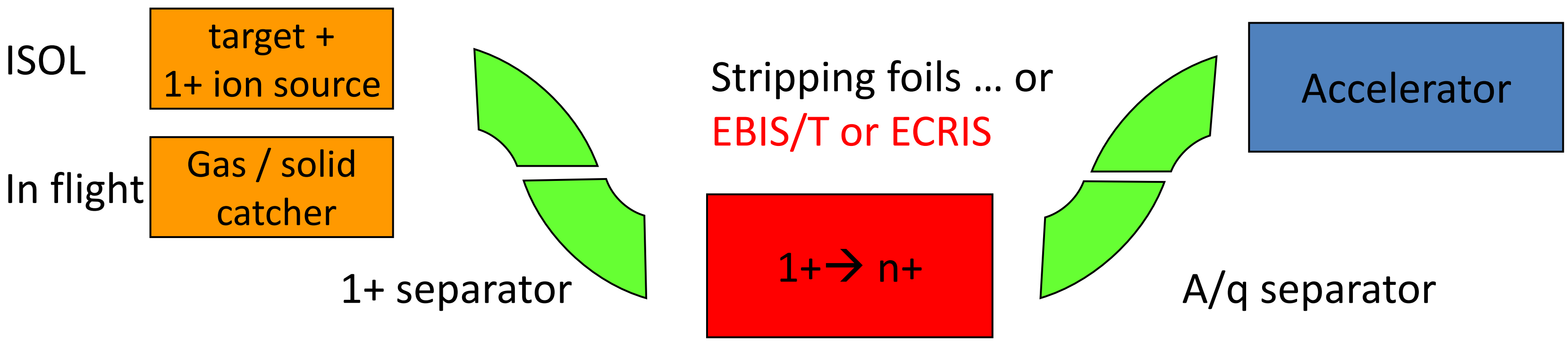
Present performances, future potentials

Pierre Delahaye

GANIL

Charge breeding

A key-technology for facilities reaccelerating Radioactive Ion Beams



Charge breeding: matching the A/q acceptance of the post-accelerator

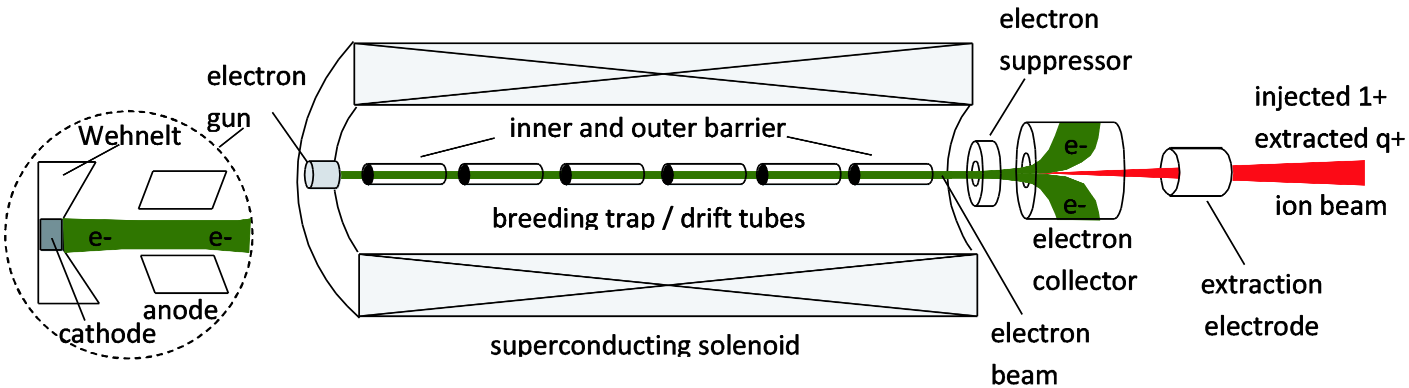
- higher charge states → **Higher energies**
  Compact postaccelerator

- Pure beams
- High efficiency and rapidity → Making the most of the rare and exotic beams: **I<<pA and $T_{1/2}$<1s**

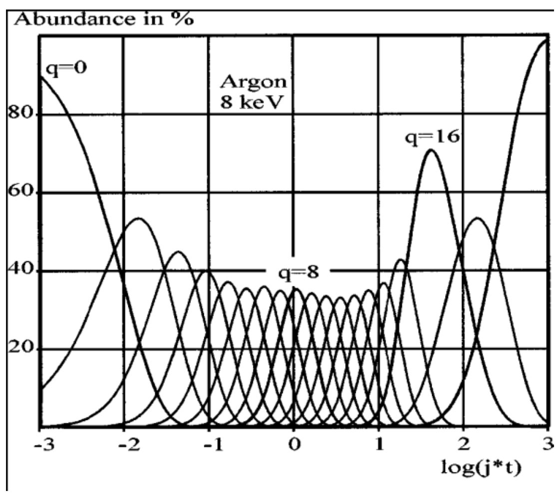
But also: **I~µA** EURISOL

EBIS/T charge breeders

EBIS/T charge breeder principle



E. D. Donets, V. I. Ilyushchenko and V. A. Alpert, JINR-P7-4124, 1968
E. D. Donets, Rev. Sci. Instrum. 69(1998)614



R. Becker, Rev. Sci. Instrum. 71(2000)816

Average charge state

$\overline{q} \sim \log(j.\tau)$

Trap capacity (elementary charges)

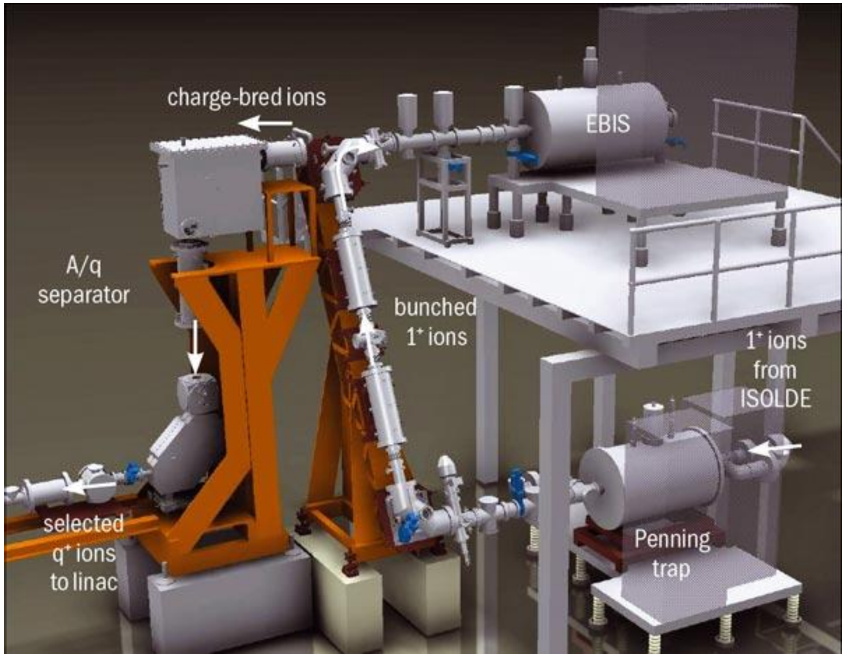
$Q=3.36\ 10^{11} L.I_e/E^{-1/2}$

Space charge limit ~10 ^{10} ion/s

Essentially a pulsed device

The REX-EBIS setup

The LaB_6 cathode



EBIS specifications

- LaB6 cathode
- $j_{cathode}$<20A/cm2
- $j_e = j_{trap} < 200 A/cm^2$
- Ie=460mA (normal operation 200mA)
- E=3.5-6keV
- 3 drift tubesL=200 to 800 mm
- Theoretical capacity $5 \cdot 10^{10}$ positive charges
- Ultra-high vacuum 10^{-10} - 10^{-11} mbar

The charge state is selected with a mass separator of Nier-Spectrometer type

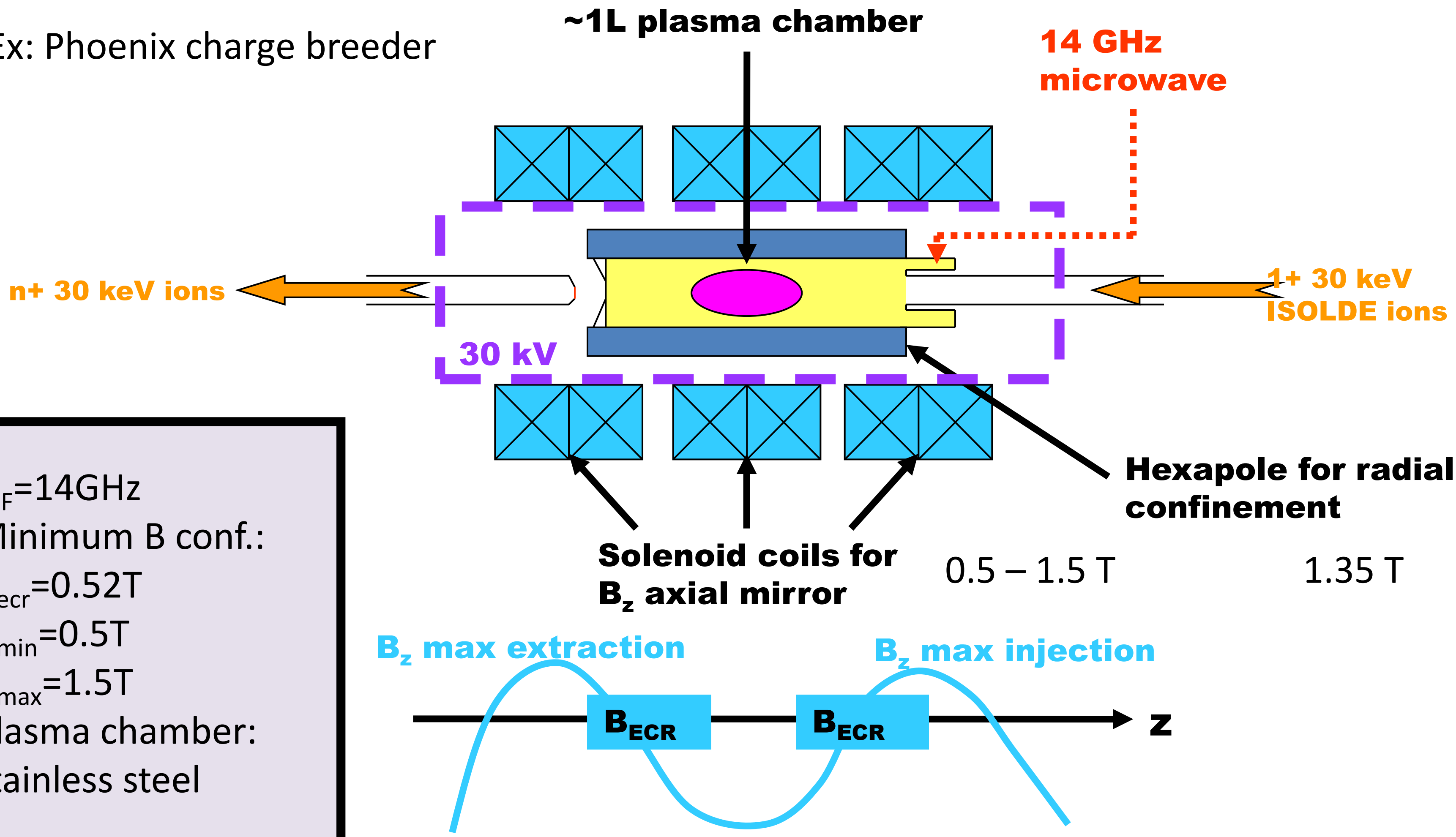
Performances: F. Wenander et al.,
Rev. Sci. Instrum. 77, 03B104 (2006)
ICIS 05 Proceedings

EBIS/T charge breeders

ECRIS charge breeders

ECRIS charge breder principle

Ex: Phoenix charge breeder



f_{RF}=14GHz
Minimum B conf.:
B_{ecr}=0.52T
B_{min}=0.5T
B_{max}=1.5T
Plasma chamber:
stainless steel

Performances: P. Delahaye et al., Rev. Sci. Instrum. 77, 03B105 (2006), P. Delahaye and M. Marie-Jeanne, NIM B 266 (2008) 4429

Essentially a CW device, but can be pulsed

ECRIS charge breeders

EBIS/T and ECRIS charge breeders

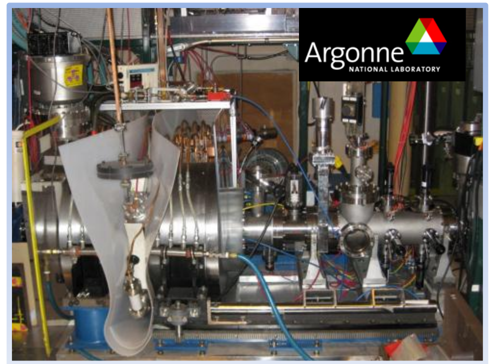
for radioactive ion beam facilities

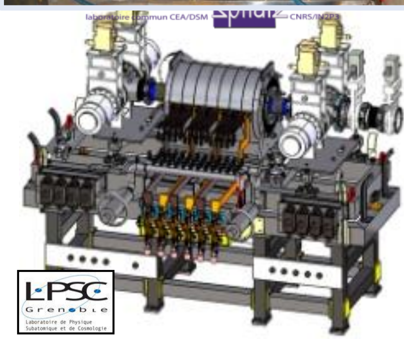
- EBIS
  - Operational at
    - REX-ISOLDE
  - In commissioning at
    - NSCL (ReA3)
  - Construction/ future Plans
    - ANL
    - TRIUMF
    - HIE ISOLDE EBIS (HEC^2)
- ECRIS
  - Operational at
    - ANL
    - TRIUMF
    - (TRIAC)
  - In commissioning at
    - VECC
    - Texas A&M
  - Ongoing R&D
    - LPSC and GANIL for SPIRAL, SPIRAL 2 and SPES

