# Optimizing charge breeding techniques for ISOL facilities in Europe: the EMILIE project

P. Delahaye for the EMILIE collaboration

# Organization of the workshop

**Monday:**
- Welcome
- Charge breeding worldwide
- EBIS beam debuncher

**Tuesday:**
- ECR charge breeding tests
- Numerical simulations
- Visit to the lab (SPIRAL 1 & 2)
- Dinner down town

**Wednesday**
- Ion traps at LPC Caen
- Optimized charge breeders for SPES and SPIRAL
- Concluding remarks, perspectives

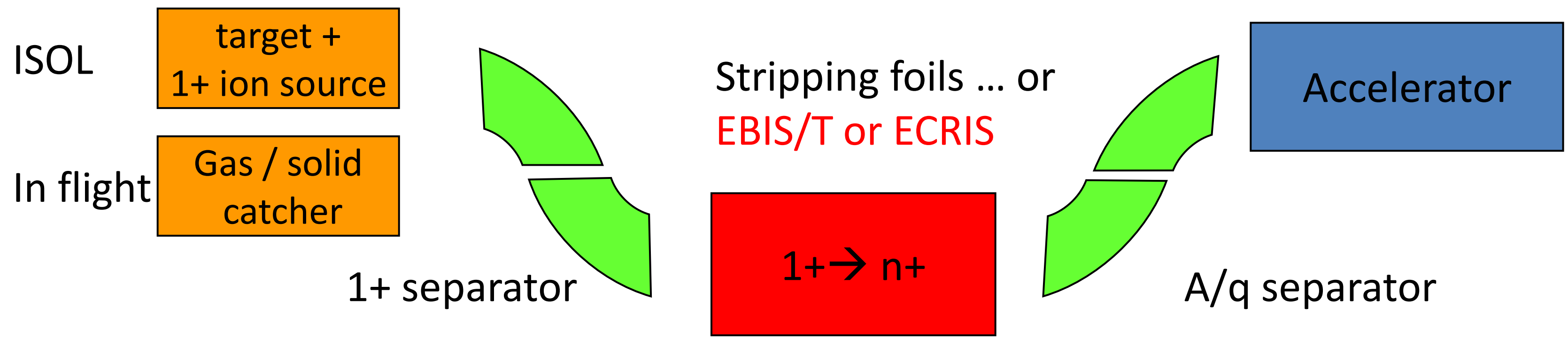
25+5 min talks
Discussion sessions

Dinner at “La Manufacture”/ Le Bistrot

Please indicate if you prefer a vegetarian meal

# Charge breeding

A key-technology for facilities reaccelerating Radioactive Ion Beams




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

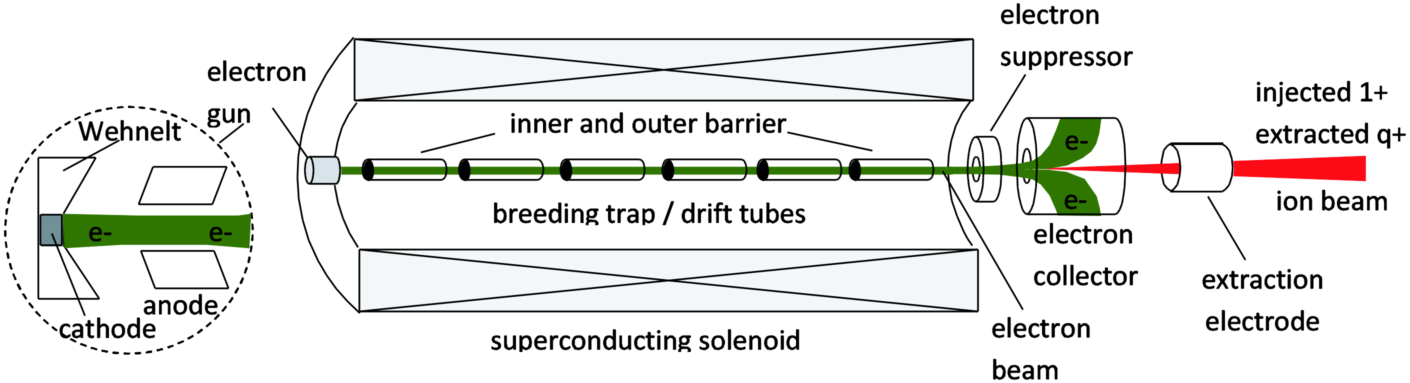
- higher charge states → **Higher energies**
  Compact postaccelerator

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

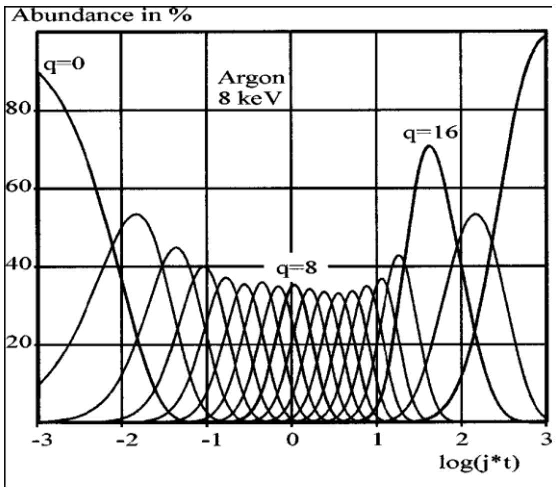
But also: **I~µA**

# What 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)

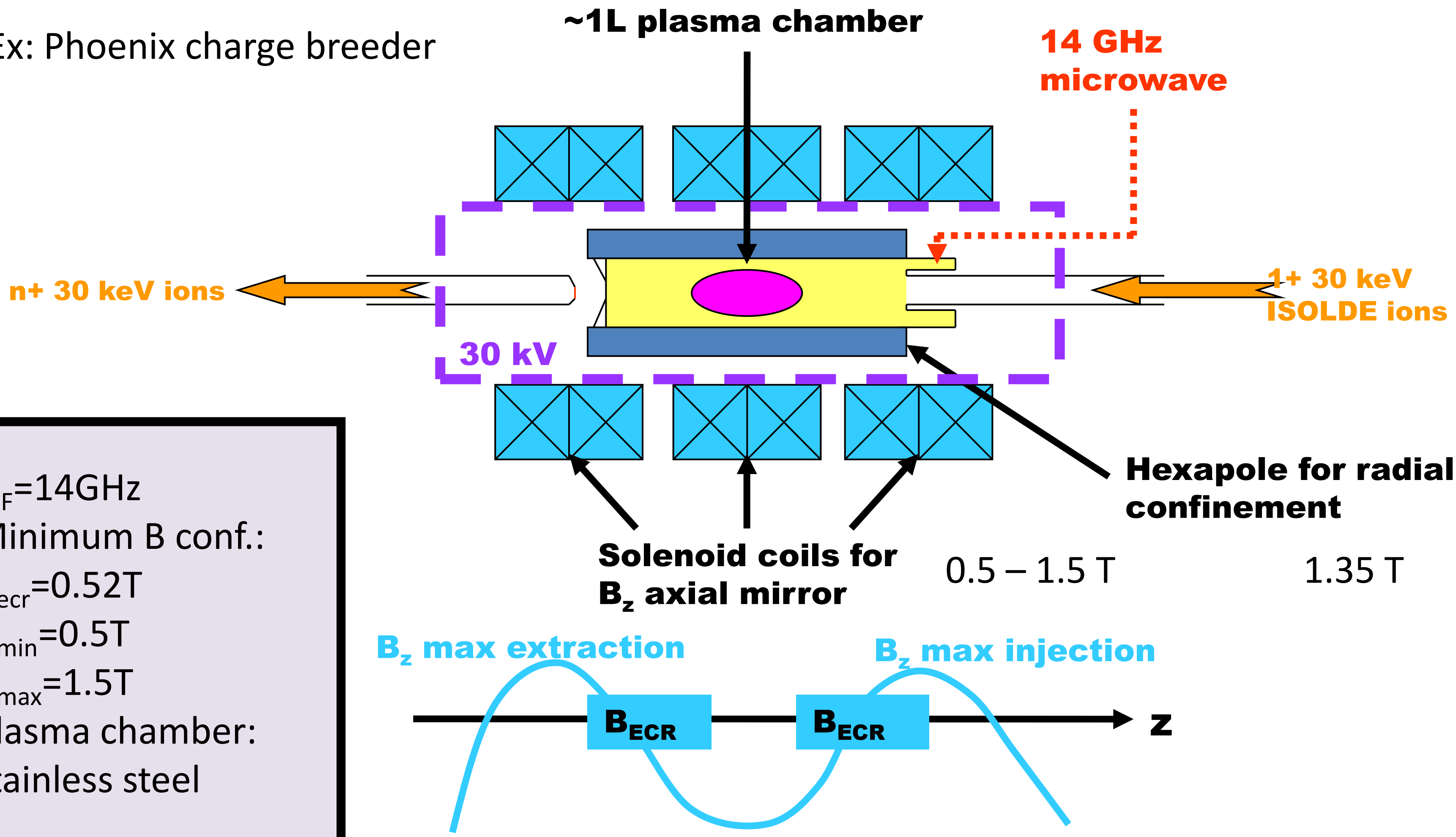
$Q=3.36\ 10^{11} L.I_e/E^{-1/2}$

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

Essentially a pulsed device

# ECRIS charge breder principle

Ex: Phoenix charge breeder



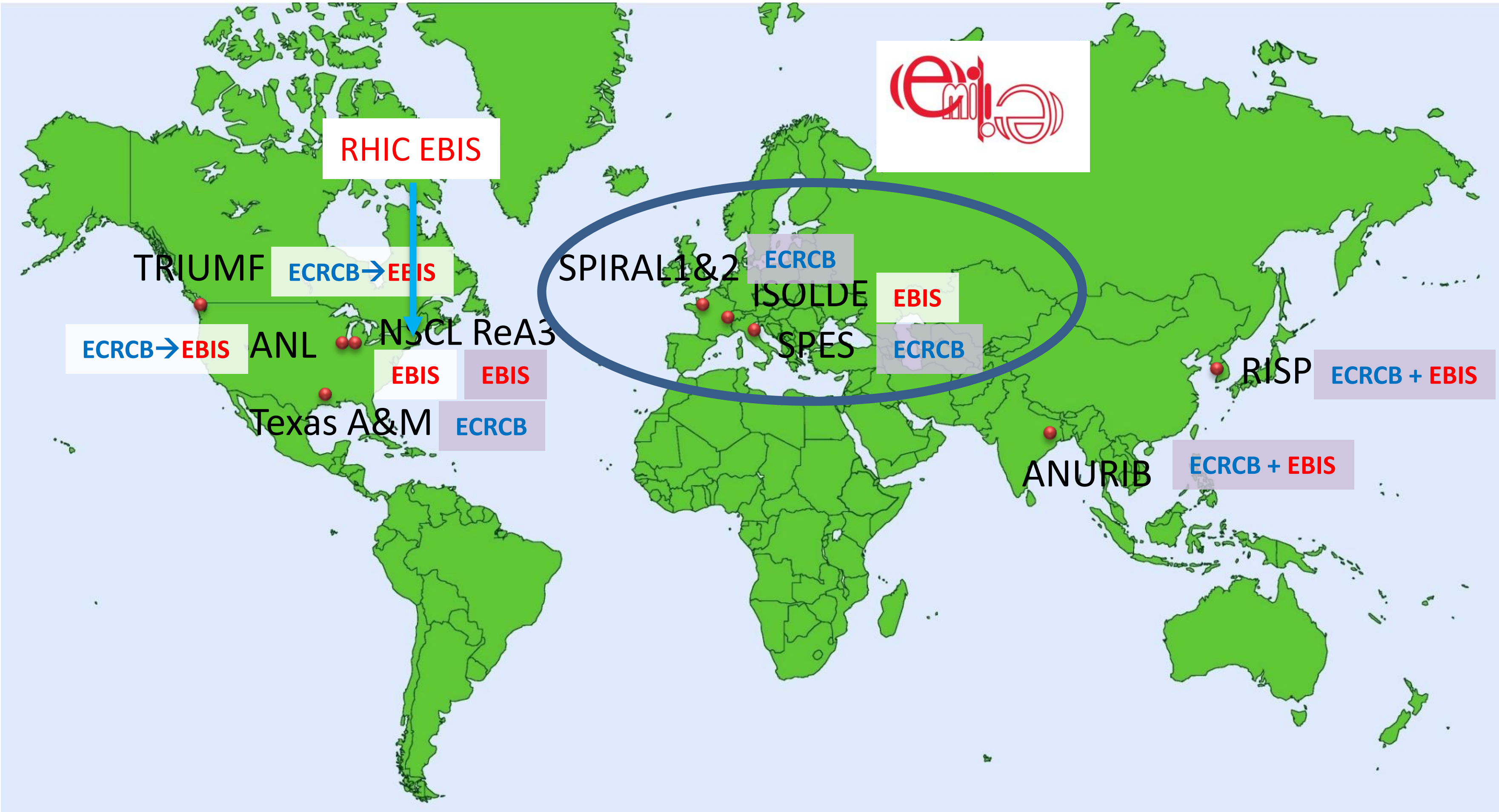

$f_{RF}$=14GHz
Minimum B conf.:
$B_{ecr}$=0.52T
$B_{min}$=0.5T
$B_{max}$=1.5T
Plasma chamber:
stainless steel