…

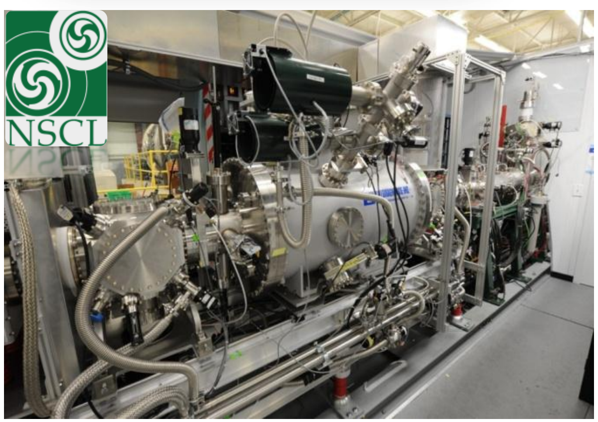
EBIS/T and ECRIS charge breeders

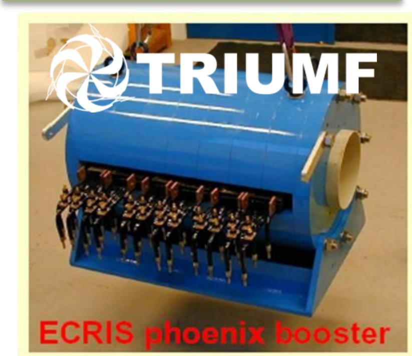
for radioactive ion beam facilities

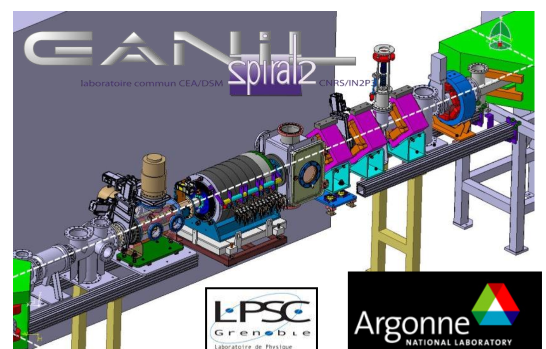




LPSC - SPIRAL2 charge breeder





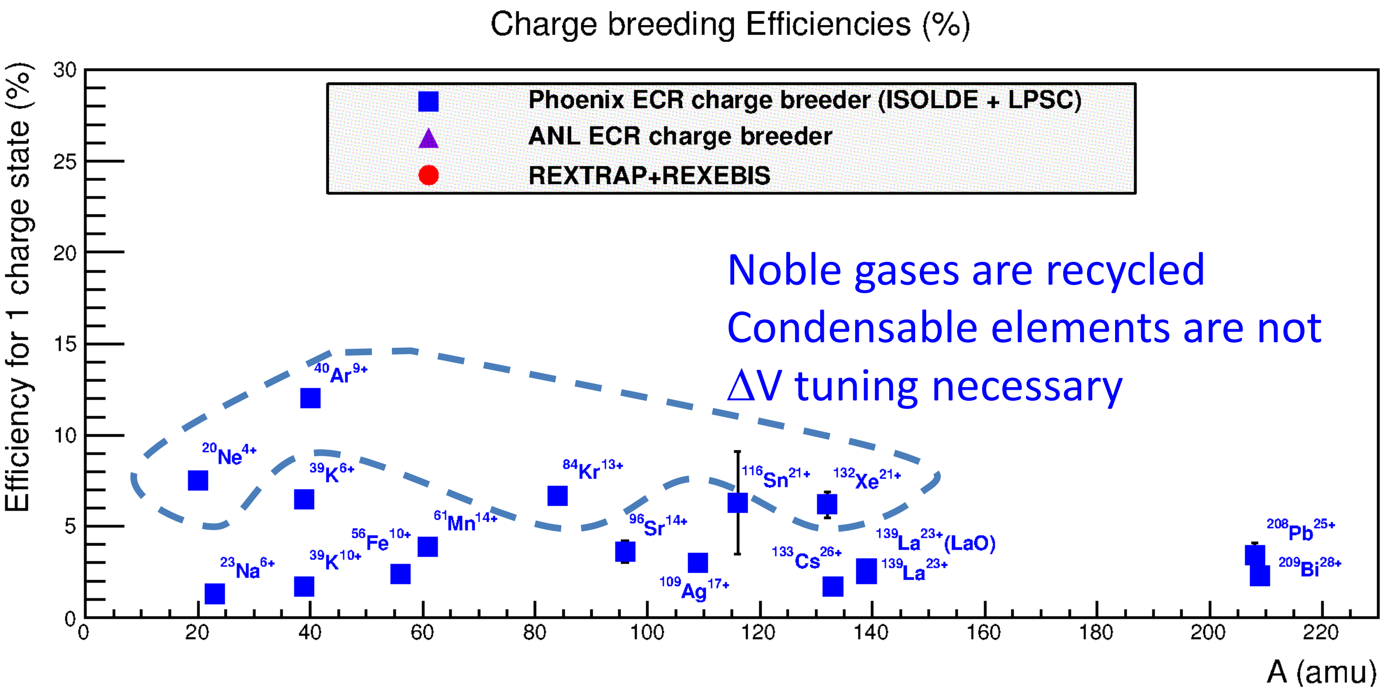


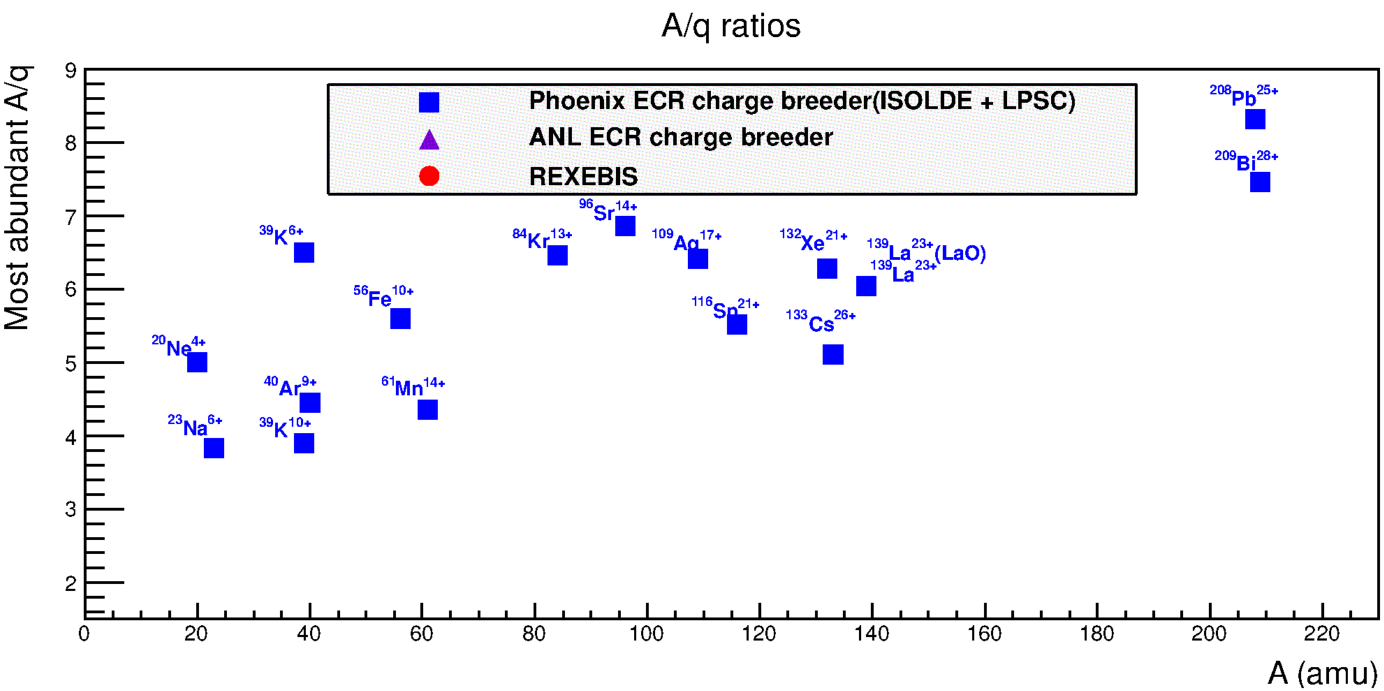
Charge state breeding performances

- EBIS
  - REXEBIS
- ECRIS
  - PHOENIX (ISOLDE + LPSC)
  - ANL Charge breeder

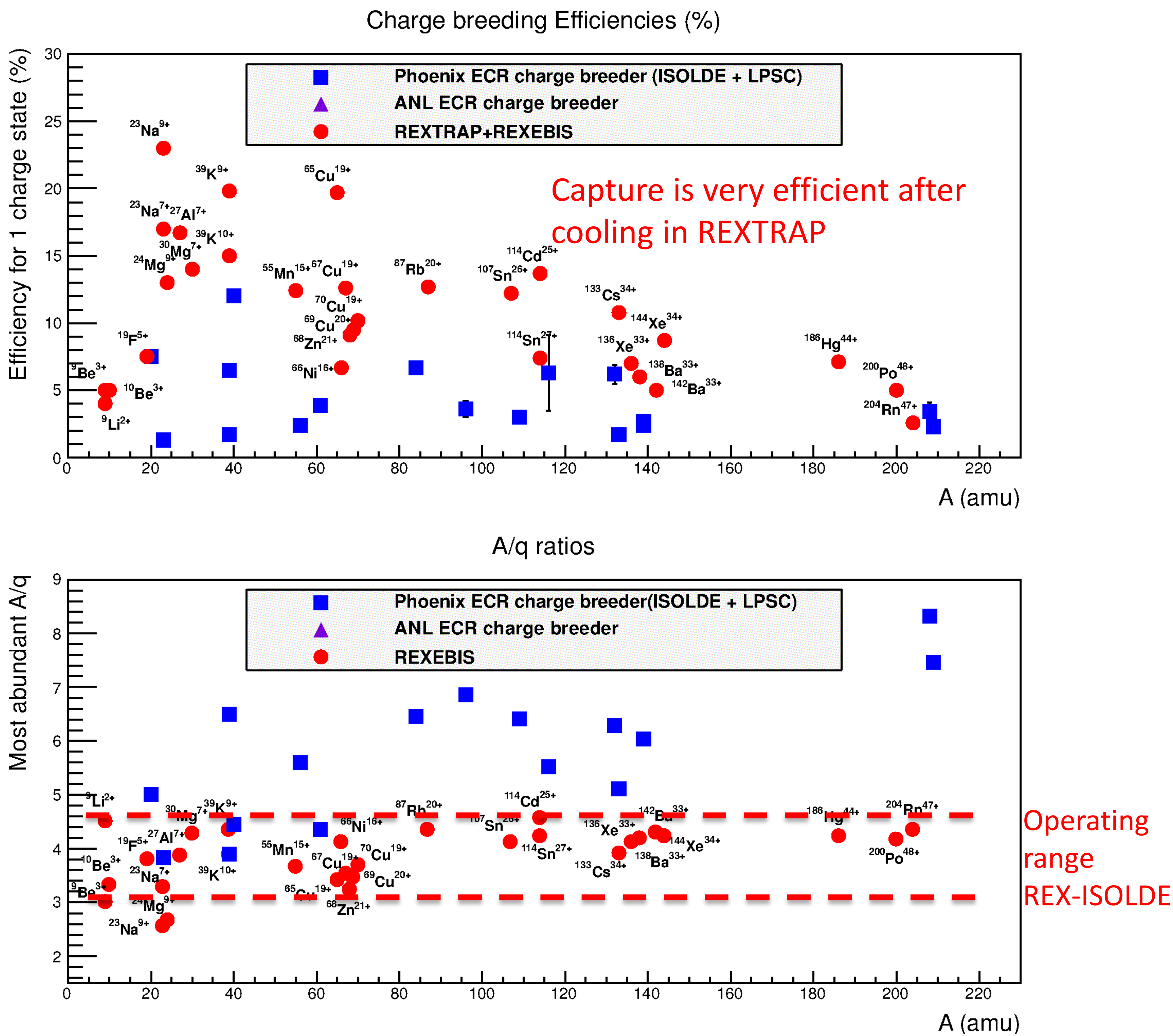
Efficiencies
Charge states (A/q ratios)
Charge state breeding time

Phoenix ECRIS

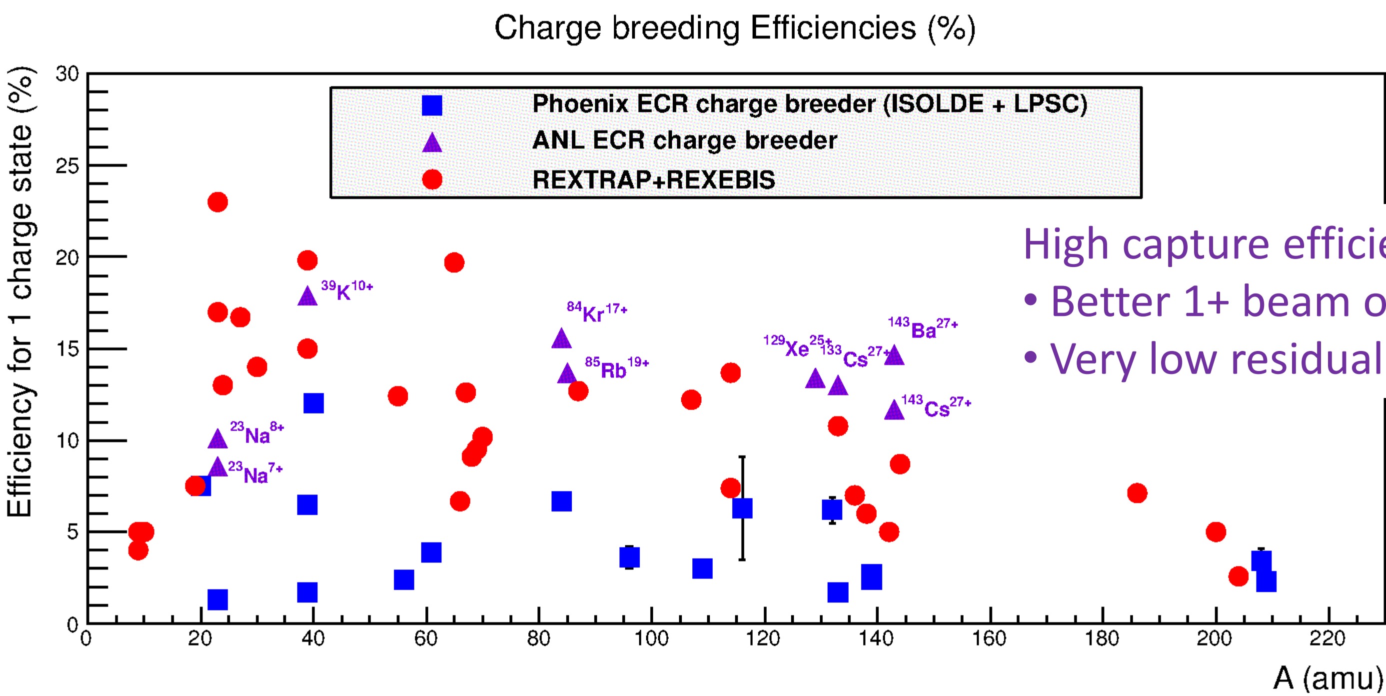




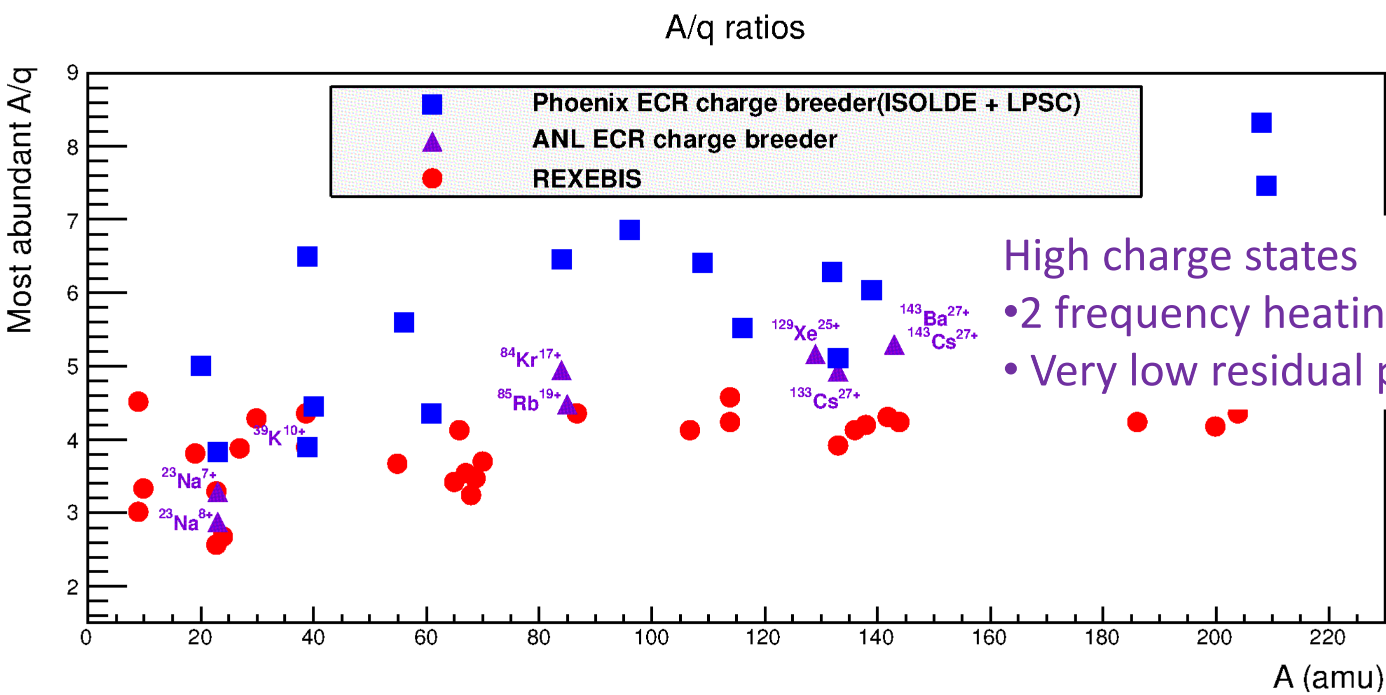
REXTRAP - REXEBIS



ANL ECRIS



High capture efficiency
- Better 1+ beam optics
- Very low residual pressure



High charge states
- 2 frequency heating
- Very low residual pressure

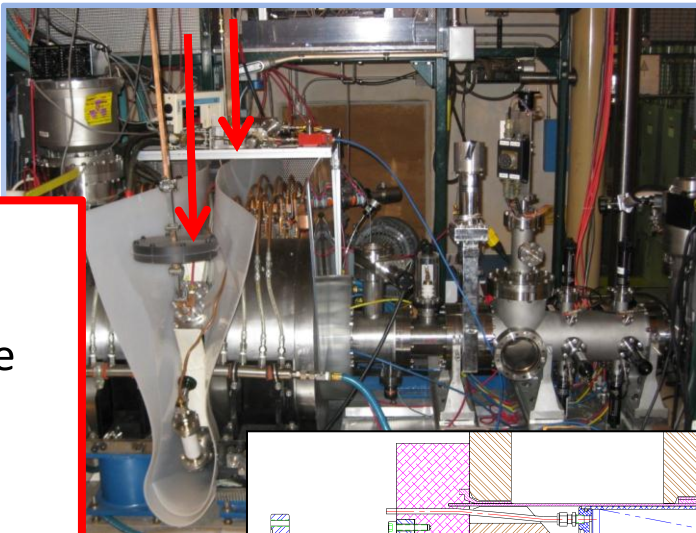
ANL ECRIS charge breeder

See talk R. C. Pardo

- Multiple frequency operation
  - Klystron: 10.44 GHz, 2 kW
  - TWTA: 11→13 GHz, 0.5 kW
- Open hexapole structu
  - RF is injected radiall
  - Uniform iron in the i symmetrical fields
  - Improved pumping t region
    - Base pressure: 2x
    - Operation: $7x10^{-8}$
    - Extraction pressure: 4x10 mbar

What is so different?

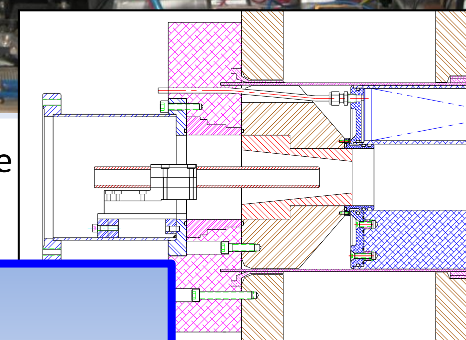
- Field symmetries
- Tunable grounded tube
- Excellent vaccuum
- 2 Frequency heating
- Cold 1+ beams
- …?



nded tube

with 2.5 cm of travel

- 50 kV high voltage

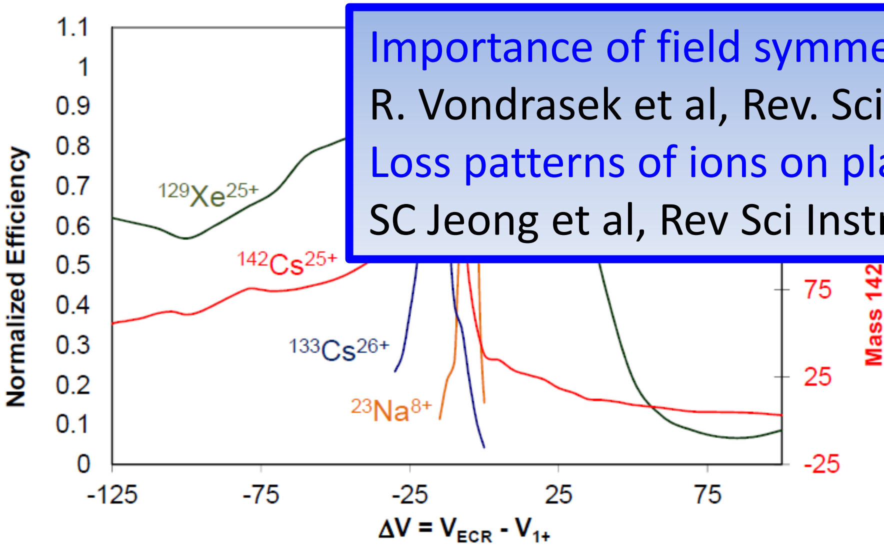


Importance of field symmetry

R. Vondrasek et al, Rev. Sci. Instrum. 83, 113303 (2012)

Loss patterns of ions on plasma chamber and electrodes

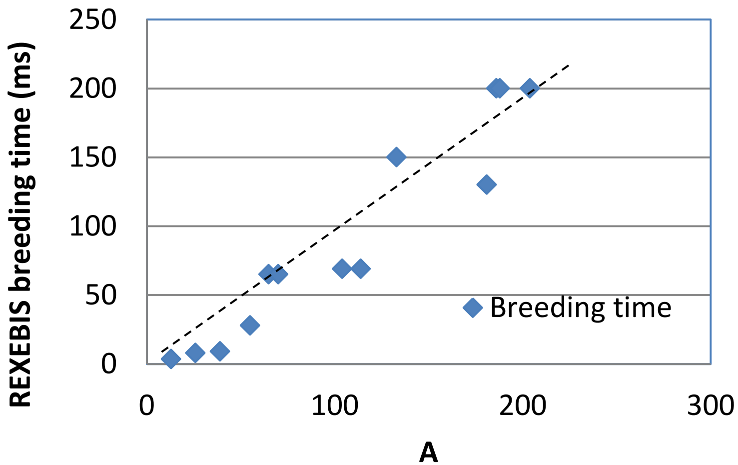
SC Jeong et al, Rev Sci Instrum. 83, 02A910 (2012)



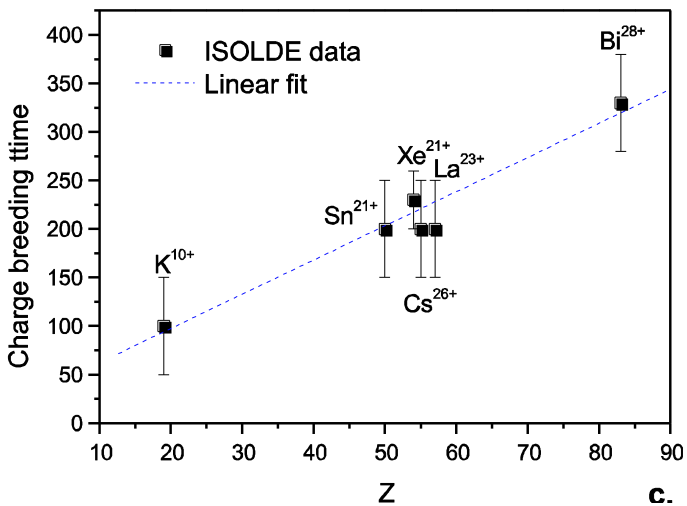
		ing condition
		1.16 T
B_{min}	0.31	0.27
B_{ext}	0.85	0.83
$B_{(radial)}$		0.86 T
Last closed surface		0.61 T

Charge breeding times

REXEBIS



Phoenix charge breeder



Accounting for REXTRAP:
20-400ms to reach A/Q<4.5

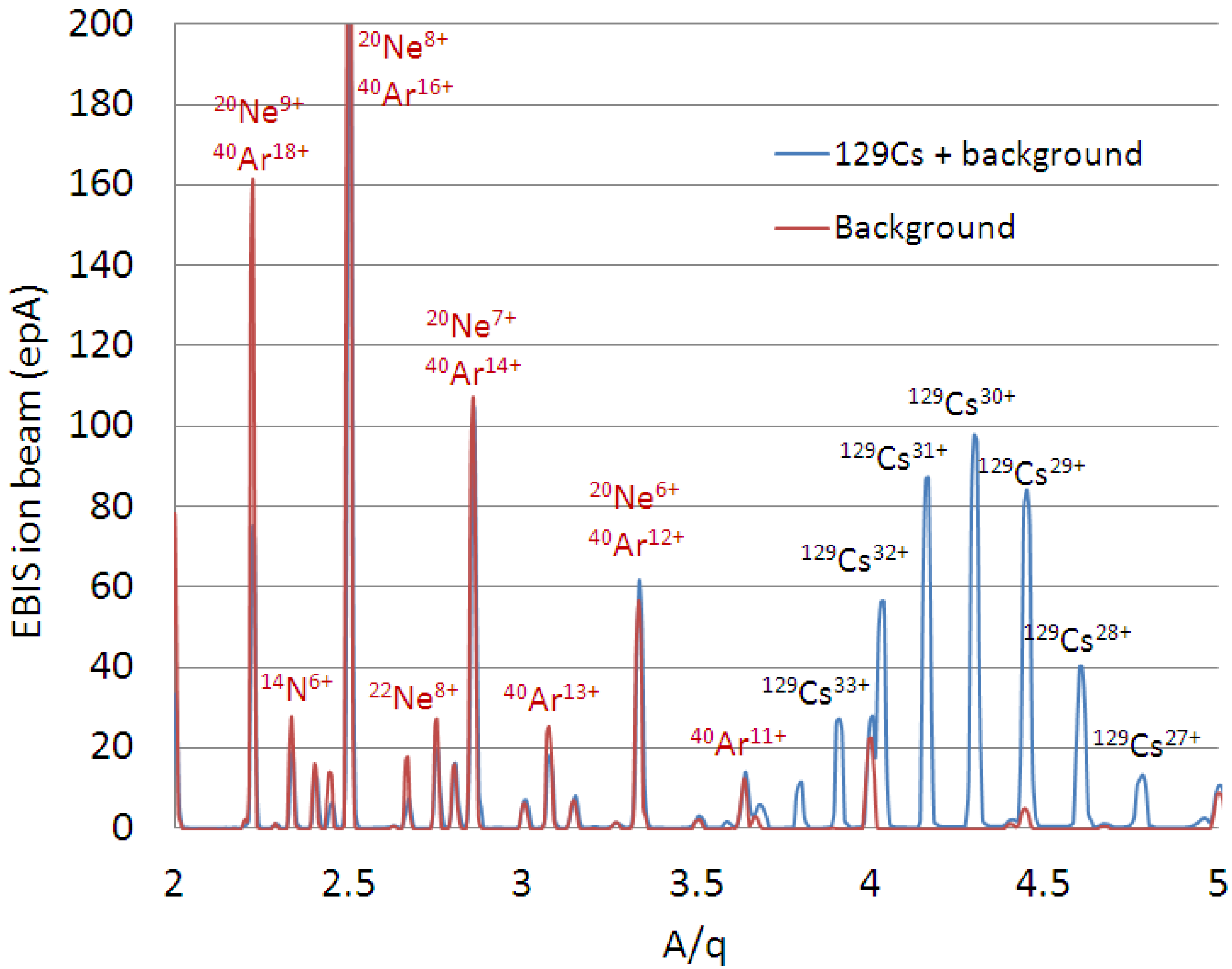
10-20ms / charge state

Seen at ANL:
for reaching highest charge states
coil tuning can possibly yield up to 40ms/charge state

Beam purity issue

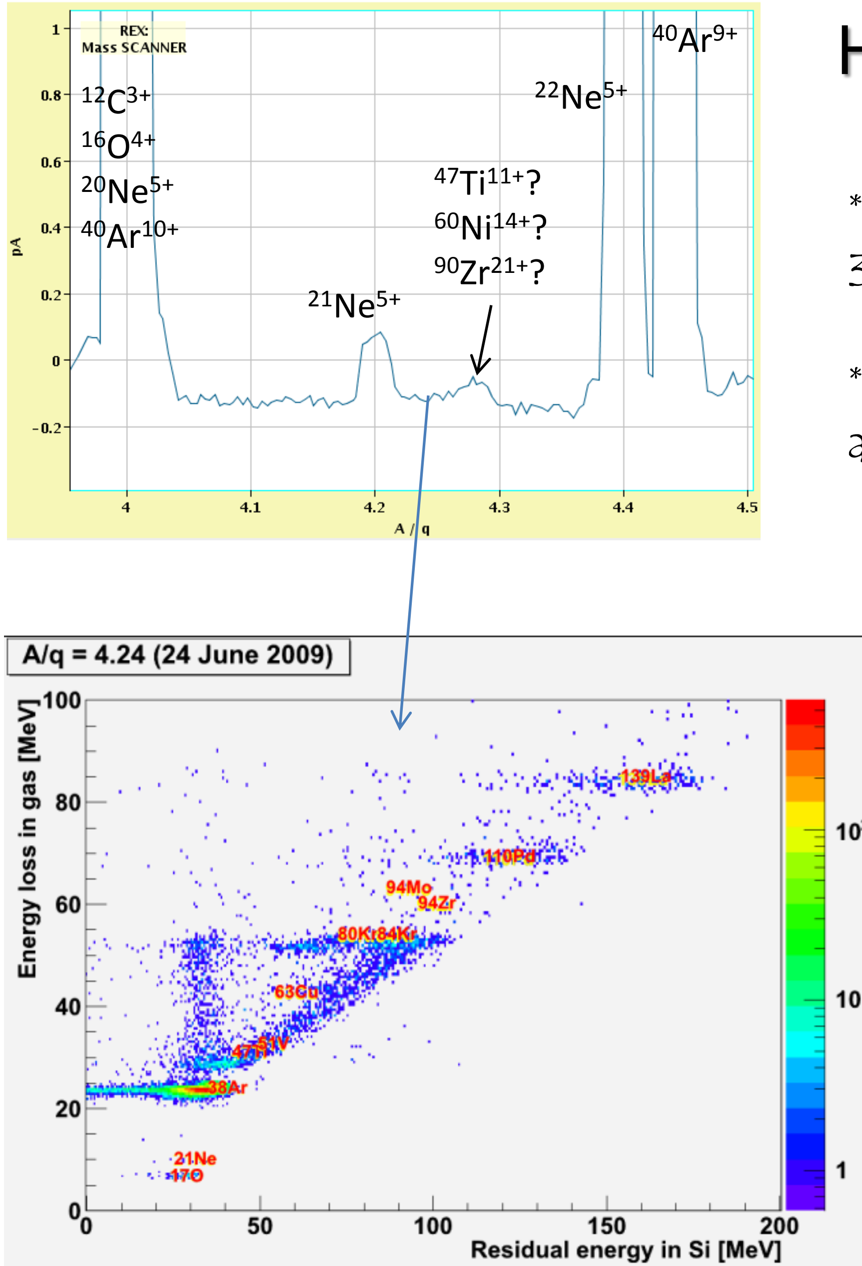
Beam purity from REX-EBIS

Clean beam?



Extracted beams from REXEBIS as function of A/q showing residual gas peaks and charge bred ^{129}Cs. The blue trace is with and the red trace without ^{129}Cs being injected.

F. Wenander, CERN courier, Jan/Feb 2012, p33



How pure is the beam really?

* C, O, Ne and Ar partial pressures around $3{\cdot}10^{-12}$, $2{\cdot}10^{-12}$, $5{\cdot}10^{-12}$ and $4{\cdot}10^{-13}$ mbar

* Important with proper beam identification after beam acceleration

A/q=4.24

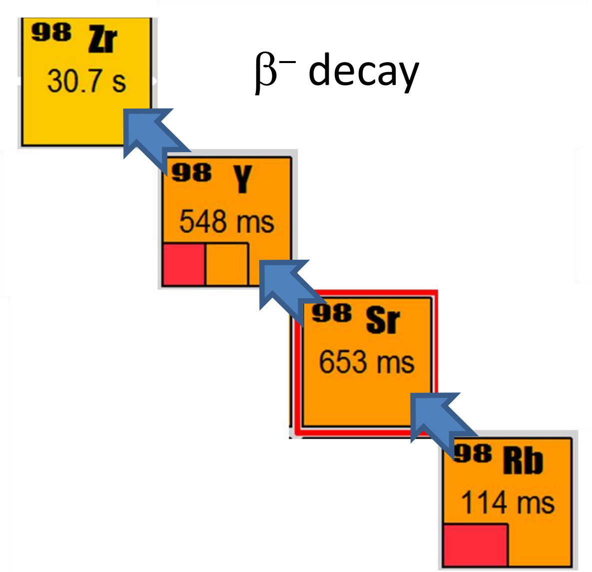
Isotope	A/q	Z	Origin
17O	4.250	8	residual gas
21Ne	4.2	10	buffer gas
38Ar	4.222	18	residual gas
47Ti	4.272	22	drift tubes
51V	4.25	23	NEG strips
63Cu	4.2	29	anode and collector
80Kr, 84Kr	4.21, 4.2	36	residual gas
94Zr	4.272	40	NEG strips
139La	4.212	57	cathode

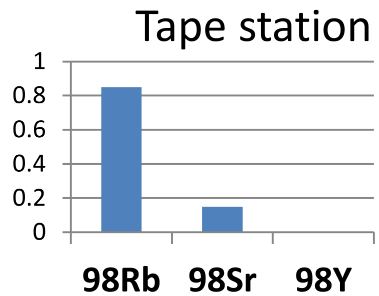
Other elements that can be present at other A/q are:

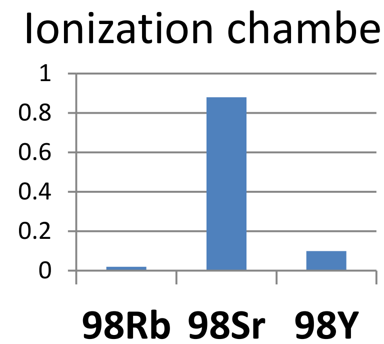
He, C, N	residual gases
B	cathode
Fe	NEG strips, stainless steel
Ni	stainless steel
Cr	stainless steel
Mo	stainless steel

In EBIS / trap decay and beam purity issues

Ex: IS451 E. Clément sp.
Coulomb excitation of ^{98}Sr at MINIBALL

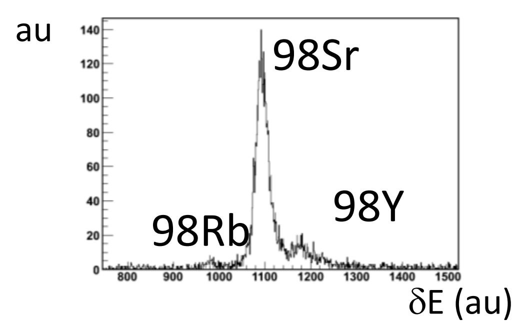






160ms trapping
160ms charge breeding

4.5% low energy efficiency
charge breeding + trapping + decay

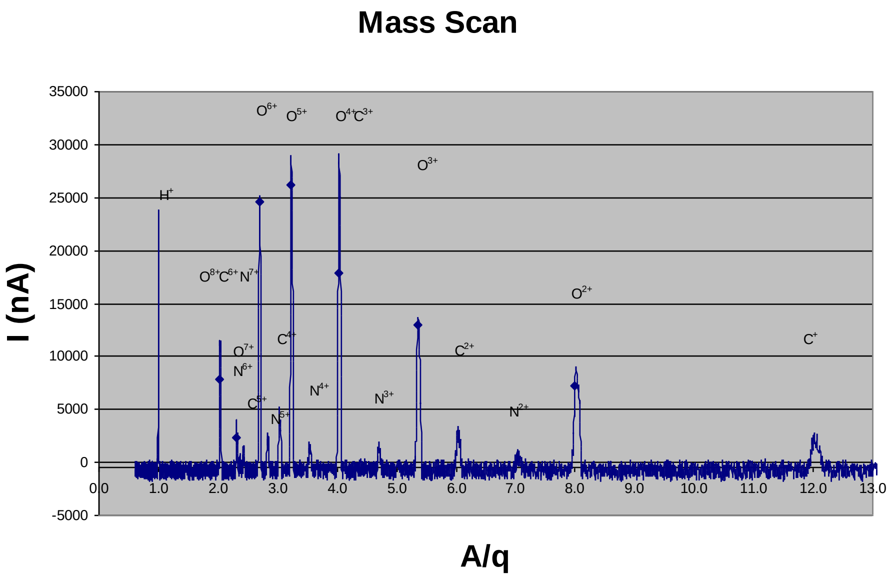


Ionization chamber signal

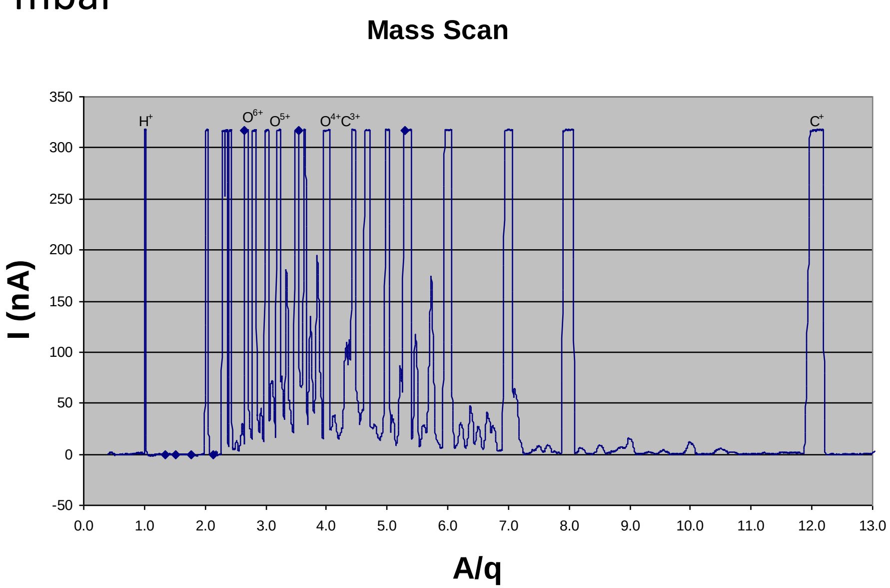
Beam purity from ECRIS charge breeders

- Troublesome restgas spectrum: C,N,O… + stainless steel components
  - TRIAC, ANL and TRIUMF charge breeders

Entrance of the ECR P=5.10^{-7}mbar



Exit P=2.10^{-7}mbar



Background >5nA 2<A/q<7

Phoenix test bench @ISOLDE

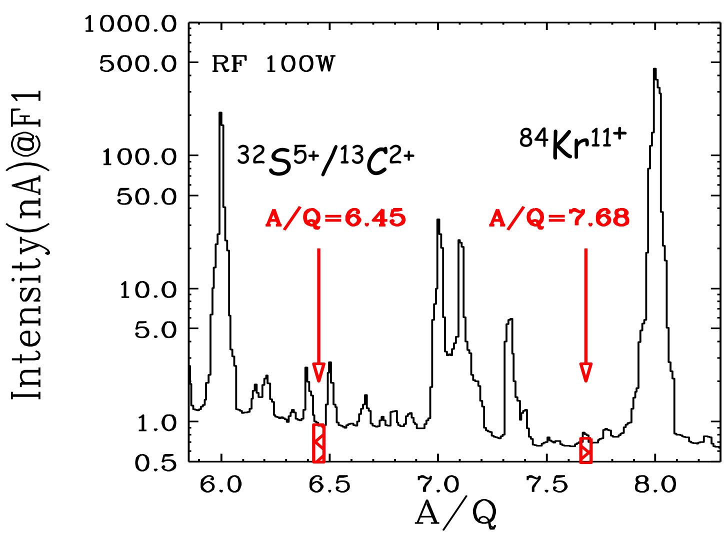
TRIAC
Tokai Radioactive Ion Accelerator Complex

TRIAC ECR charge breeder

First post-acceleration of pure beams from ECRIS charge breeders!

N. Imai et al, RSI 79, 02A906 2008

- **Impurity between A/q= 6 and 8 reduced by:**
  - A/q selection by CB analyzing magnet / Beam transport (~30m BTL) / Acceleration
  - Replacing all parts including plasma chamber by Al pieces
  - Using sandblasting, ultrasound cleaning and baking



Proof of principle for 2 regions of interest

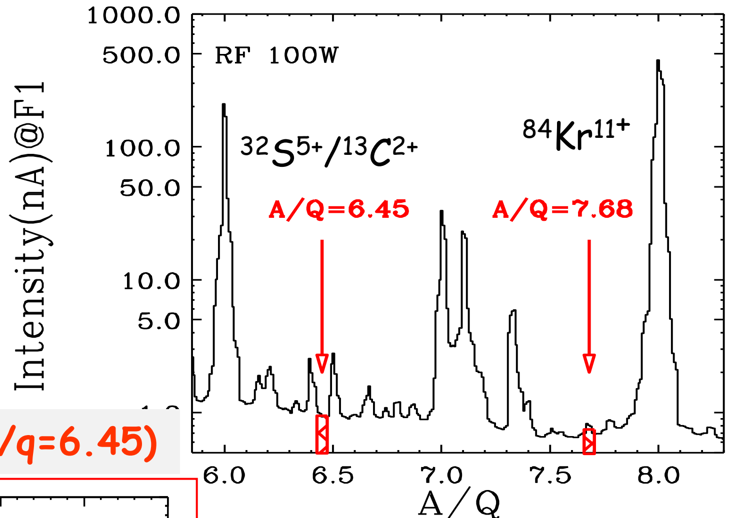
$^{129}Xe^{20+}$ A/q=6.45

$^{92}Kr^{12+}$ A/q=7.68

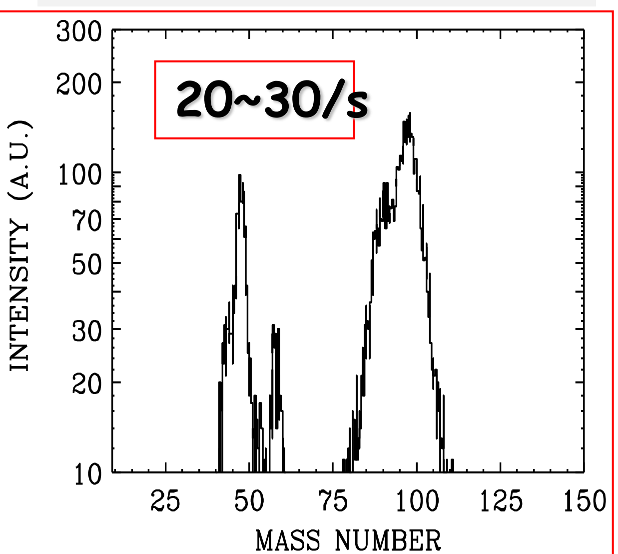
TRIAC ECR charge breeder

First post-acceleration of pure beams from ECRIS charge breeders!