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

# Charge breeding of Radioactive ion beams

# World status: 2016




See talks R. Vondrasek, E. Beebe

| | |
|---|---|
| ECRCB | In commissionning or planned |
| EBIS | running |

See talk M. Blessenohol S. Dobrodey

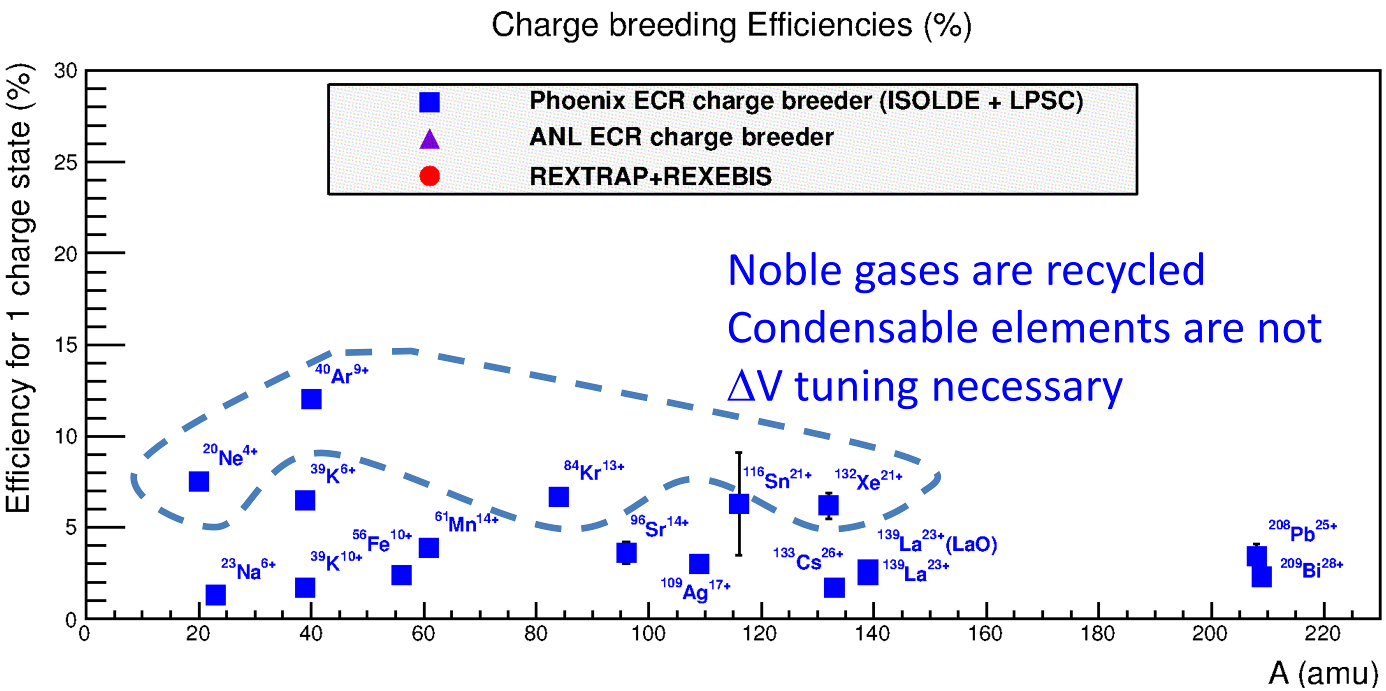
# Charge state breeding performances

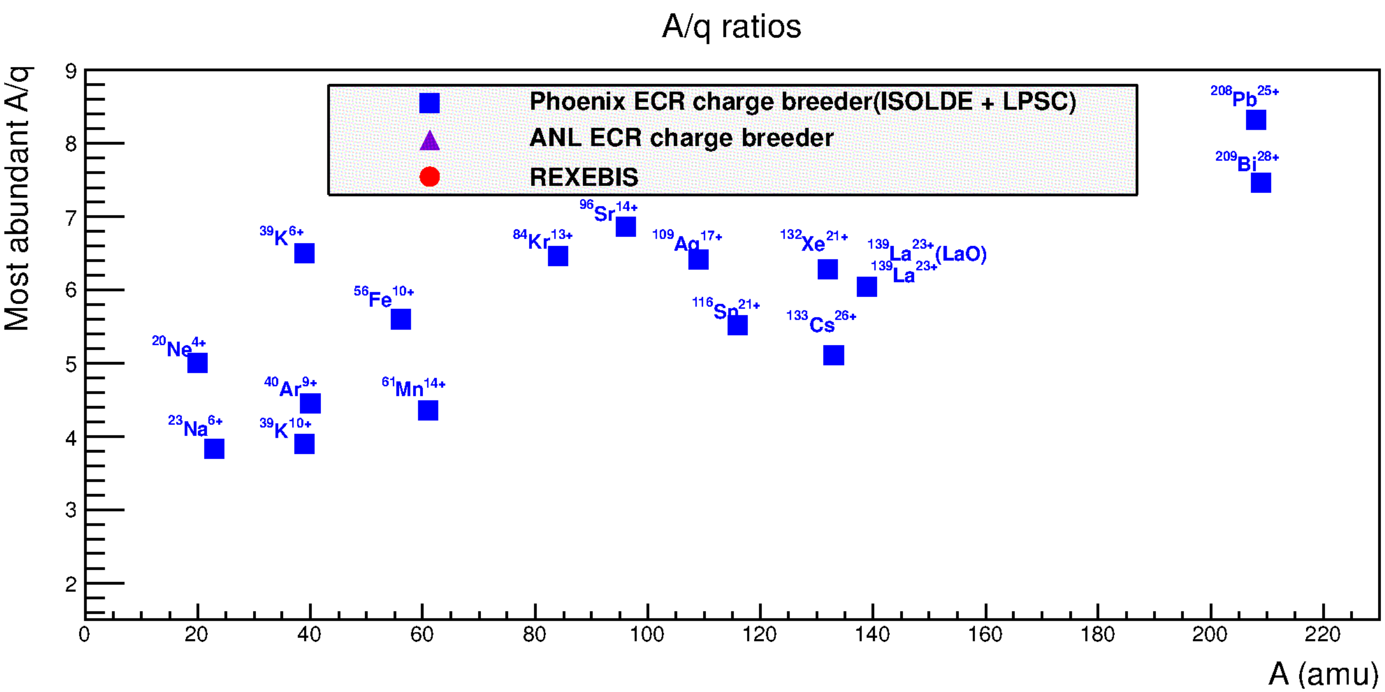
- EBIS
  - REXEBIS
- ECRIS
  - PHOENIX (ISOLDE + LPSC)
  - ANL Charge breeder

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

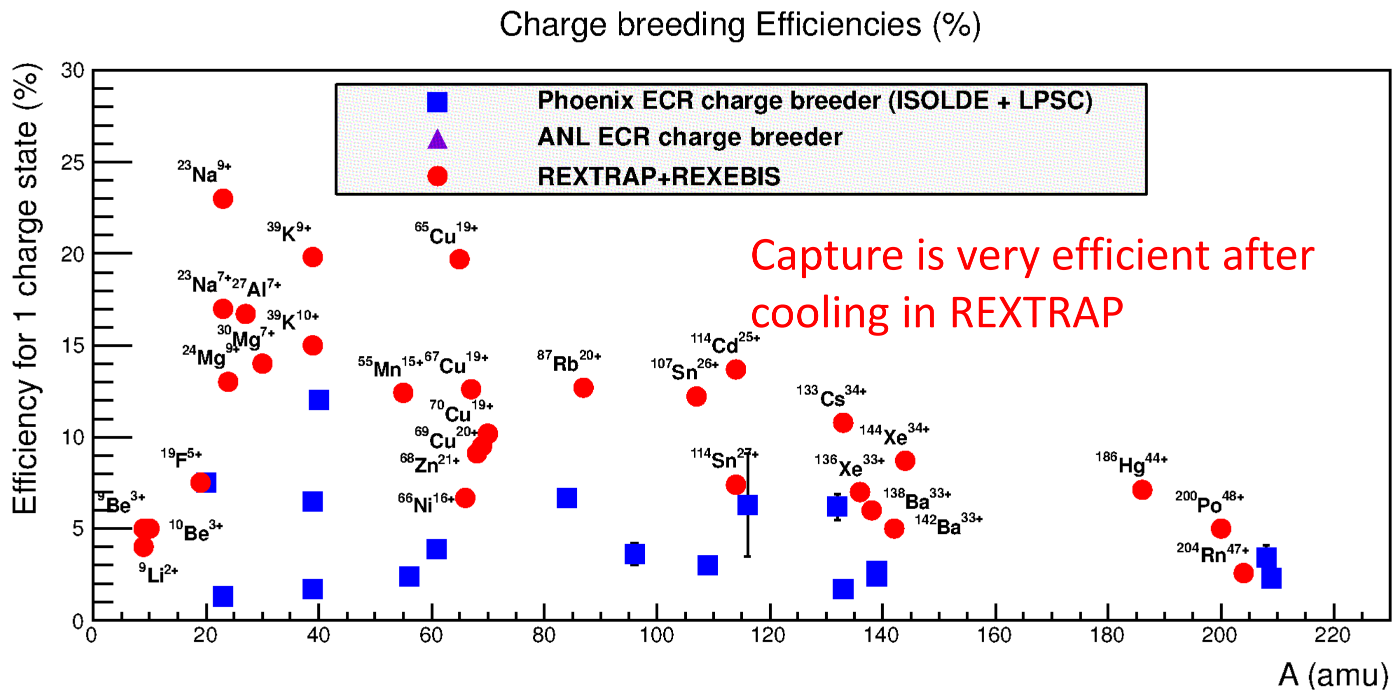
Status 2012!