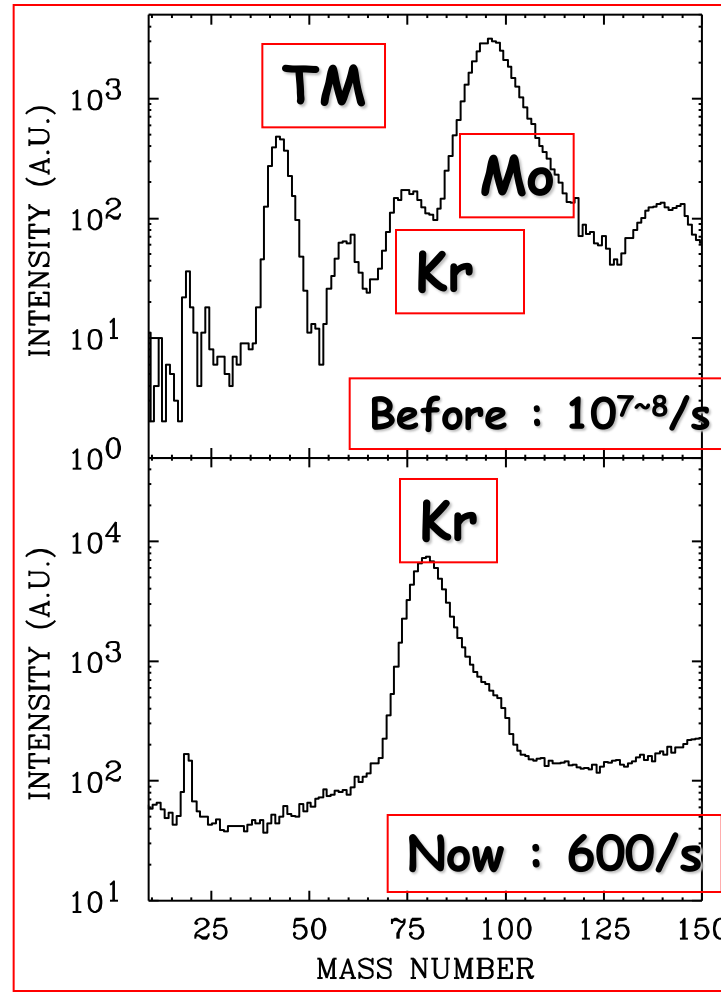
N. Imai et al, RSI 79, 02A906 2008



Mass spectrum (@A/q=6.45)

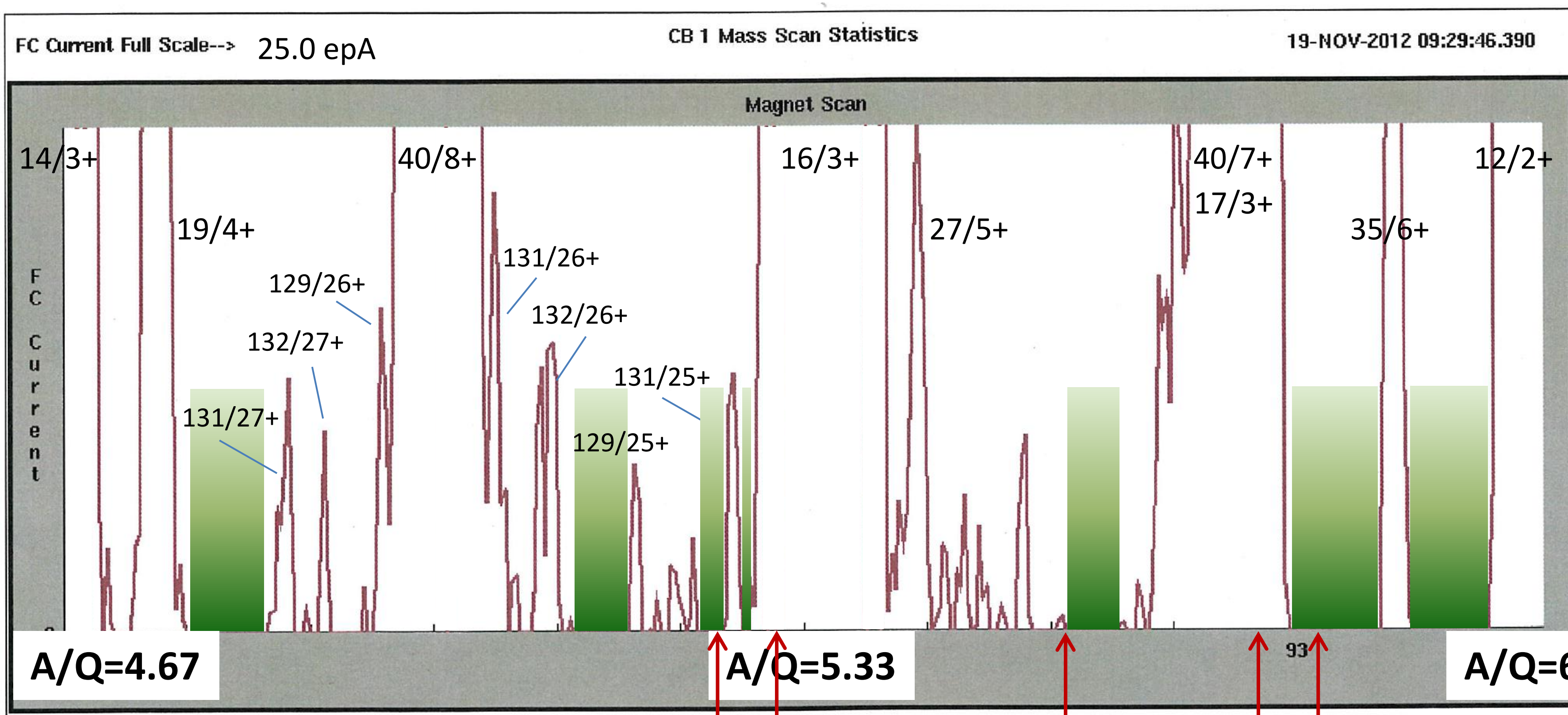


Mass spectrum (@A/q=7.68)



A/Q=4.67

ANL mass spectrum



Background current <0 epA

141/27+ ~1 kHz background rate in SBD

143/27+ 330 kHz background rate in SBD

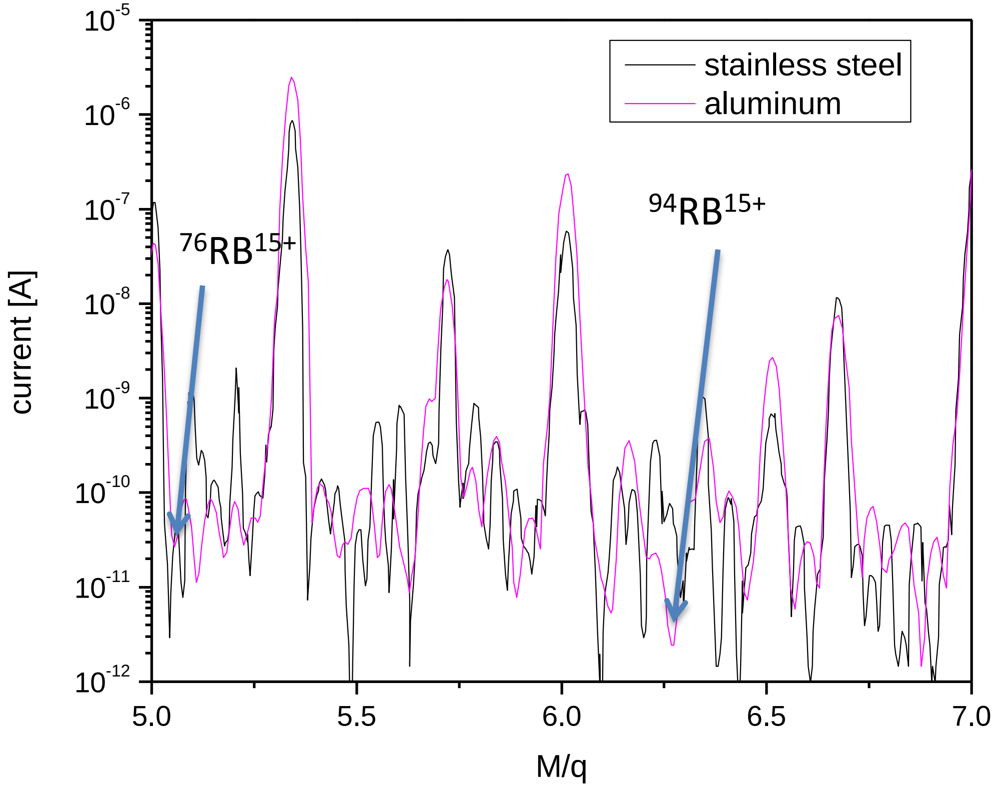
144/26+ 10 kHz background rate in SBD

143/25+ 66 kHz background rate in SBD

144/25+ 900 Hz background rate in SBD

SBD=Surface barrier detector

Latest progresses



mass spectrum after exchange of all electrodes to aluminum and coating plasma chamber and iron with pure aluminum

peaks from ^{56}Fe, ^{52,53}Cr… missing or reduced

$\Rightarrow$new test with ^{76,94}Rb

background identified

$^{76}Rb^{15+}$ A/q=5.06

$^{61}Ni^{12+}$, $^{76}Se^{15+}$, $^{76}Ge^{15+}$

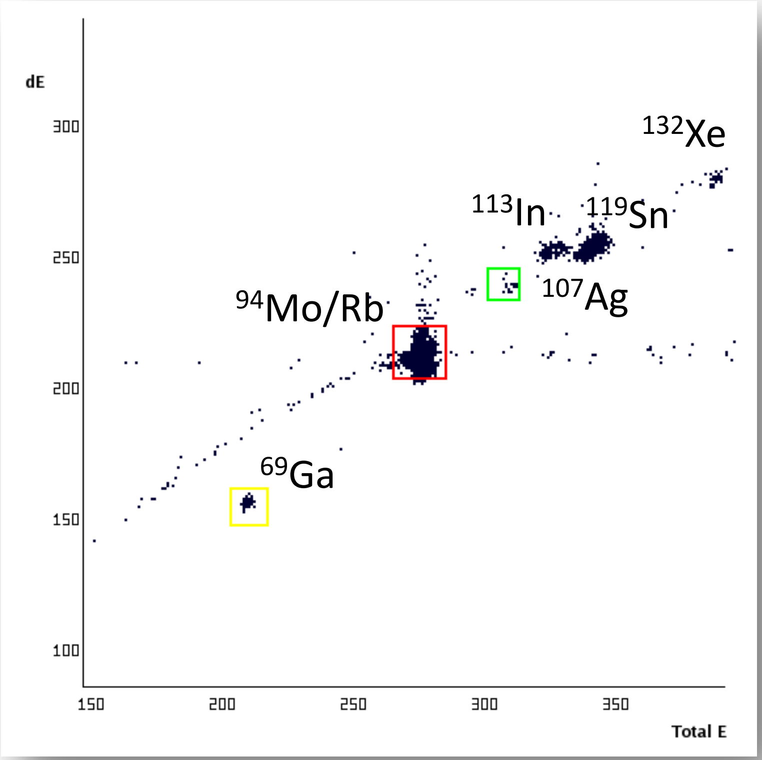
$^{94}Rb^{15+}$ A/q=6.26

$^{69}Ga^{12+}$, $^{94}Mo^{15+}$, $^{107}Ag^{17+}$, $^{113}In^{18+}$, $^{119}Sn^{19+}$, $^{132}Xe^{21+}$,

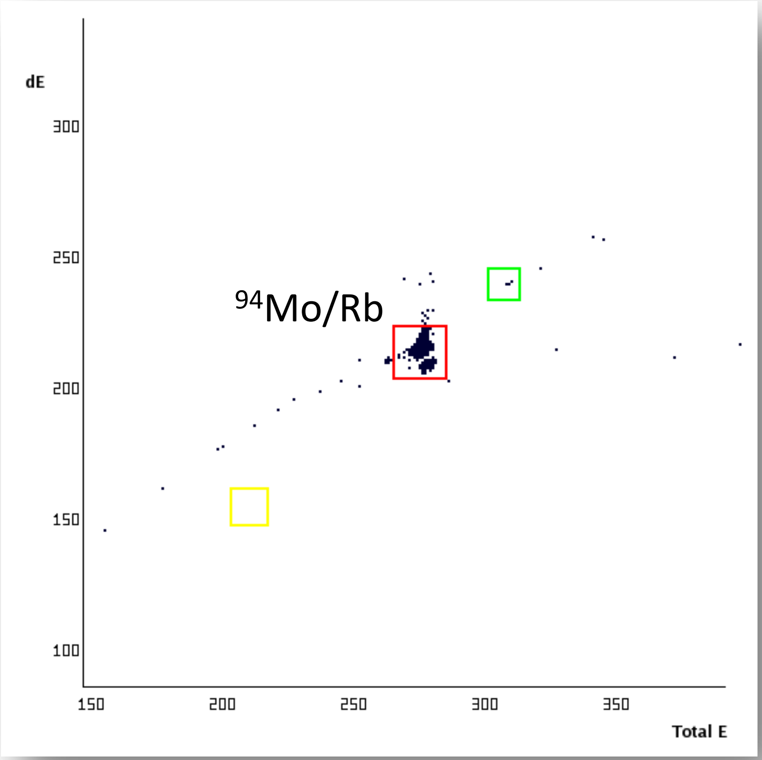
Latest progresses

using LINAC chain as mass filter (M/ΔM≈1000)
additional stripping at 1.5 MeV/u to $^{94}Rb^{22+}$

Before final filtration



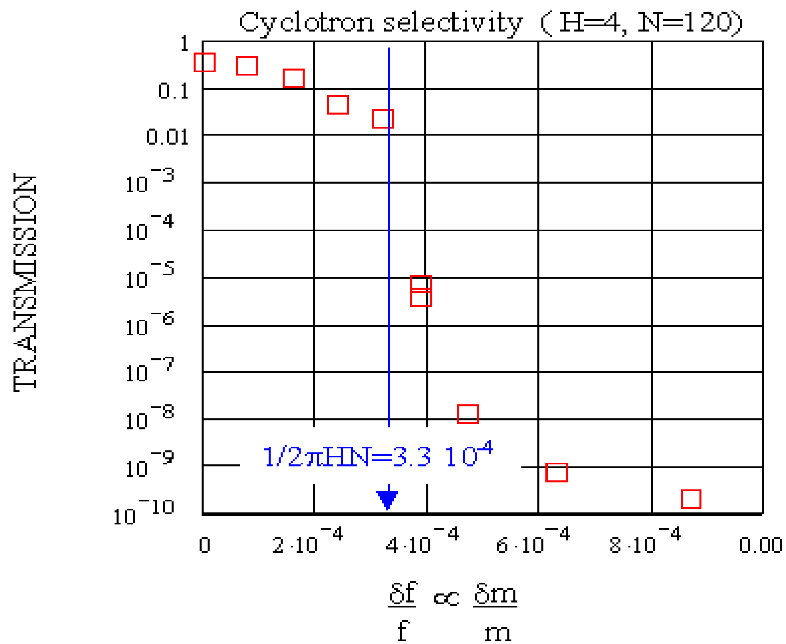
After final filtration



SPIRAL 1 & 2 post-accelerator

Nanogan ECRIS source

CIME cyclotron



B. Jacquot et al, *GANIL status report*

http://arxiv.org/ftp/nucl-ex/papers/0502/0502016.pdf

Suppression ~10 for R=m/δm~1/(2πHN) up to 6000

Suppression ~10^6 for δm/m=5.10^{-4}

Towards the future

- Future plans
  - Ongoing R&D EBIS
    - New EBIS charge breeder @ NSCL
    - EBIS debuncher GANIL
    - HEC^2 EBIS @ ISOLDE
  - SPIRAL 1, 2 and SPES ECRIS charge breeders

Towards the future

- Future plans
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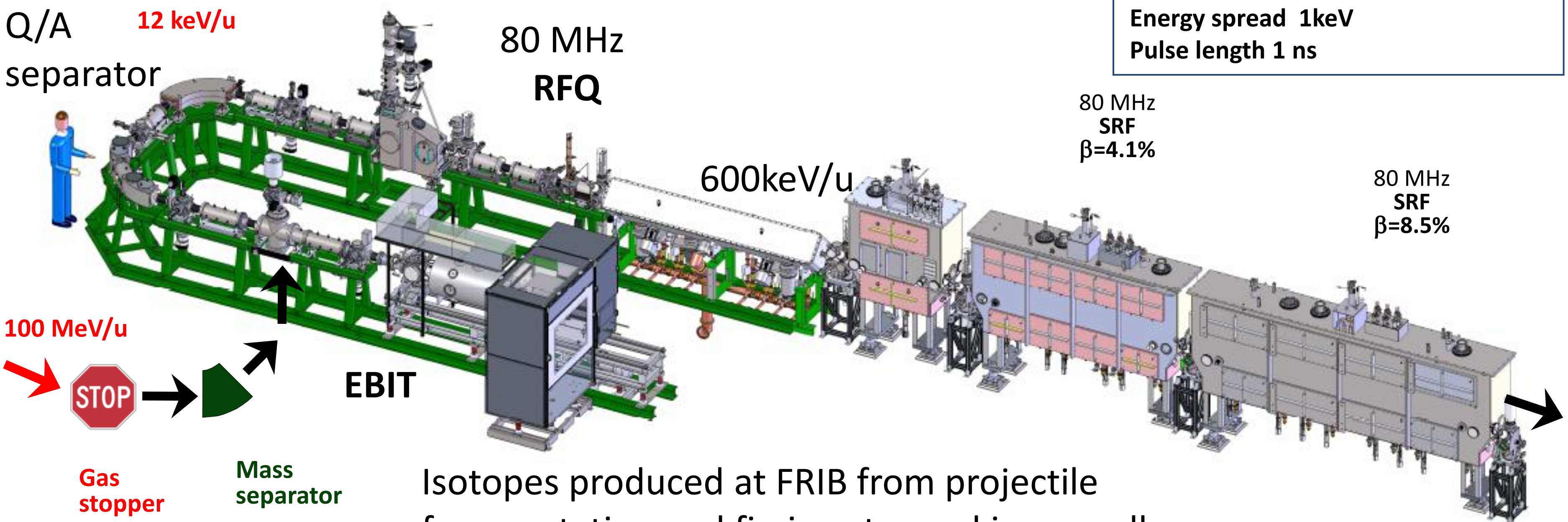
ReA facility: in comissionning

- See talk D. Leitner
- See poster A. Lapierre

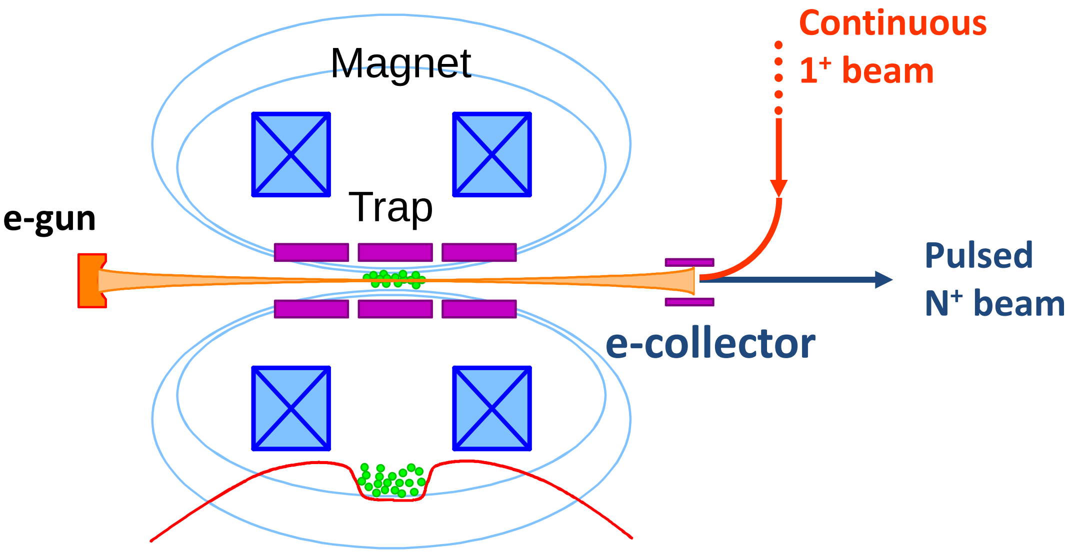
Energy 0.3- 3 MeV/u for ^{238}U, higher for lighter ions
Energy spread 1keV
Pulse length 1 ns



Isotopes produced at FRIB from projectile fragmentation and fission stopped in gas cell

EBIT design: continuous accumulation

Over the barrier injection

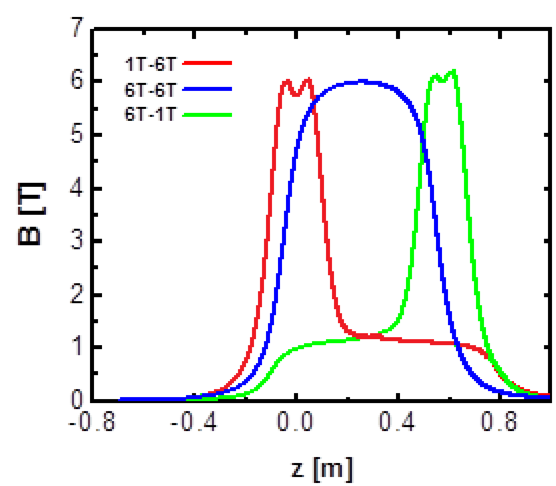


Expected performance

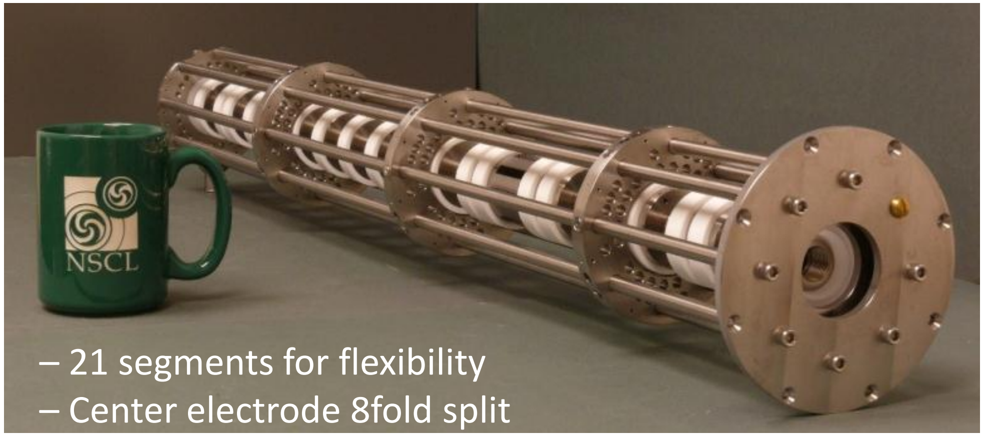
- Breeding times << 50 ms
- Efficiency > 50%
- Beam rates > 10^9/s
- Variable duty cycle
- Clean beams

EBIT: Key design parameters:

- magnetic field: up to 6 T
- **I_e= 0.5…5 A, E_e < 30keV**
- **current density: up to ~10^4 A/cm^2**



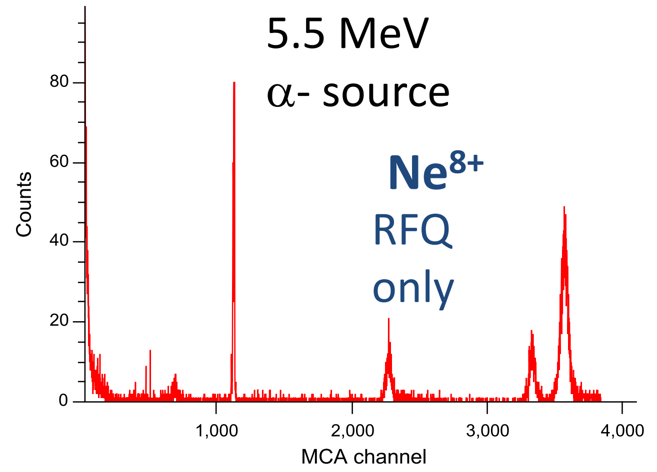
Trap: ~ 0.8m long



Recent achievements

July 2011:
Accelerated Ne^{8+}

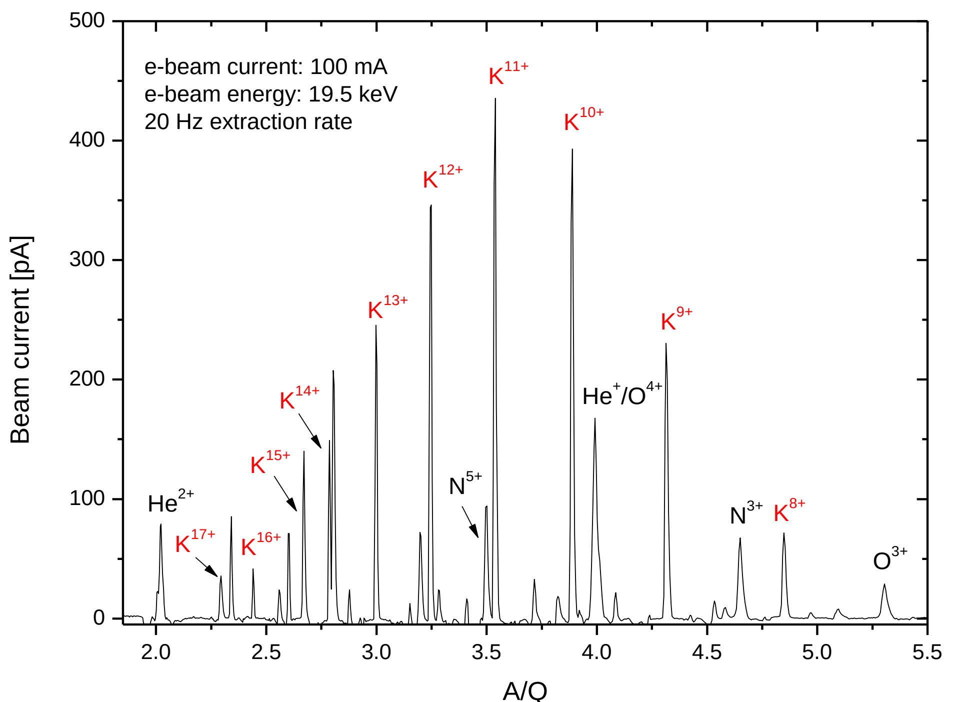
- From gas injector
- Pulsed extraction, up to 10Hz
- 2T field
- 15 keV, 36mA electrons
- 30kV extraction



RFQ +
1 SRF cavity
at different acceleration gradients

/ Energy

Mass-over-charge spectrum of charge-bred ^{39}K ions from TIS



See poster
A. Lapierre

May 2012:

First acceleration of charge-bred, externally produced ions with RFQ + SRF:

K^{16+} → ~ 1MeV/u

Towards the future

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  - Ongoing R&D EBIS
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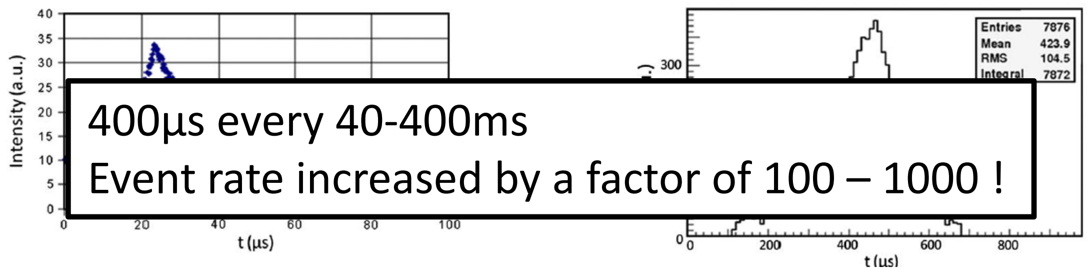
    - **EBIS debuncher GANIL**
    - HEC^2 EBIS @ ISOLDE
  - SPIRAL 1, 2 and SPES ECRIS charge breeders

EBIS beam debuncher

Slow extraction from REXEBIS



400µs every 40-400ms
Event rate increased by a factor of 100 – 1000 !

FWHM~30µs FWHM~400µs

D. Voulot et al., NIMB 266(2008)4103

CW EBIS charge breeder

Less dead time, piling-up and fake coincidence problems

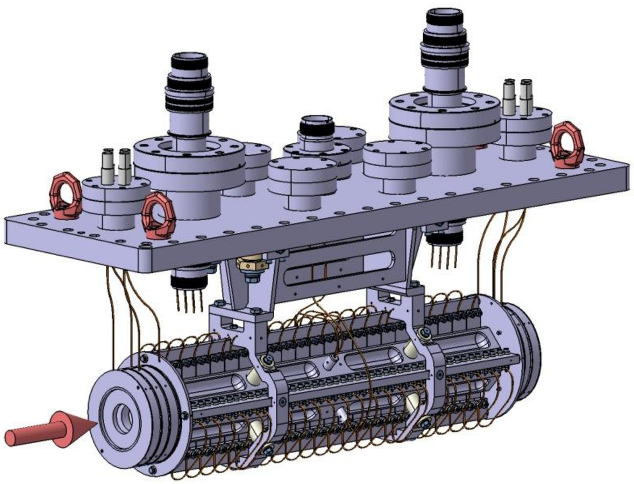
REX-EBIS and MINIBALL: data acquisition problems with intensities as low as 10^5-10^6 pps

EBIS challenges:

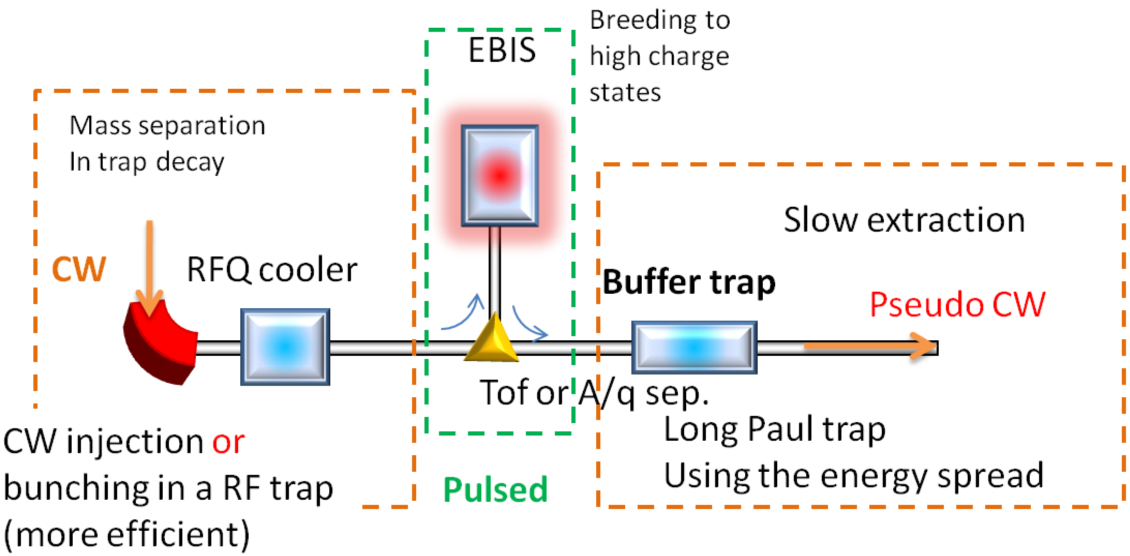
For mid term ISOL facilities time structure is the prime issue before space charge limitations

EBIS beam debuncher

- Linear RFQ under UHV



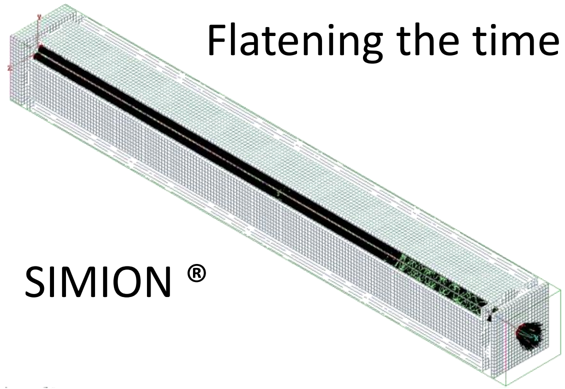
CW EBIS concept

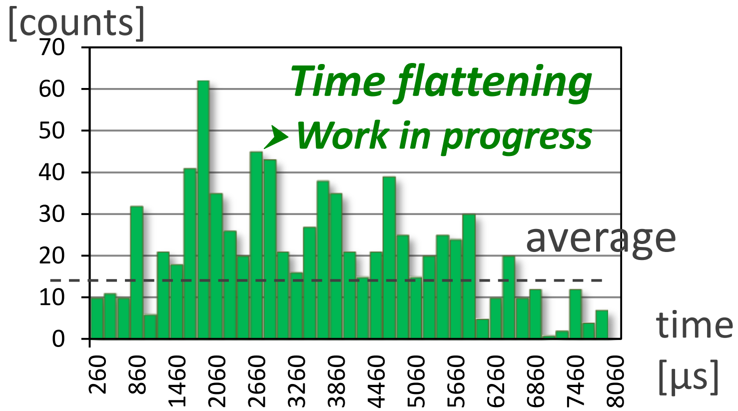


  - RF for radial confinement (400V, 2MHz)
  - DC potentials on the segments for longitunal space phase manipulation (a few 100V)

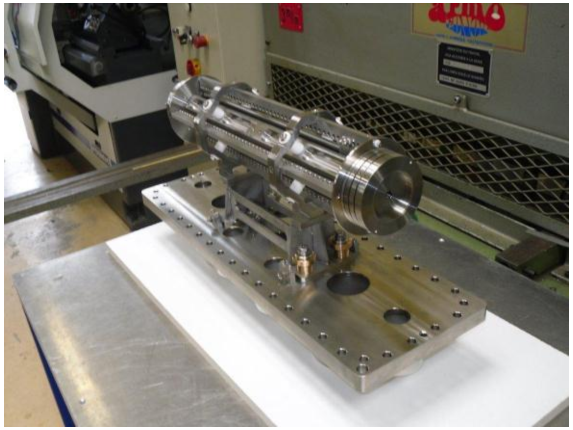
Latest progresses

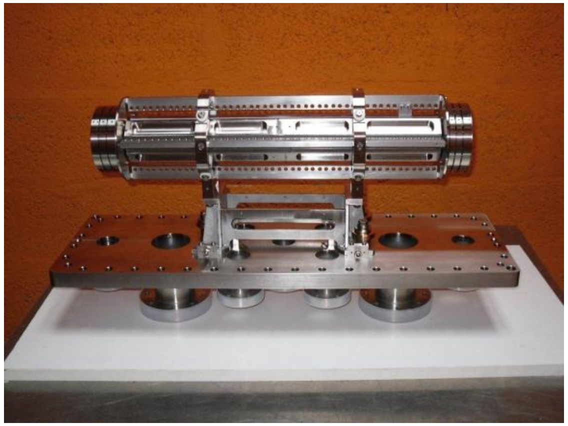
- Simulations - E. Traykov, GANIL





- Trap structure built by LPC Caen





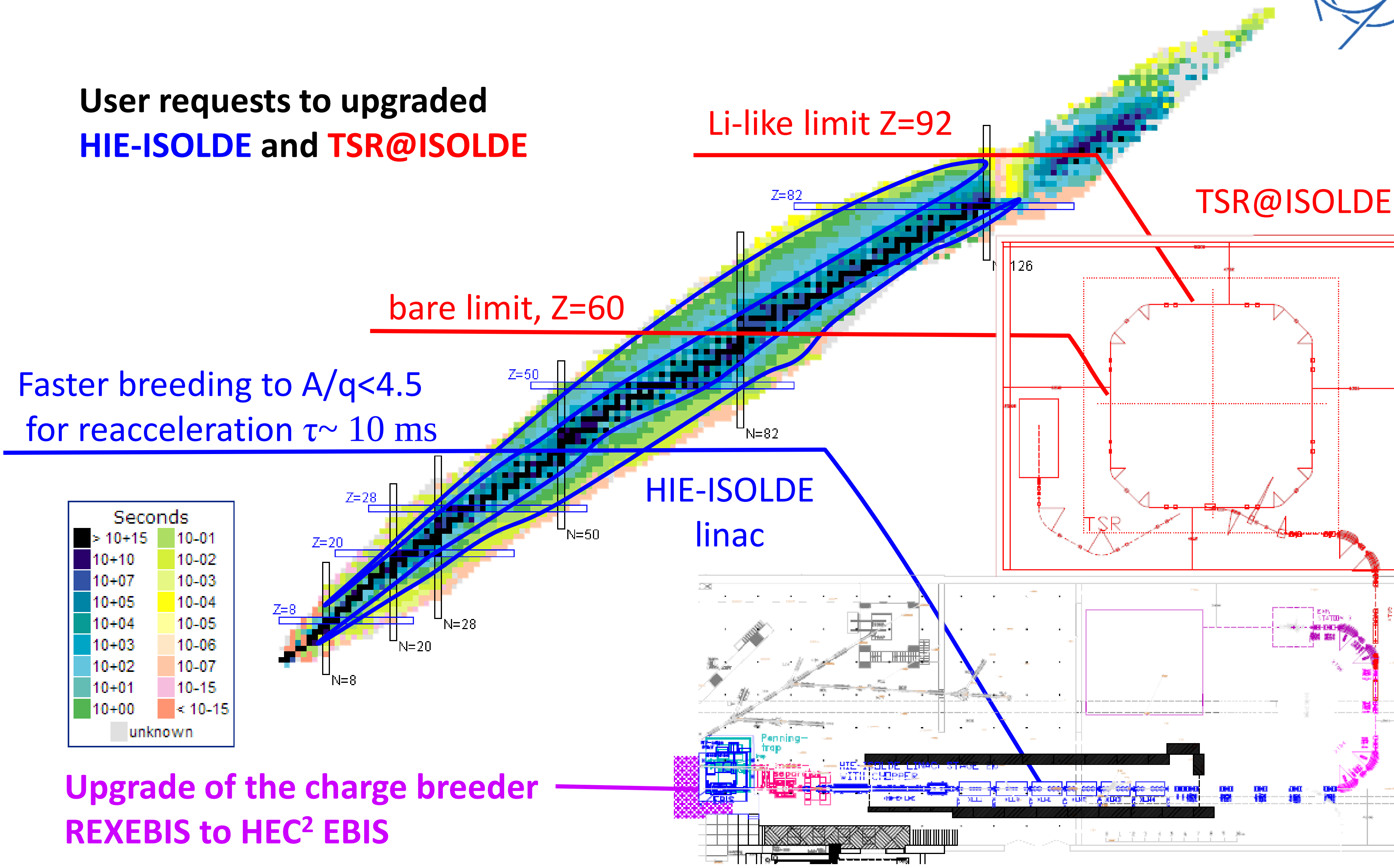
Tests in LPC Caen in 2013 with singly charged ions
Tests in GANIL in 2013-2014 with ECRIS chopped beams

Towards the future

- Future plans
  - Ongoing R&D EBIS
    - New EBIS charge breeder @ NSCL
    - EBIS debuncher GANIL
    - **HEC^2 EBIS @ ISOLDE**
  - SPIRAL 1, 2 and SPES ECRIS charge breeders

Motivation for upgrade of ISOLDE charge breeder at CERN

User requests to upgraded HIE-ISOLDE and TSR@ISOLDE



Upgrade of the charge breeder REXEBIS to HEC² EBIS

See talk R. Catherall

Implications for the charge breeder upgrade, HEC^2 EBIS

HEC^2 = High Energy Compression Current

Objectives:

- High-Z q=Z to Z-3

$$N_q = N_{q-1}\frac{\sigma_{q-1}^{II}(E_e)}{\sigma_q^{RR}(E_e)} \rightarrow E_{min} \sim 150\ keV$$

target abundance — Energy

- 100 Hz A/q<4.5/
  1Hz High-Z q=Z..Z-3

$$t_q = \frac{e}{J_e}\sum_{j=1}^{q}\frac{1}{\sigma_j^{II}(E_e)} \rightarrow J_e \sim 10^4\ A/cm^2$$

breeding time — Compression

- Breeder acceptance and throughput

$$I_{ion} \approx \frac{N_q}{t_q} \sim \frac{I_e^2 lB}{\sqrt{E_e}} \qquad \alpha \sim \sqrt{\frac{I_e}{\sqrt{E_e}}} \qquad I_e \sim 2-5\ A$$

Ion current — acceptance — Current

Main challenges:

- Increase current/compression by a factor of 10/5 compared to achieved so far
- Keeping HCI from escape and recombination (vacuum and cooling)

Work in progress: get the HEC^2 e$^-$ beam

BROOKHAVEN NATIONAL LABORATORY CERN

See Poster A. Shornikov, F. Wenander

Towards the future

- Future plans
  - Ongoing R&D EBIS
    - New EBIS charge breeder @ NSCL
    - EBIS debuncher GANIL
    - HEC^2 EBIS @ ISOLDE
  - **SPIRAL 1, 2 and SPES ECRIS charge breeders**

Gaining understanding on ECRIS charge breeding

- Optimization of the Phoenix charge breeder for SPES, SPIRAL and SPIRAL 2

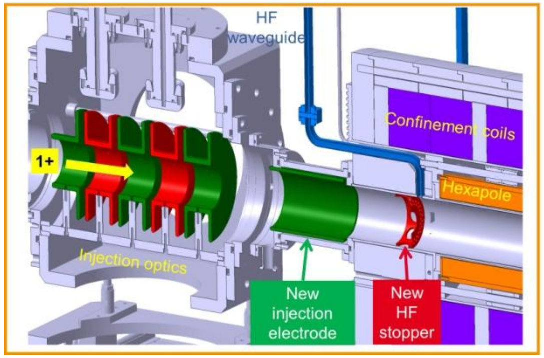
LPSC inventor of the ECR charge breeding method