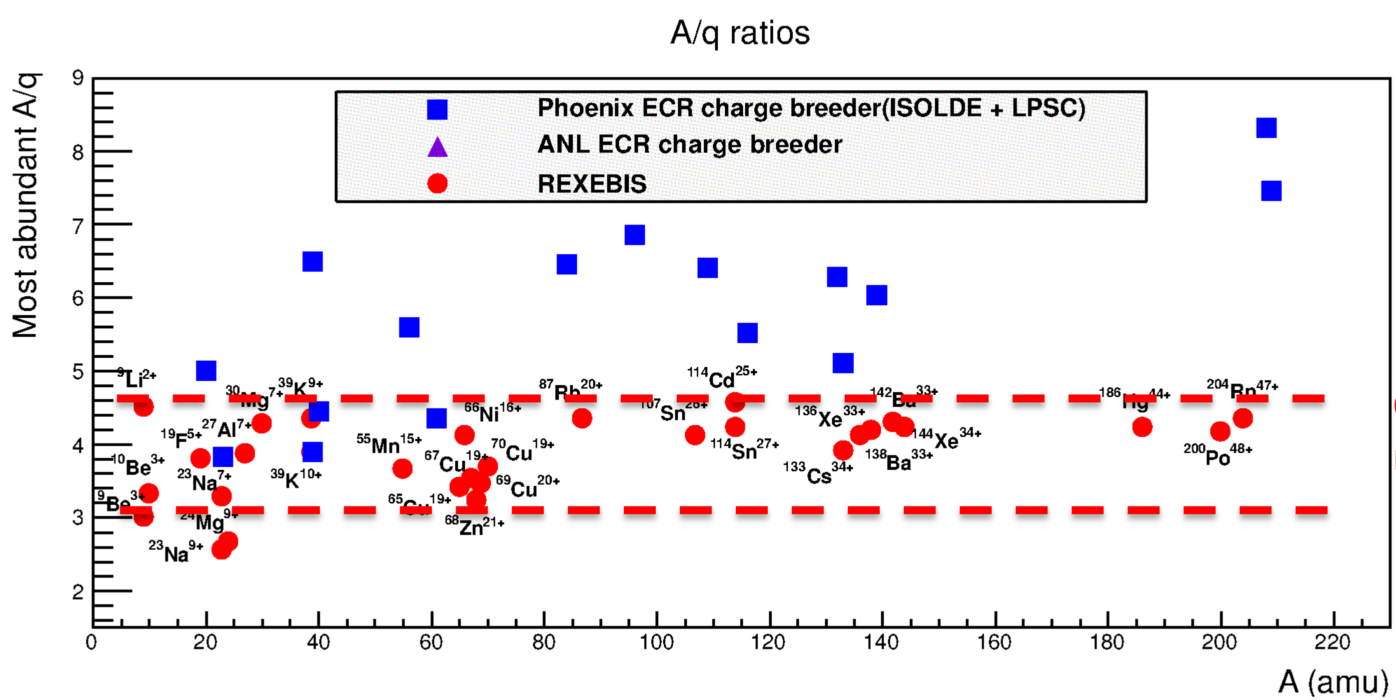
# Phoenix ECRIS



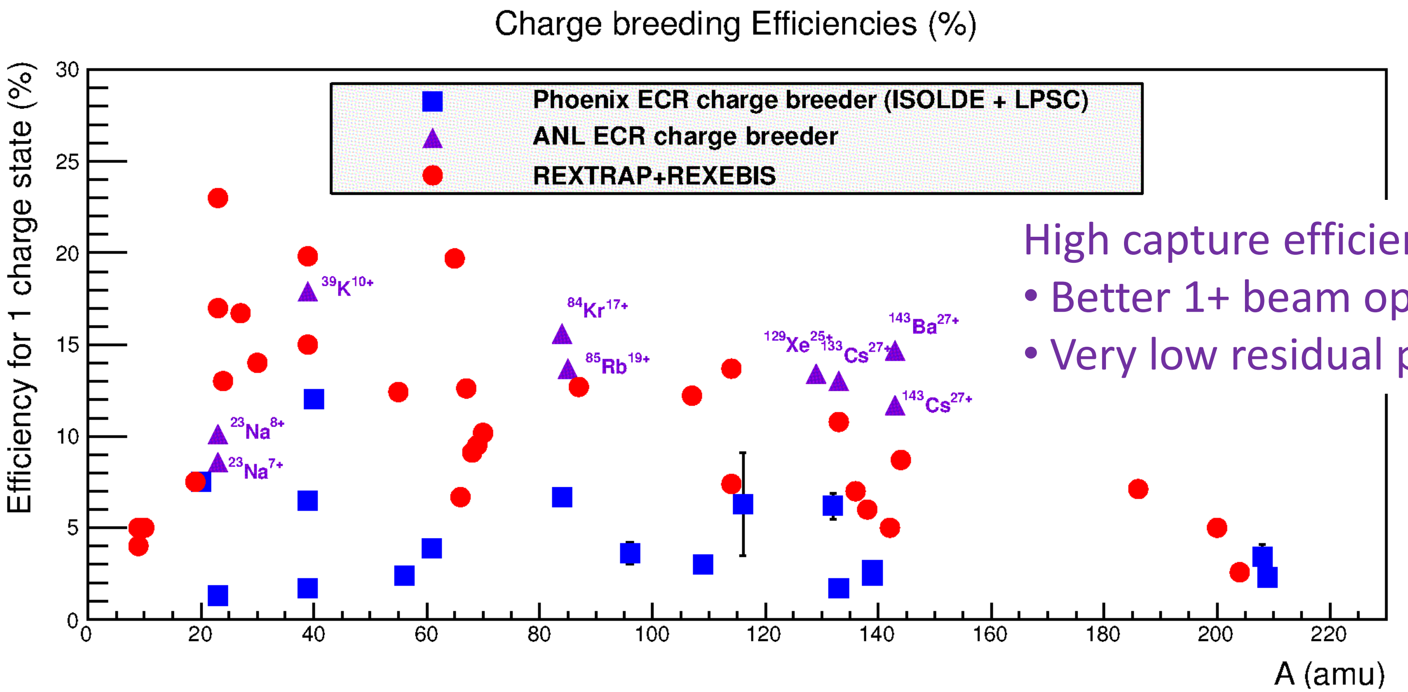
**REXTRAP - REXEBIS**



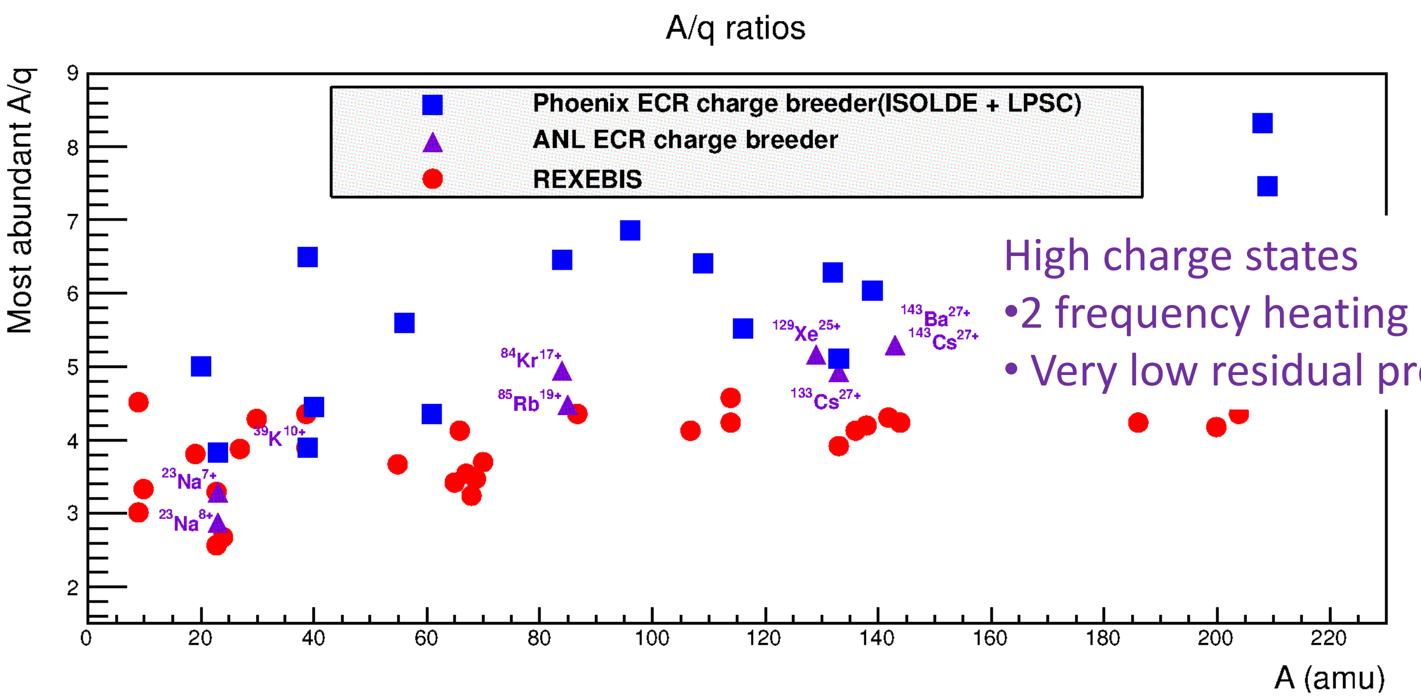

Operating range REX-ISOLDE