First operational ECR charge breeder design: LPSC PHOENIX BOOSTER
Two copies Tested at ISOLDE and TRIUMF (presently operational)
A few upgrades performed

Symmetrization of the magnetic field at the 1+ beam injection

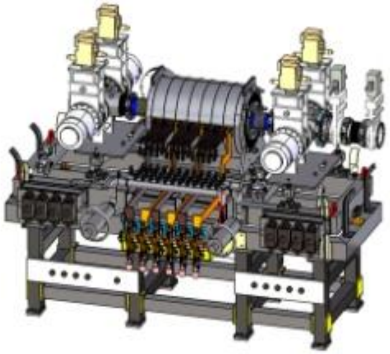
High voltage improvement

Grounded tube suppression, HF coupling improvement



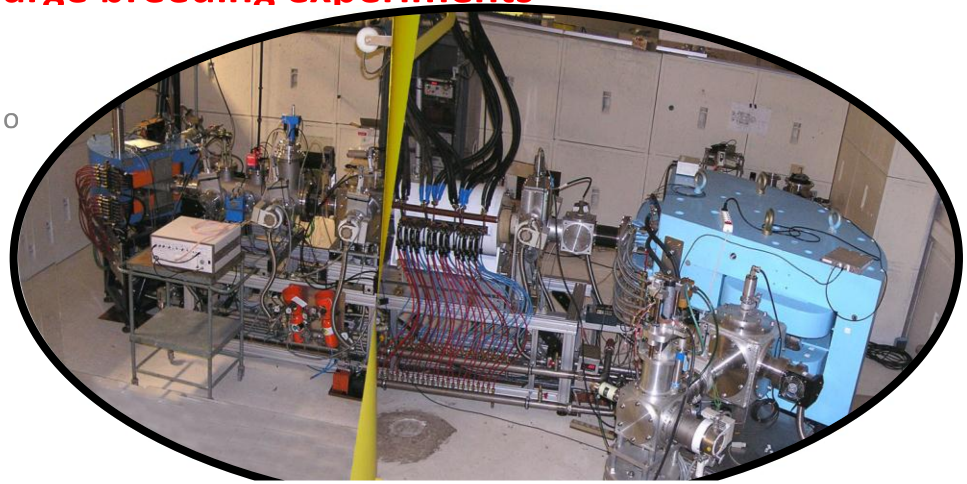
Unique test stand fully dedicated for ECR charge breeding experiments

Available for EMILIE experimental program, and for LPSC R&D



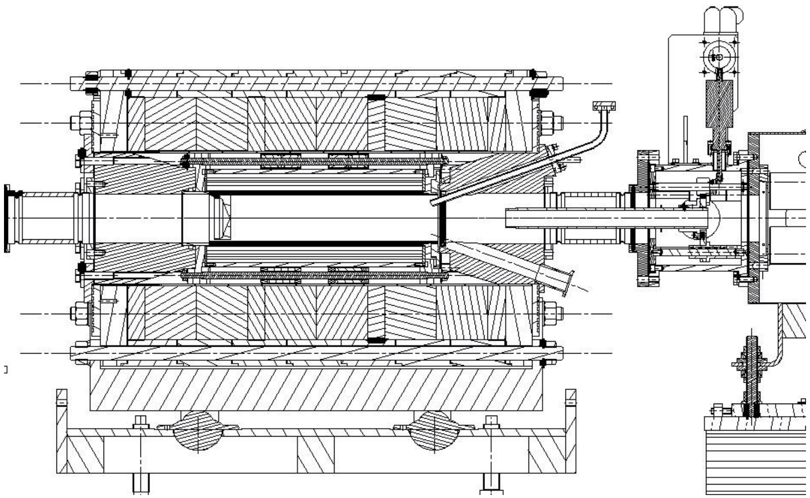
7th o

LPSC - SPIRAL2 charge breeder



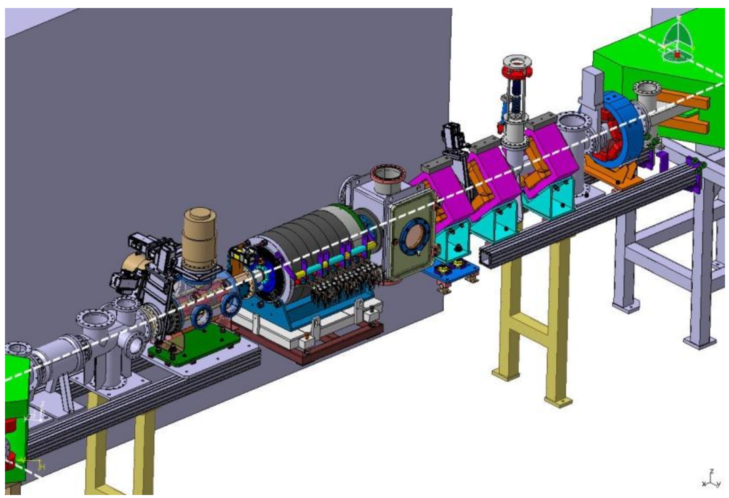
Improvement of the n+ beam optics: +15% charge breeding efficiencies

Phoenix charge breeder upgrade and installation at SPIRAL

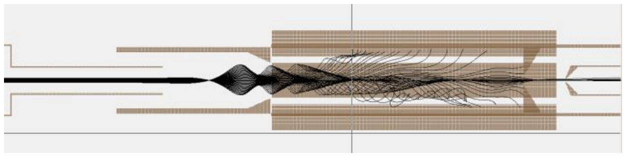


Remote controlled injection tube
Modified HF injection
UHV design

ENSAR : pure beams



Optimization towards light masses



SIMION ® calculations ongoing

Latest tests at ANL: up to 9.6% Na^{8+} and 17.7% for K^{10+}

Extensive simulation program at INFN

NUMERICAL SIMULATION ON:

***MW coupling to the Phoenix Booster*:**

- Influence of the Grounded Tube
- Taking into consideration the Magnetic profile

↓

CONCEPTUAL DESIGN OF A NEW PLASMA CHAMBER

***1+ Beam Capture*:**

- Influence OF the ECR plasma
- Low Mass Ions Injection
- Influence ON the ECR plasma

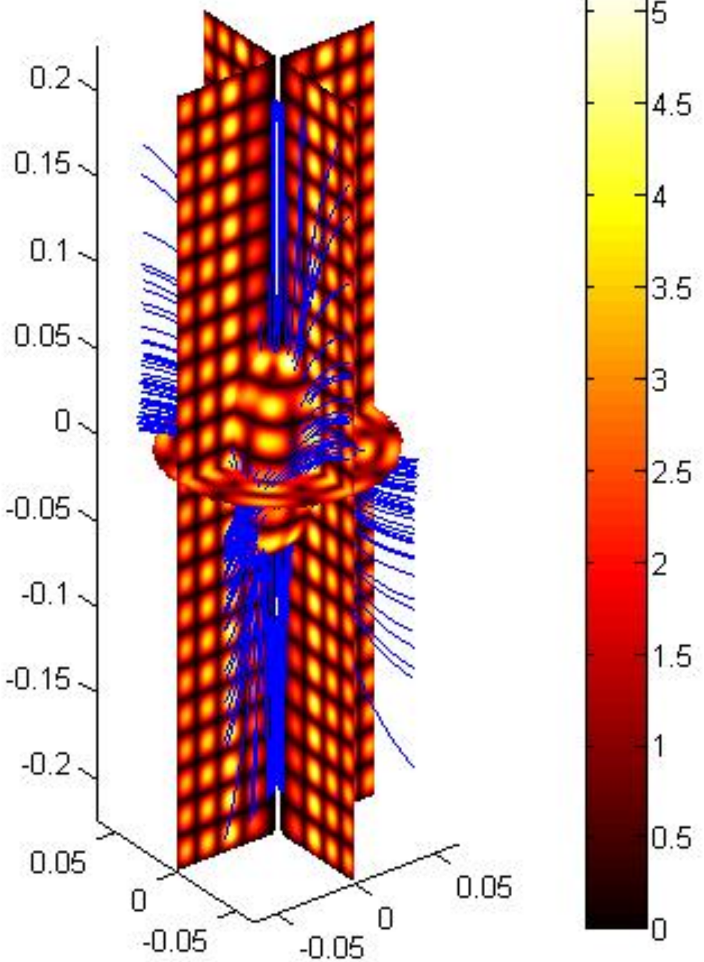
↓

INTEGRATE AN EXISTING ECR PLASMA SIMULATION TOOL DEVELOPED @ LNS

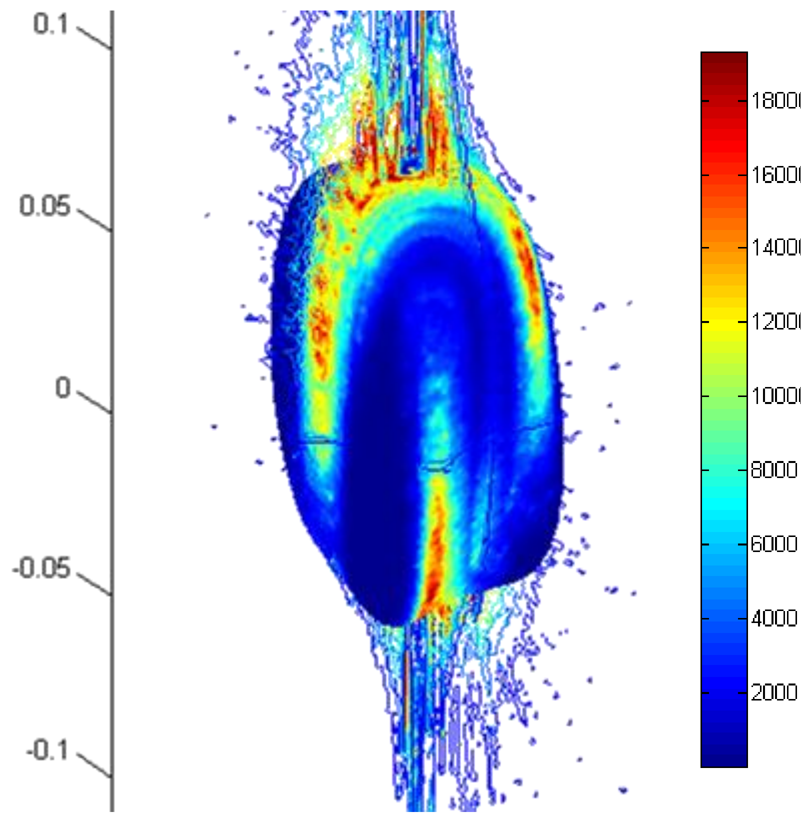
The pattern of the electromagnetic field influences also the plasma density distribution so:

WHICH IS THE INFLUENCE ON THE CAPTURE OF THE 1+ BEAM?

Electric field pattern



Plasma density distribution in proximity of ECR surface



D. Mascali et al., Proceedings of ECRIS 2010

NOTE that the plasma is almost completely confined inside the resonance surface

Conclusions

- High performance ECRIS and EBIS charge breeders are operational
  - High efficiency
  - High charge states
  - Short breeding times (<<1s)
- Beam purity remains an issue, especially with ECRIS charge breeders
- R&D going on
  - EBIS charge breeders
    - Developing CW capabilities
    - Shortening charge breeding time by higher electron beam compression
    - Enlarging capacities by higher electron currents
  - ECRIS charge breeders
    - Improving on beam purity !
    - Understanding the capture process, optimizing performances

Thanks a lot for your attention!
Many thanks to all my friends and colleagues!

GANIL
L. Maunoury
E. Traykov
P. Jardin

LPC Caen
G. Ban
J. F. Cam
C. Vandamme

LPSC
T. Lamy
J. Angot

TRIUMF
F. Ames

ANL
R. Vondrasek

ISOLDE
F. Wenander
A. Shornikov

KEK
S. Jeong

NSCL
S. Schwarz
G. Bollen

INFN LNL
A. Galatà
G. Prete

INFN LNS
L. Celona

JYFL
H. Koivisto

J. Angot, G. Ban, L. Celona, J. Choinski, , P. Delahaye (GANIL IN2P3, coord.), A. Galata (INFN, deputy coord.), P. Gmaj, A. Jakubowski, P. Jardin, T. Kalvas, H. Koivisto, V. Kolhinen, T. Lamy, D. Lunney, L. Maunoury, A. M. Porcellato, G. F. Prete, O. Steckiewicz, P. Sortais, T. Thuillier, O. Tarvainen, E. Traykov, F. Varenne, and F. Wenander

Backup slides

The **EMILIE** project

« Enhanced Multi-Ionization of short Lived Isotopes for EURISOL »

Charge breeding techniques for ISOL facilities

- Started 1/1/2012
- Web site: http://www.emilie-eurisol.eu/
- Consortium agreement being finalised
- Logo found
- Activities summarized in the following!

Partner	Funds
IN2P3 (coord)	250k€
INFN	80 k€
HIL	159 k€
JYFL	24 k€

Consortium of 9 europeans laboratories

J. Angot, G. Ban, L. Celona, J. Choinski, , P. Delahaye (GANIL IN2P3, coord.), A. Galata (INFN, deputy coord.), P. Gmaj, A. Jakubowski, P. Jardin, T. Kalvas, H. Koivisto, V. Kolhinen, T. Lamy, D. Lunney, L. Maunoury, A. M. Porcellato, G. F. Prete, O. Steckiewicz, P. Sortais, T. Thuillier, O. Tarvainen, E. Traykov, F. Varenne, and F. Wenander

Modeling of electron and ion dynamics with Monte-Carlo calculations: ELECTRONS

A MATLAB code solves the equation of motion of a single particle:

$$\frac{d\vec{v}}{dt} = \begin{cases} \dfrac{q}{M}\left[\vec{v}\times\vec{B}+\vec{E}_s\right] & (i) \\ \dfrac{q}{m}\left(1-\dfrac{v^2}{c^2}\right)^{3/2}\left[\vec{v}\times\vec{B}_S+\vec{v}\times\vec{B}_{em}+\vec{E}_{em}-\dfrac{1}{c^2}\left(\vec{E}_{em}\cdot\vec{v}\right)\vec{v}\right] & (e) \end{cases}$$

$$\begin{aligned}
\dot{x} &= v_x \\
\dot{y} &= v_y \\
\dot{z} &= v_z \\
\dot{v}_x &= F(v)[(v_y B_z - v_z B_y) + (v_y B_{em_z} - v_z B_{em_y}) + E_{em_x} - \\
&- \frac{1}{c^2}(E_{em_x} v_x + E_{em_y} v_y) v_x] \\
\dot{v}_x &= F(v)[(v_z B_x - v_x B_z) + (v_z B_{em_x} - v_x B_{em_z}) + E_{em_y} - \\
&- \frac{1}{c^2}(E_{em_x} v_x + E_{em_y} v_y) v_y] \\
\dot{v}_z &= F(v)[-B_x v_y + v_x B_y - B_{em_x} v_y + v_x B_{em_y} - \\
&- \frac{1}{c^2}(E_{em_x} v_x + E_{em_y} v_y) v_z]
\end{aligned}$$

Magnetostatic field for the plasma confinement

Magnetic and electric fields associated with the pumping wave

MATLAB solves the six first order ODEs by means of the "*ode45*" Runge-Kutta routine.

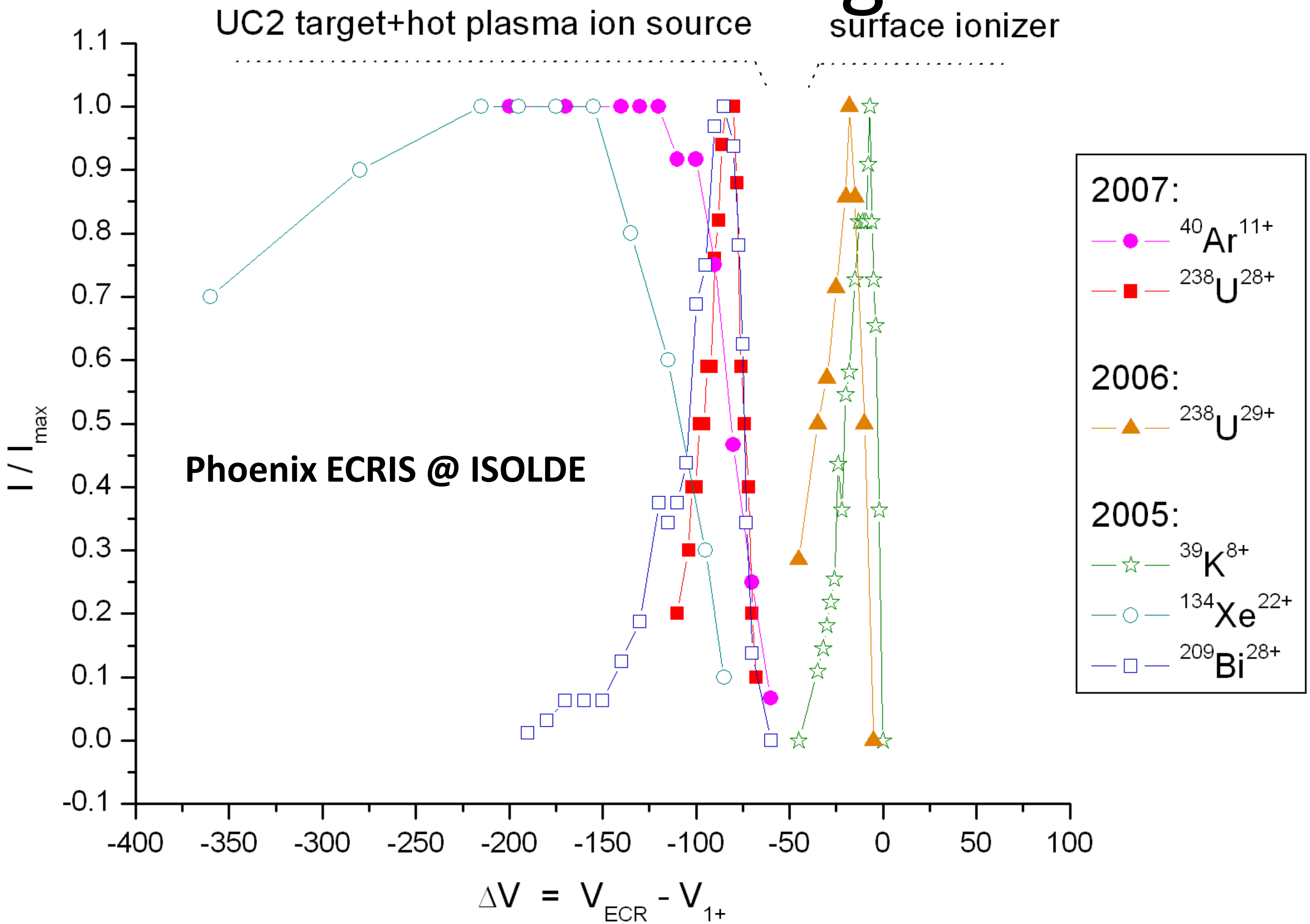
- 3000 electrons/week, 8 CPU

- $\delta t = 10^{-12}$ s ~ 10 points of integration per Larmor radius

- **Collisions are taken into account**

- Fully 3D calculations with B-min structure

ΔV tuning



UC2 target+hot plasma ion source
surface ionizer
Phoenix ECRIS @ ISOLDE
I / I_max
ΔV = V_ECR - V_1+
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-400
-350
-300
-250
-200
-150
-100
-50
0
50
100
2007:
40Ar11+
238U28+
2006:
238U29+
2005:
39K8+
134Xe22+
209Bi28+

Identification of beam impurities originating from CB (ECR plasma constituents)