## ANL ECRIS




High capture efficiency

- Better 1+ beam optics
- Very low residual pressure




High charge states

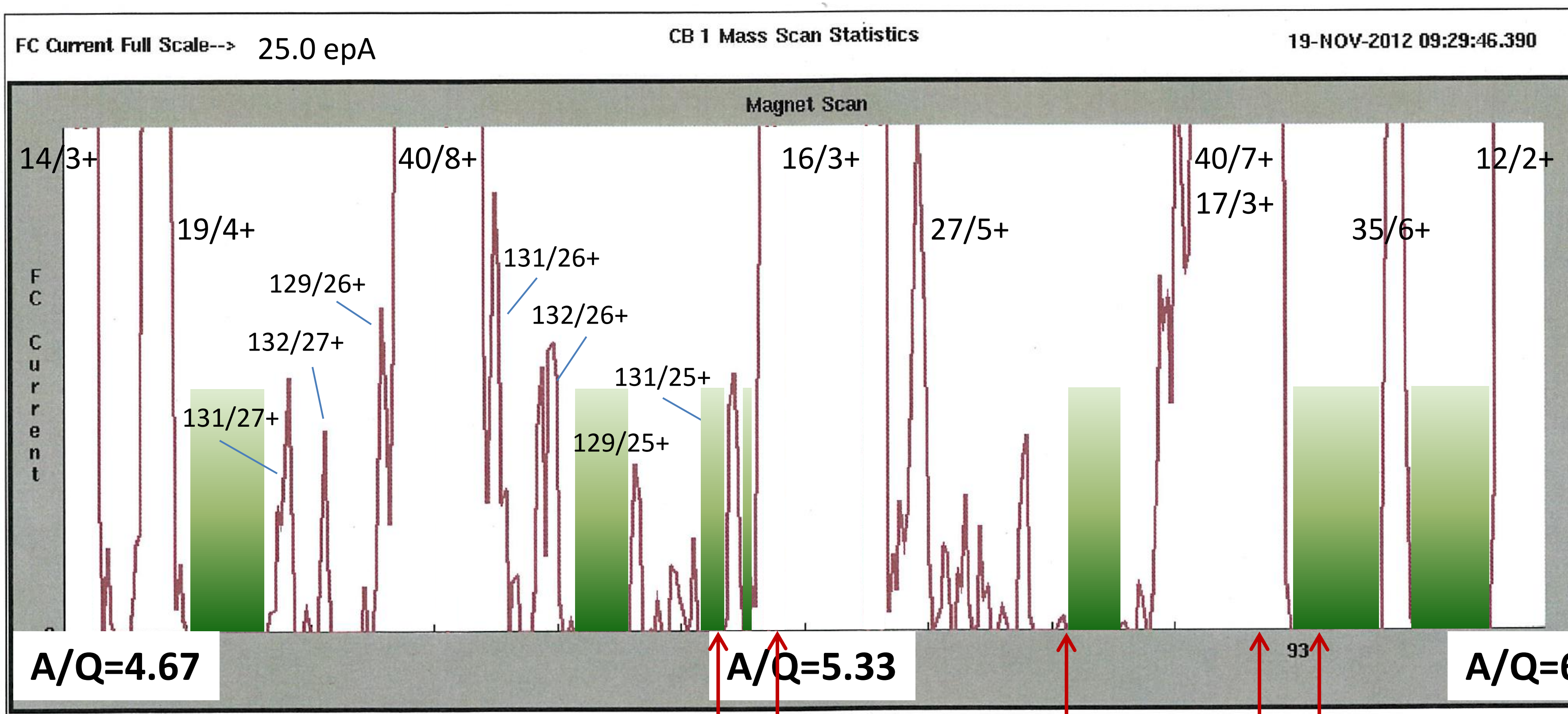
- 2 frequency heating
- Very low residual pressure