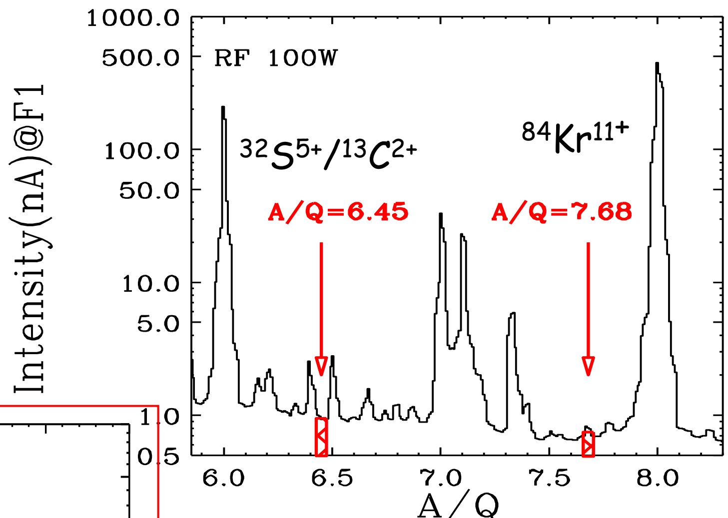
Impurity for ions with ***A/q between 6 and 8***

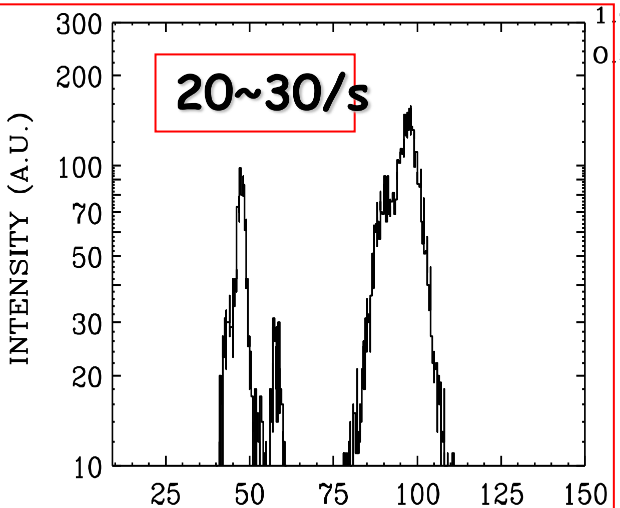
:A/q selection by CB analyzing magnet / Beam transport (~30m BTL) / Acceleration

➔ Significantly, reduced by

: ***Aluminum Surface-cleaning*** of the inner wall seeing the ECR plasma by sandblasting, washing and backing. (A1050 (pure-Al), A6063(Al-Mg-Si))

TRIAC
Tokai Radioactive Ion Accelerator Complex





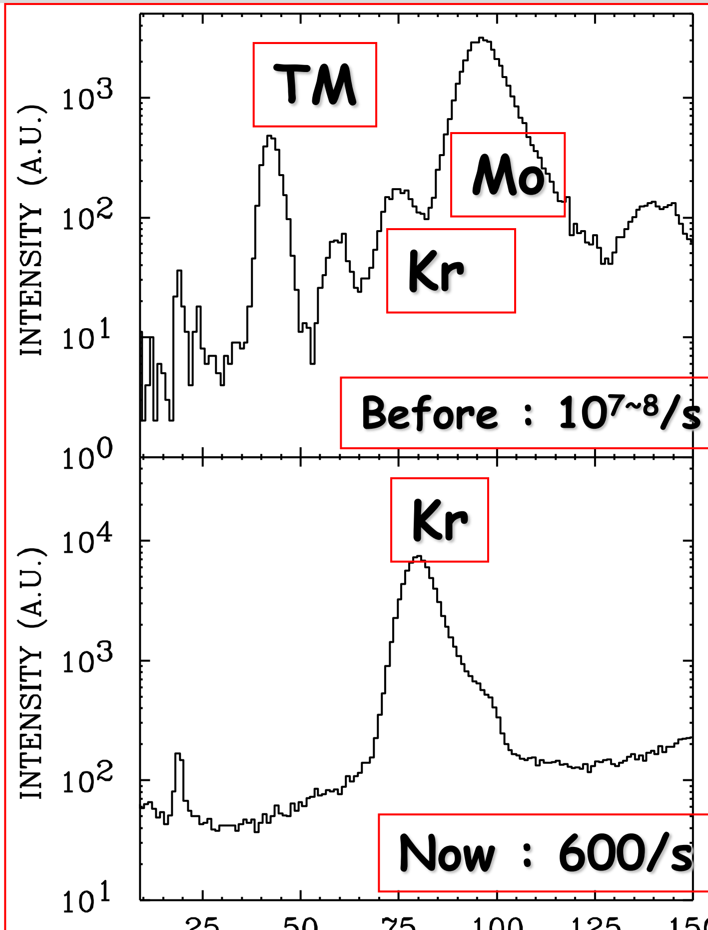
Mass spectrum (@A/q=6.45)

A/q distribution

@ CB analyzing magnet

The A/q selection for further transport and acceleration are indicated by arrows.

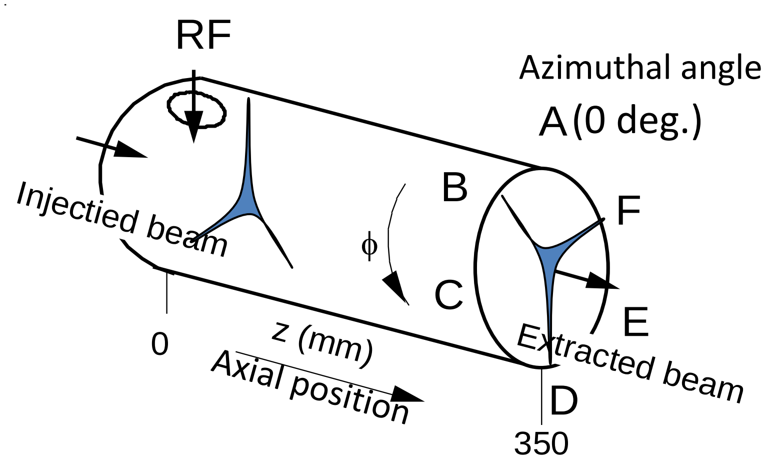
Ion species very close to the windows are also presented.

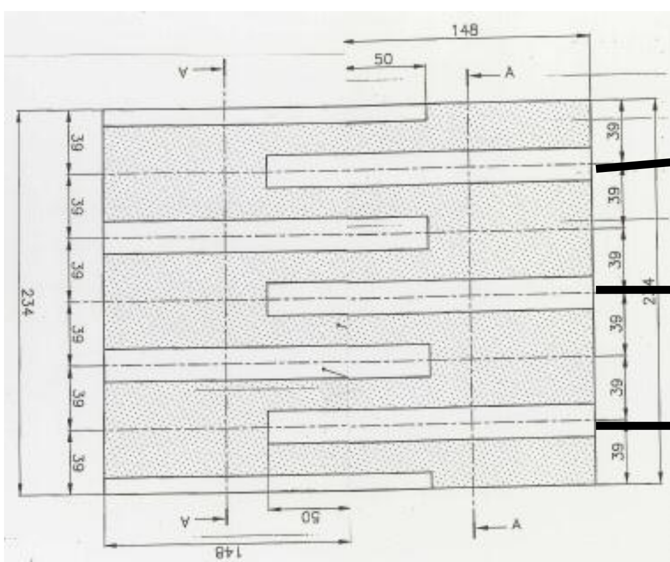


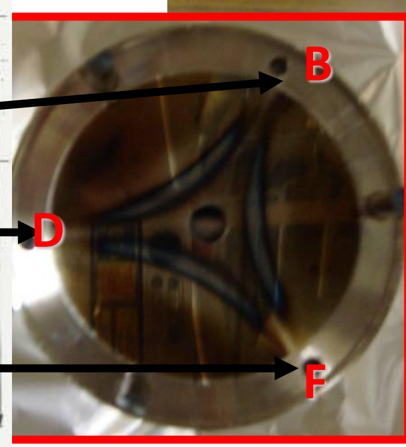
Mass spectrum (@A/q=7.68)

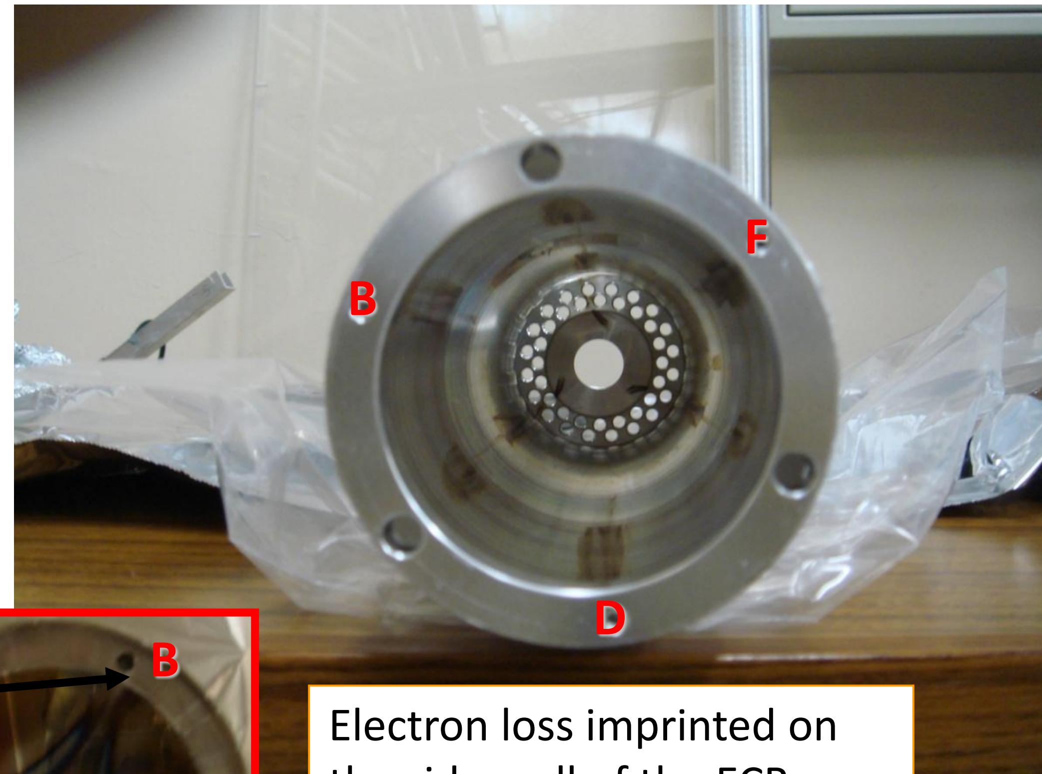
Electron loss pattern in ECRIS ~ Ion loss pattern ?

- A hint to understand the small ε_{CB} for non-gaseous element -



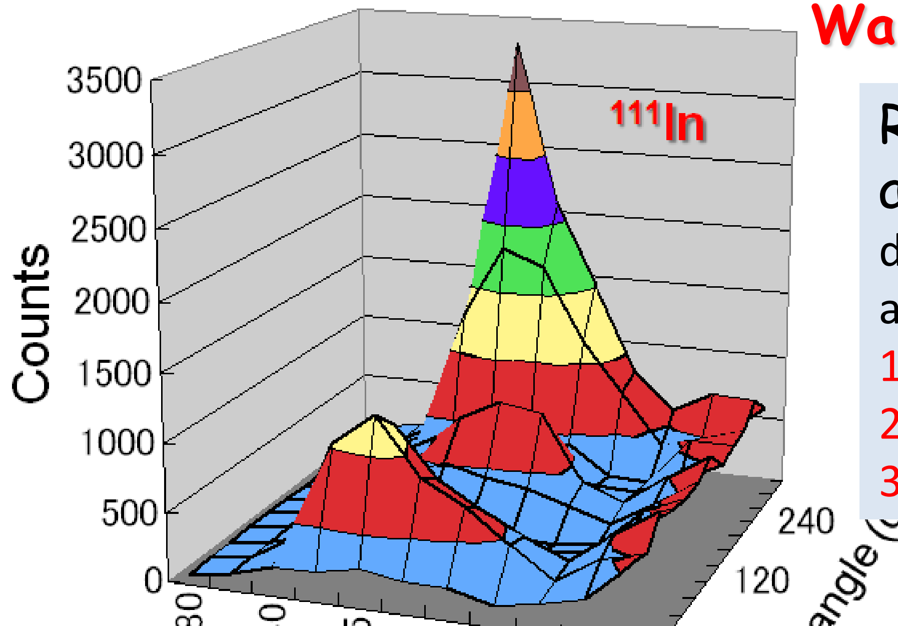






Electron loss imprinted on the side-wall of the ECR plasma chamber and at the extraction side.

Wall distribution of ions injected for CB

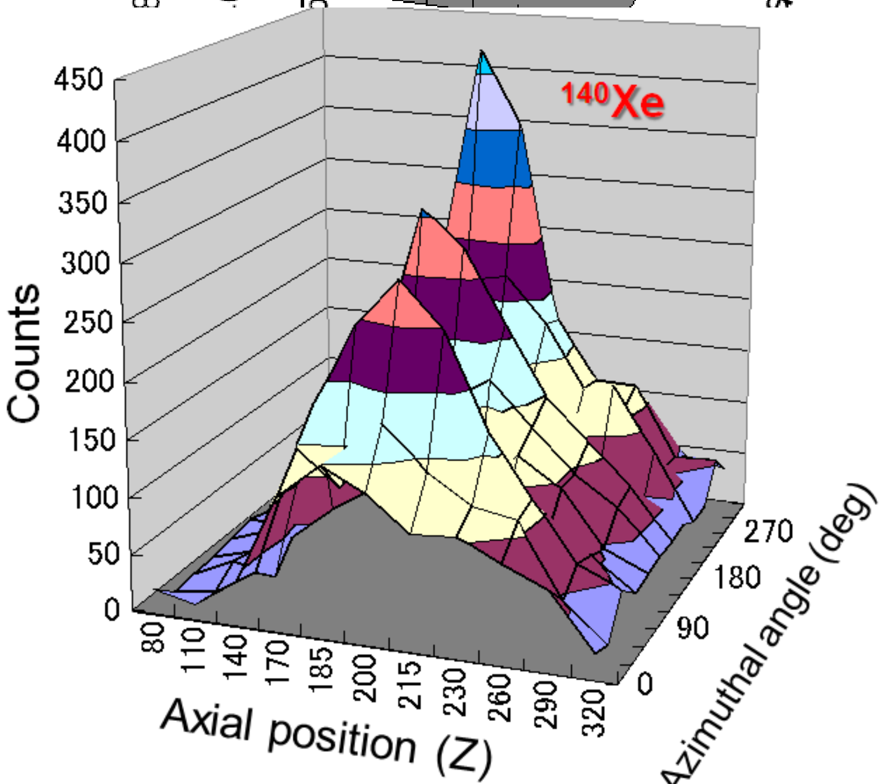


Residual activities on plasma chamber after the CB operation

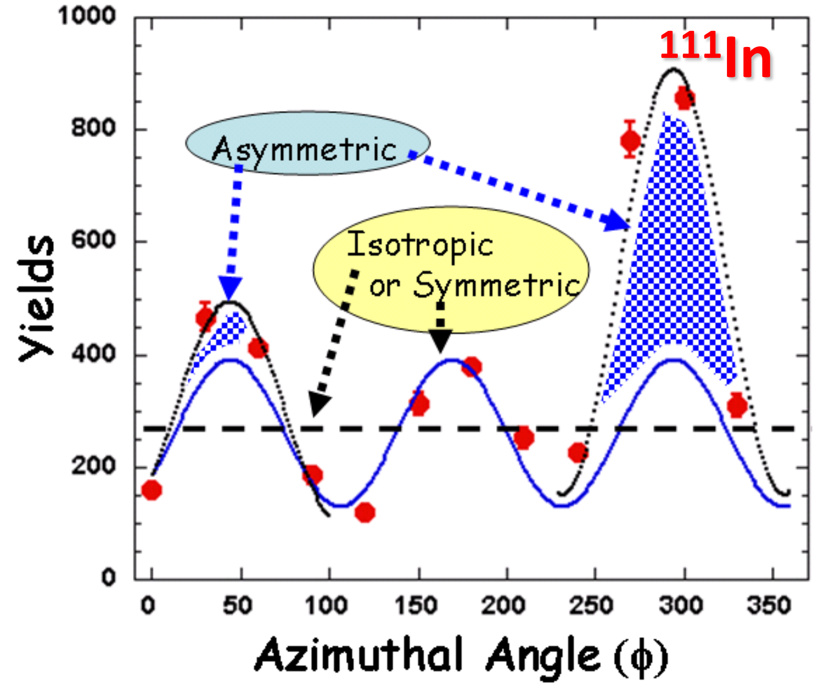
decomposed into **3 parts**

according to the azimuthal dependence;

1. ***Isotropic pattern***
2. ***120 –degrees azimuthally symmetric pattern***
3. ***Asymmetric pattern***



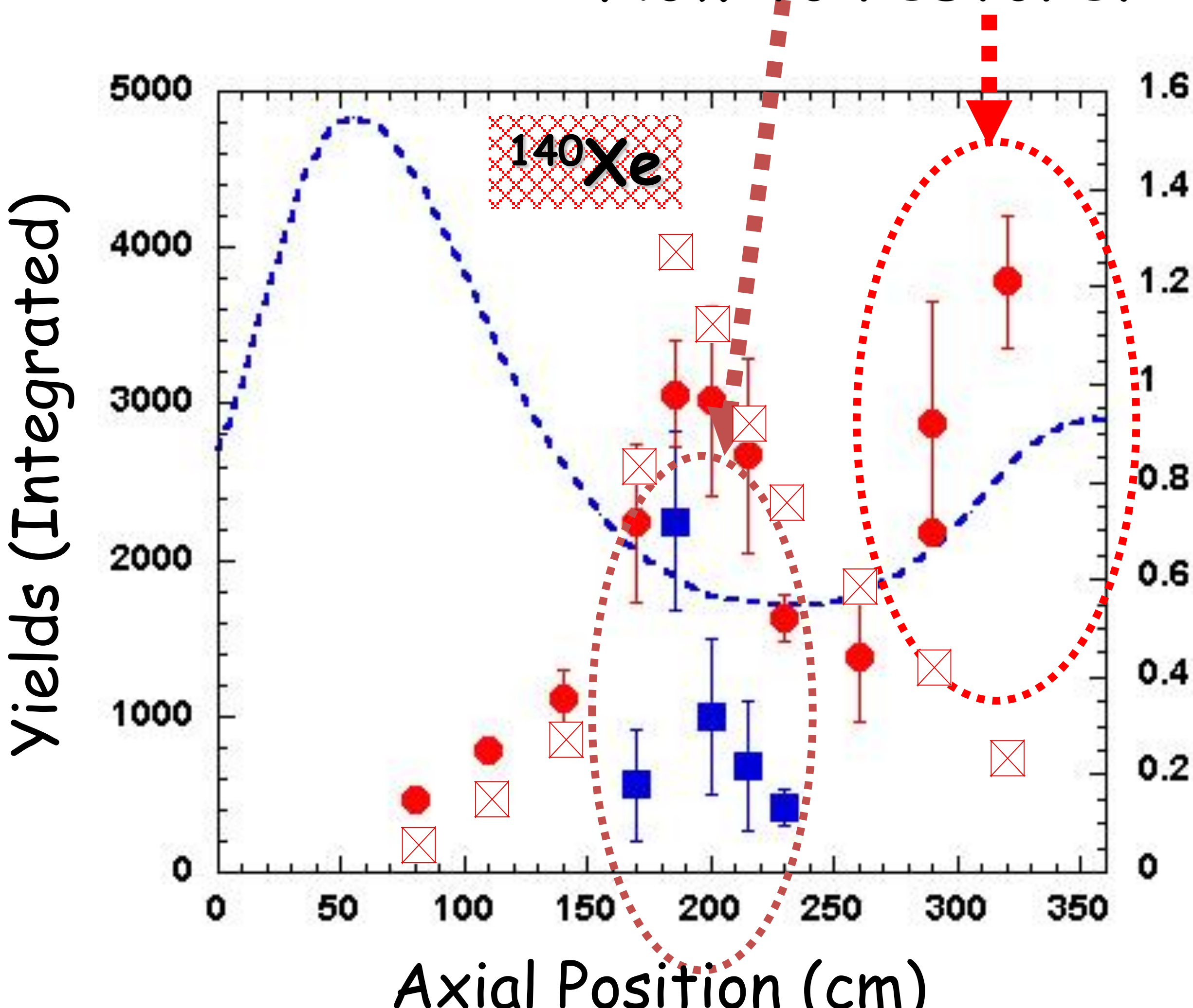
Azimuthal distribution @ Z~200



Longitudinal distribution
^{111}In vs. ^{140}Xe

- 40% activities were found around extraction side.
  - Not best position of the anode ?
  - Poor radial confinement ?
- 14% was found as asymmetry
  - Not best beam injection

Is it possible restore?
How to restore?