# Beam purity issue

See talk R. Vondrasek

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

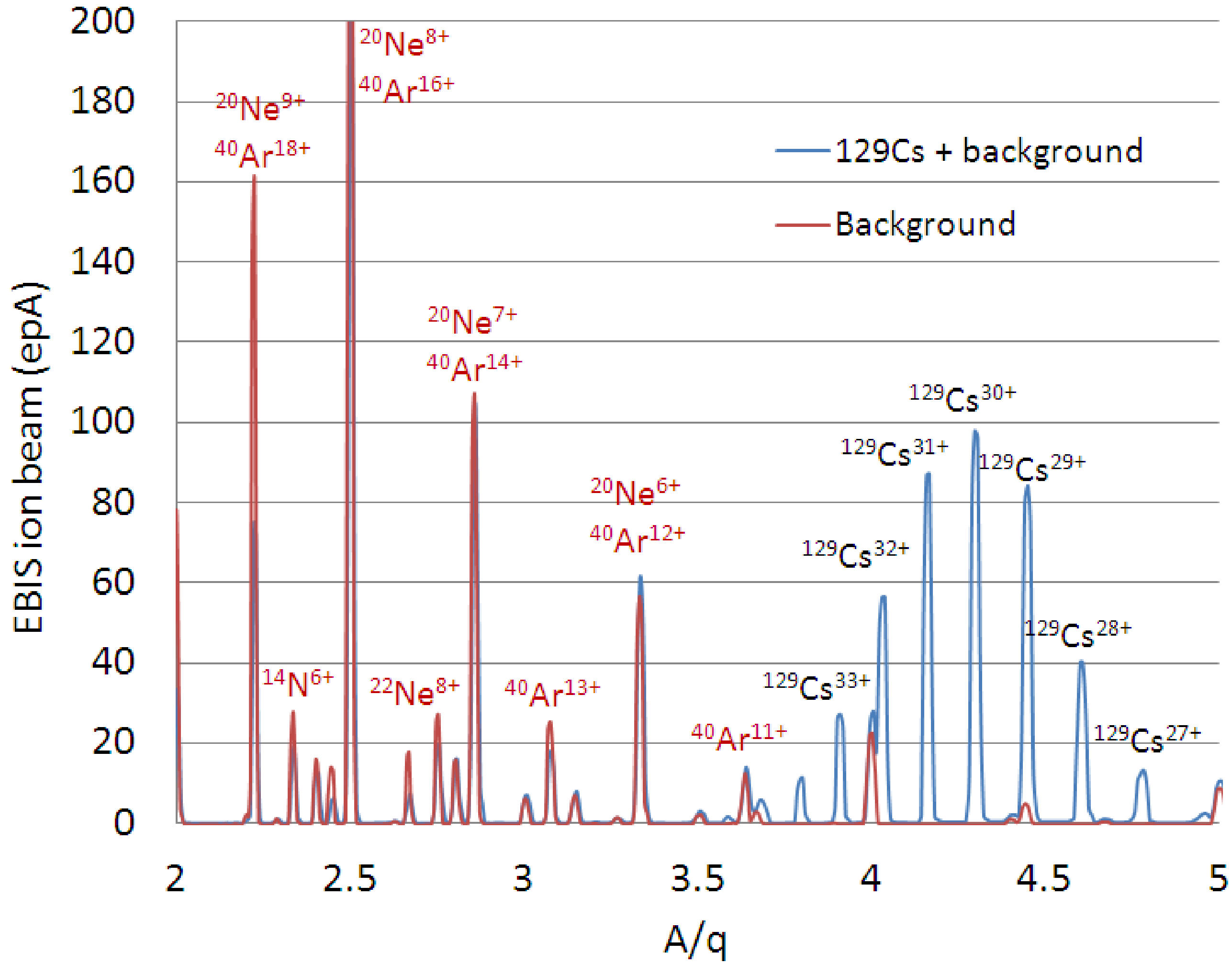
143/25+ 66 kHz background rate in SBD

144/25+ 900 Hz background rate in SBD

**SBD=Surface barrier detector**

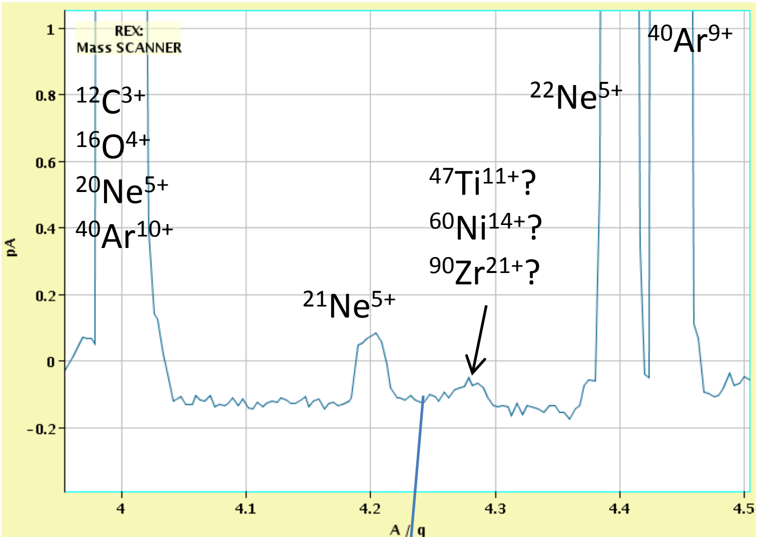
# Beam purity from REX-EBIS

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.*

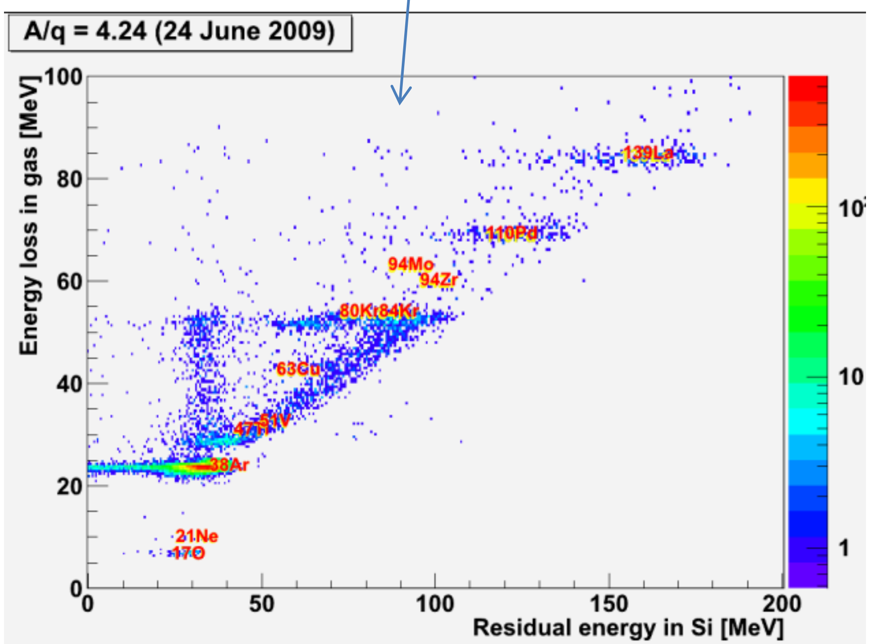
F. Wenander, CERN courier, Jan/Feb 2012, p33




# How pure is the beam really?

* C, O, Ne and Ar partial pressures around $3\cdot10^{-12}$, $2\cdot10^{-12}$, $5\cdot10^{-12}$ and $4\cdot10^{-13}$ mbar