Buffer trap configuration

Segmented trap in UHV

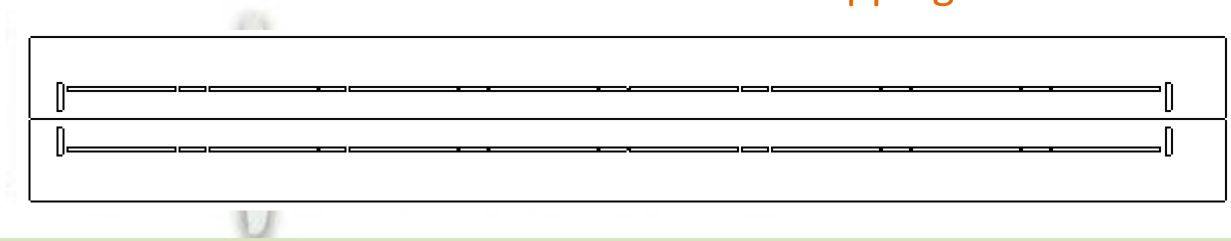
Entrance electrode

No buffer gas, UHV design

DC for axial + RF for radial trapping

Exit electrode

Injection from EBIS



CW beam

Pulsed N+ beams
Width = 30-40 μs

Example for ^{132}Sn
T = 180 ms
$\Delta E = 10 * q$ eV?
Q = +33

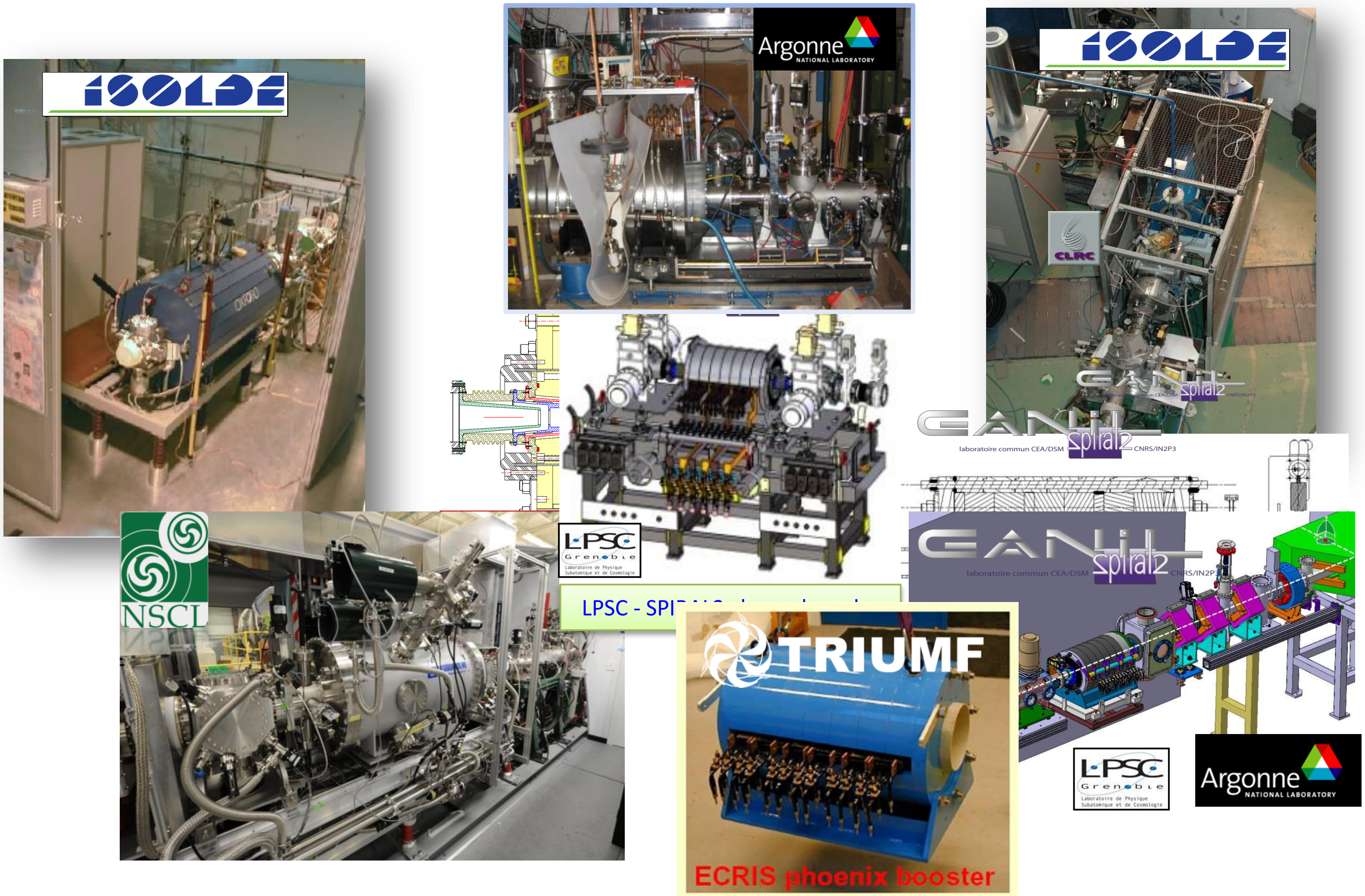
- CW beams using

1) Injection in a long trapping area (flight time = injection pulse duration)
2) Segmentation for forming bunches by raising barrier potentials
3) E-spread for slow extraction of the bunches from the buffer trap one after the other

Segmentation allows for a lot of flexibility
One of the many DC programs to be investigated for a "perfect CW"

EBIS/T and ECRIS charge breeders

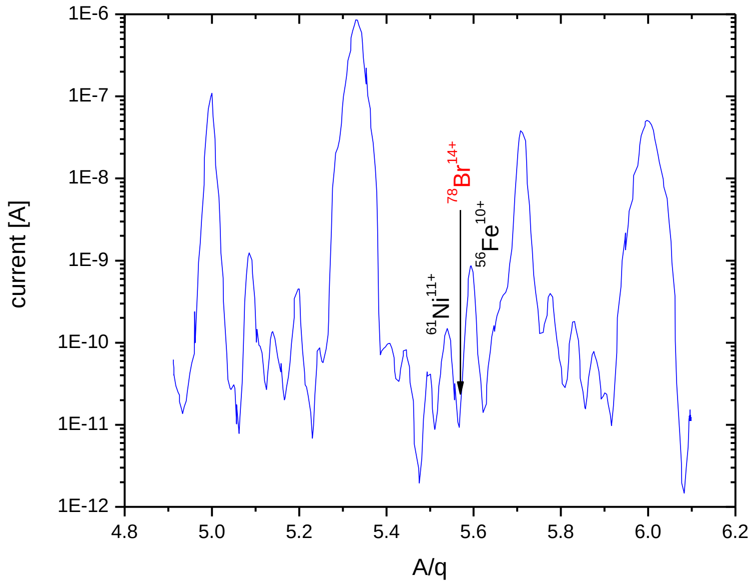
for radioactive ion beam facilities



Beam purity issue at TRIUMF

A number of charge bred radioactive isotopes

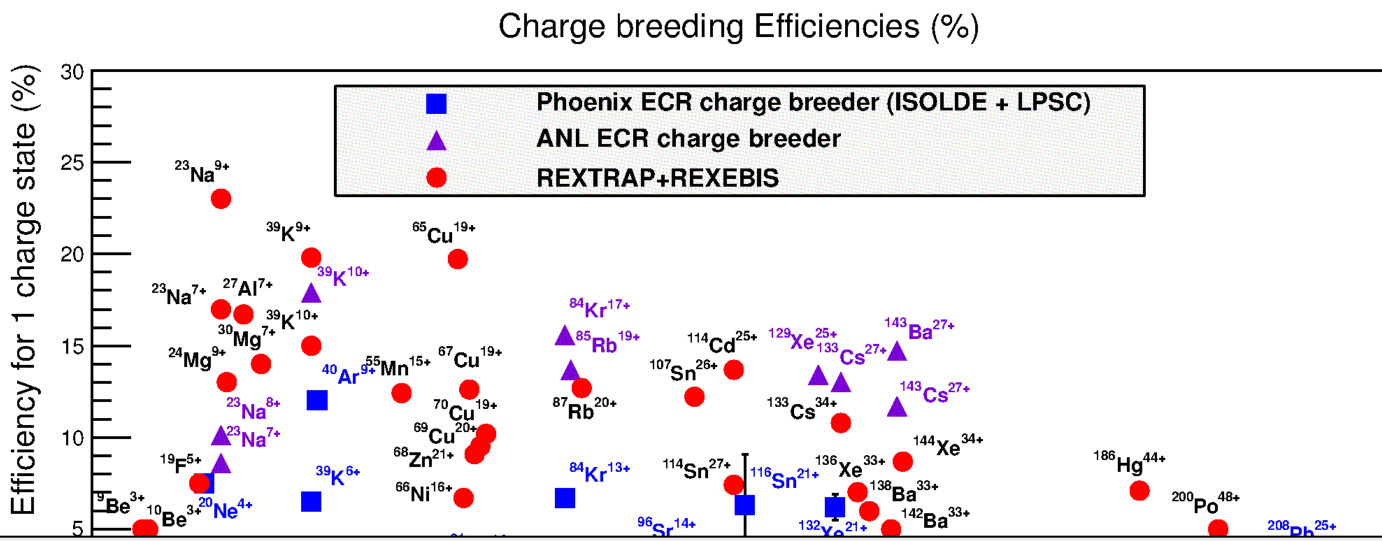
isotope	q	A/q	efficiency [%]	I (in) [1/s]	background [pA]
46K	9	5.11	0.5	4.0E4	340
64Ga	13	4.92	0.7	8.4E4	150
64Ga	14	4.57	0.75	8.4E4	210
74Br	14	5.28	3.1	3.2E7	10000
74Br	15	4.93	2.1	3.2E7	25
78Br	14	5.57	4.5	2.8E7 AlBr	20
74Kr	15	4.93	6.2	2.1E6	25
76Rb	15	5.07	1.68	3.8E6	15
80Rb	13	6.15	1.17	5.7E7	35
80Rb	14	5.71	1.1	5.7E7	70000
122Cs	19	6.42	1.1	3.1E5	6
124Cs	20	6.2	1.37	2.75E7	50



$^{78}Br^{14+}$ (1E6 ion/s) A/q = 5.57 amu/e

- injected as AlBr from ZrC target
- accelerated to 5MeV/u
- measured at TIGRESS detector
- background ≈ 20 pA

Fighting against large background from stainless steel and residual gases



REX-EBIS

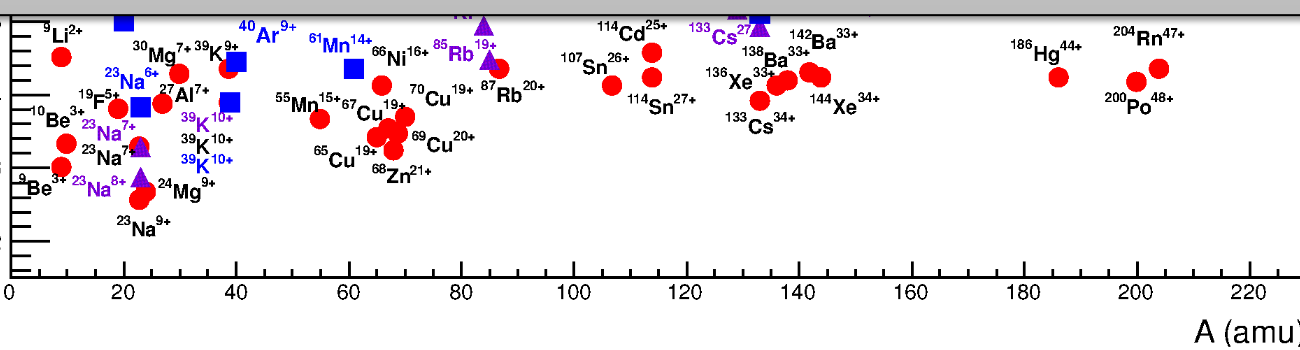
F. Wenander , , in International Symposium on Electron Beam Ion Sources and Traps, Stockholm, Sweden, 7–10 April 2010, 2010 JINST 5 C10004.

ANL charge breeder

R. Vondrasek, A. Levand, R. Pardo, G. Savard, and R. Scott, Rev. Sci. Instrum. 83, 02A913 (2012)

Phoenix charge breeder

P. Delahaye, O. Kester, C. Barton, T. Lamy , M. Marie-Jeanne and F. Wenander, Eur. Phys. J. A 46 (2010)421-433 and ref. therein



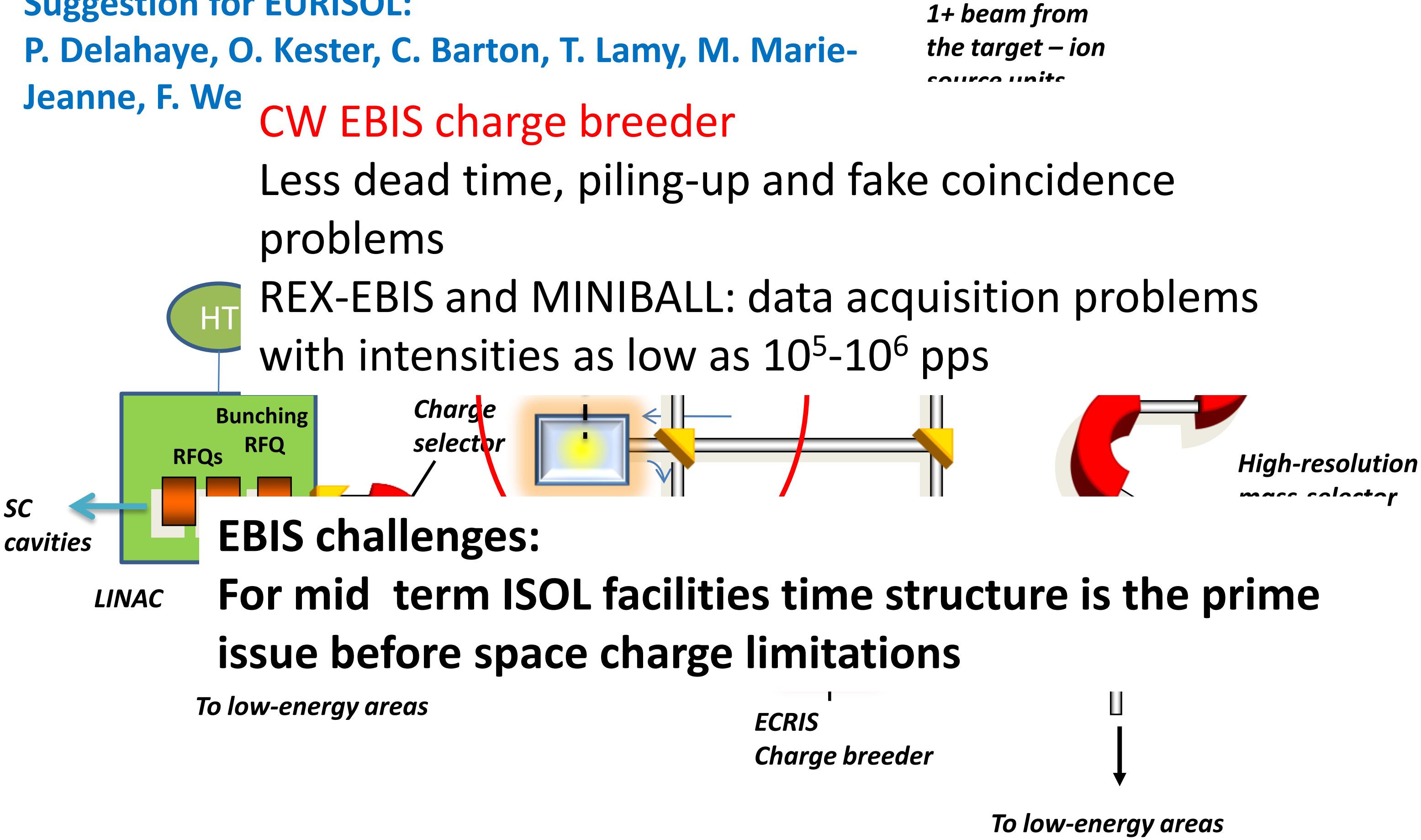
EBIS debuncher: motivations

Suggestion for EURISOL:
P. Delahaye, O. Kester, C. Barton, T. Lamy, M. Marie-Jeanne, F. We

CW EBIS charge breeder

Less dead time, piling-up and fake coincidence problems

REX-EBIS and MINIBALL: data acquisition problems with intensities as low as 10^5-10^6 pps



EBIS challenges:

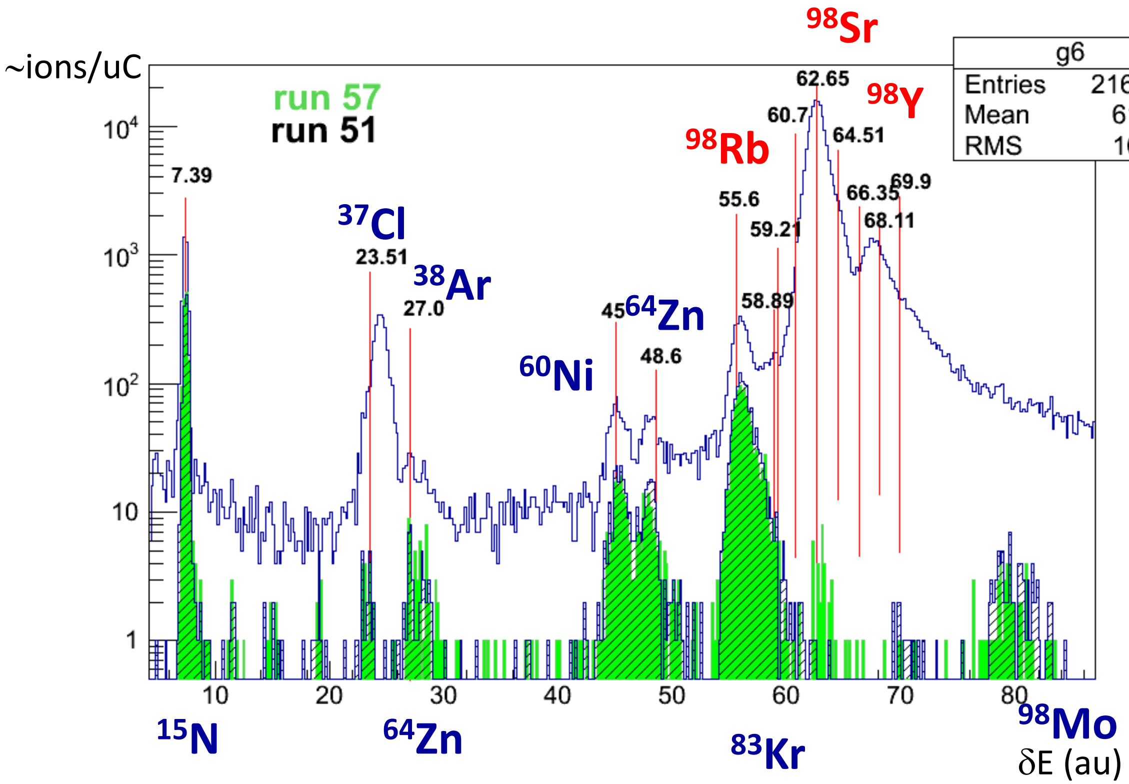
For mid term ISOL facilities time structure is the prime issue before space charge limitations

CW beams!

Detail of the EURISOL Layout

Modified from P. Butler's presentation, NuPECC meeting June 2007

In EBIS / trap decay and beam purity issues



In green: without protons

Stable beam contaminants from EBIS ~a few 100/s