* Important with proper beam identification after beam acceleration




## A/q=4.24

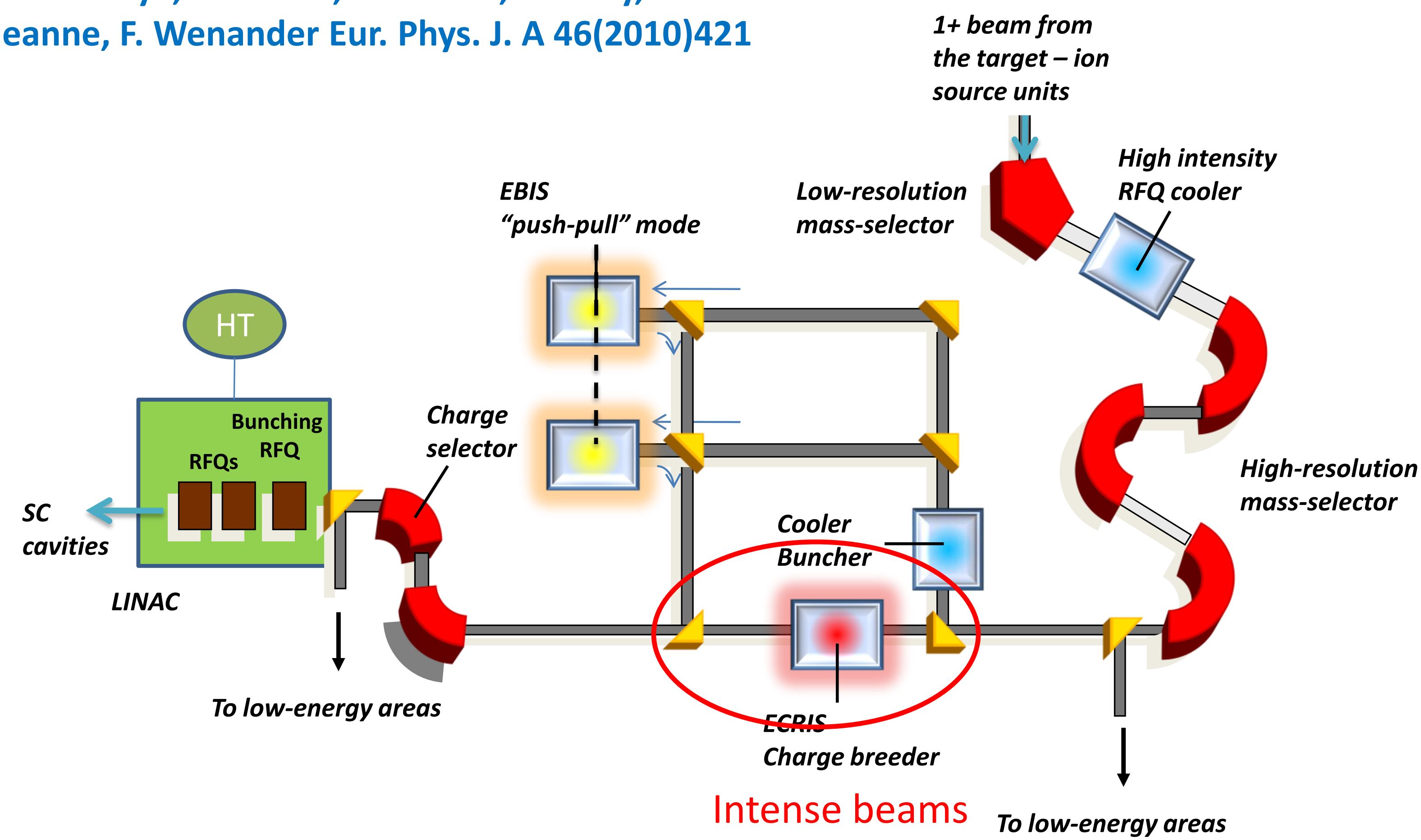
| Isotope | A/q | Z | Origin |
|---|---|---|---|
| 17O | 4.250 | 8 | residual gas |
| 21Ne | 4.2 | 10 | buffer gas |
| 38Ar | 4.222 | 18 | residual gas |
| 47Ti | 4.272 | 22 | drift tubes |
| 51V | 4.25 | 23 | NEG strips |
| 63Cu | 4.2 | 29 | anode and collector |
| 80Kr, 84Kr | 4.21, 4.2 | 36 | residual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

# Following the suggestion made for EURISOL

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

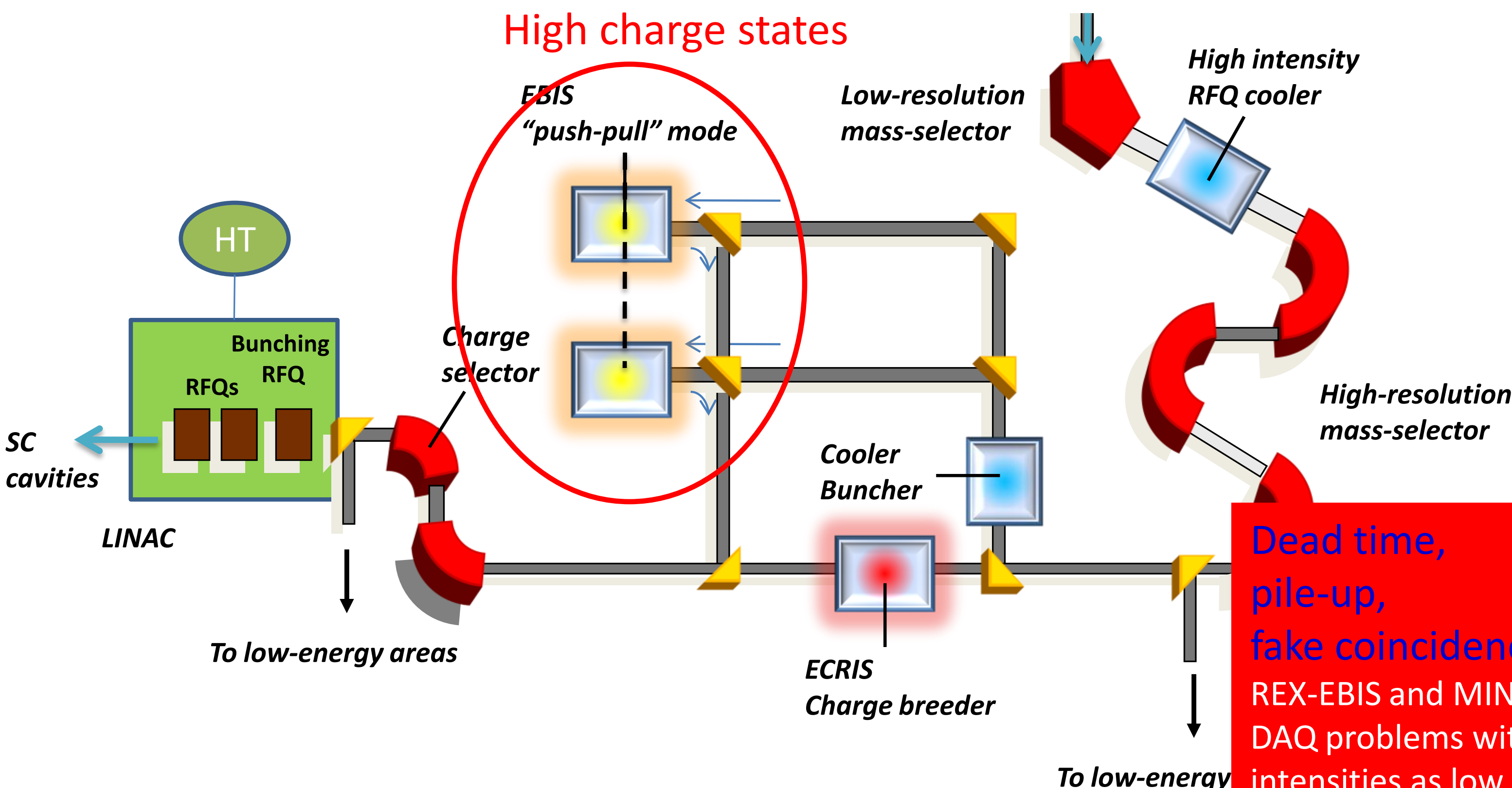



*ECRIS challenges*

Beam purity and capture efficiency optimizations

# Following the suggestion made for EURISOL

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




**Dead time,**
**pile-up,**
**fake coincidences**

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

*EBIS challenges*

For mid-term ISOL facilities time structure is the main issue

(before space charge limitations)

# EMILIE objectives

- **EBIS debuncher**
  - Simulation, Construction and test of a novel concept of EBIS beam debuncher

**First tests at LPC Caen**

See talks E. Traykov and G. Ban

- **Optimization of the performances of ECR charge breeders of Phoenix type**
  - Gaining understanding in the 1+ n+ technique
    - Charge breeding tests at LPSC

      See talks H. Koivisto and J. Angot
    - Charge breeder test bench at HIL

      See talk L. Standylo
    - Numerical simulations

      See talk(s) A. Galatà
  - Optimization of performances

**Optimization of the SPIRAL and SPES charge breeders**

See talks A. Galatà and L. Maunoury

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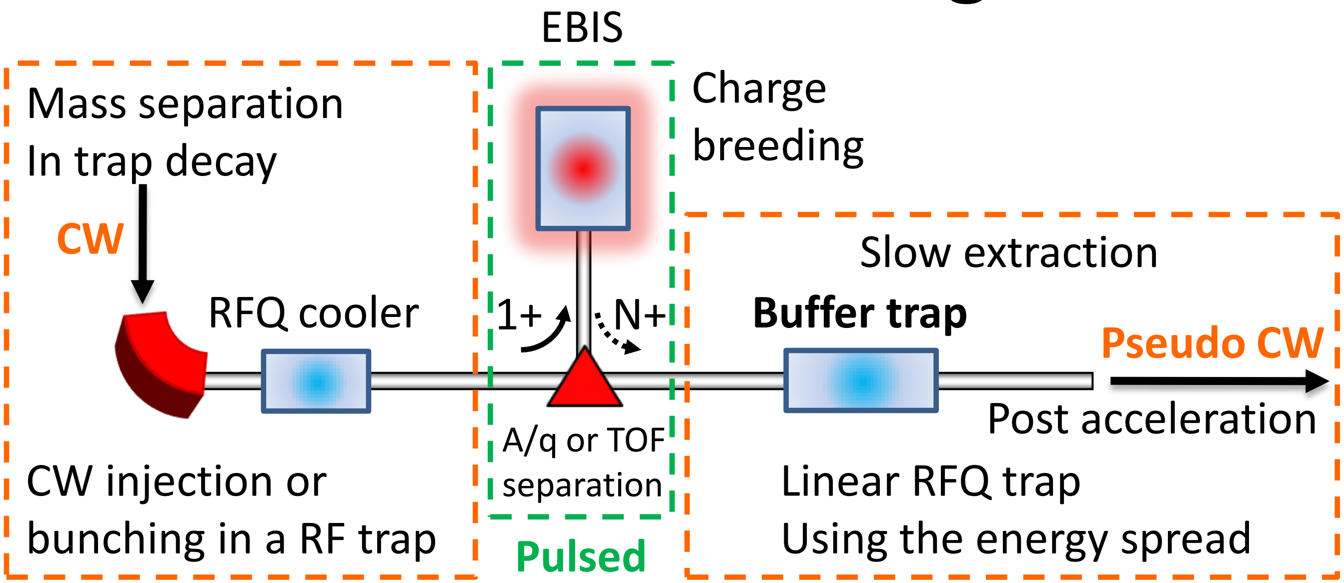
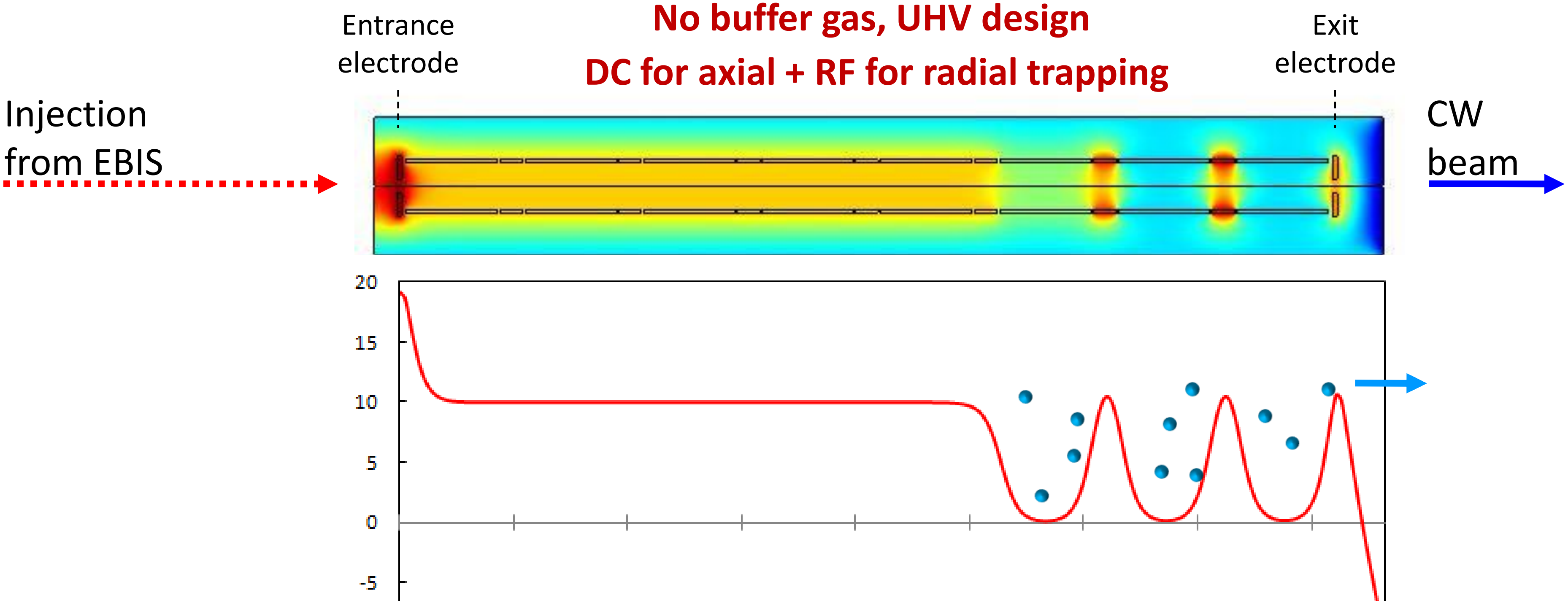
# CW EBIS charge breeder




Dead time,
pile-up,
fake coincidences
REX-EBIS and MINIBALL:
DAQ problems with
intensities as low as
$10^5$-$10^6$ pps

**No buffer gas, UHV design**

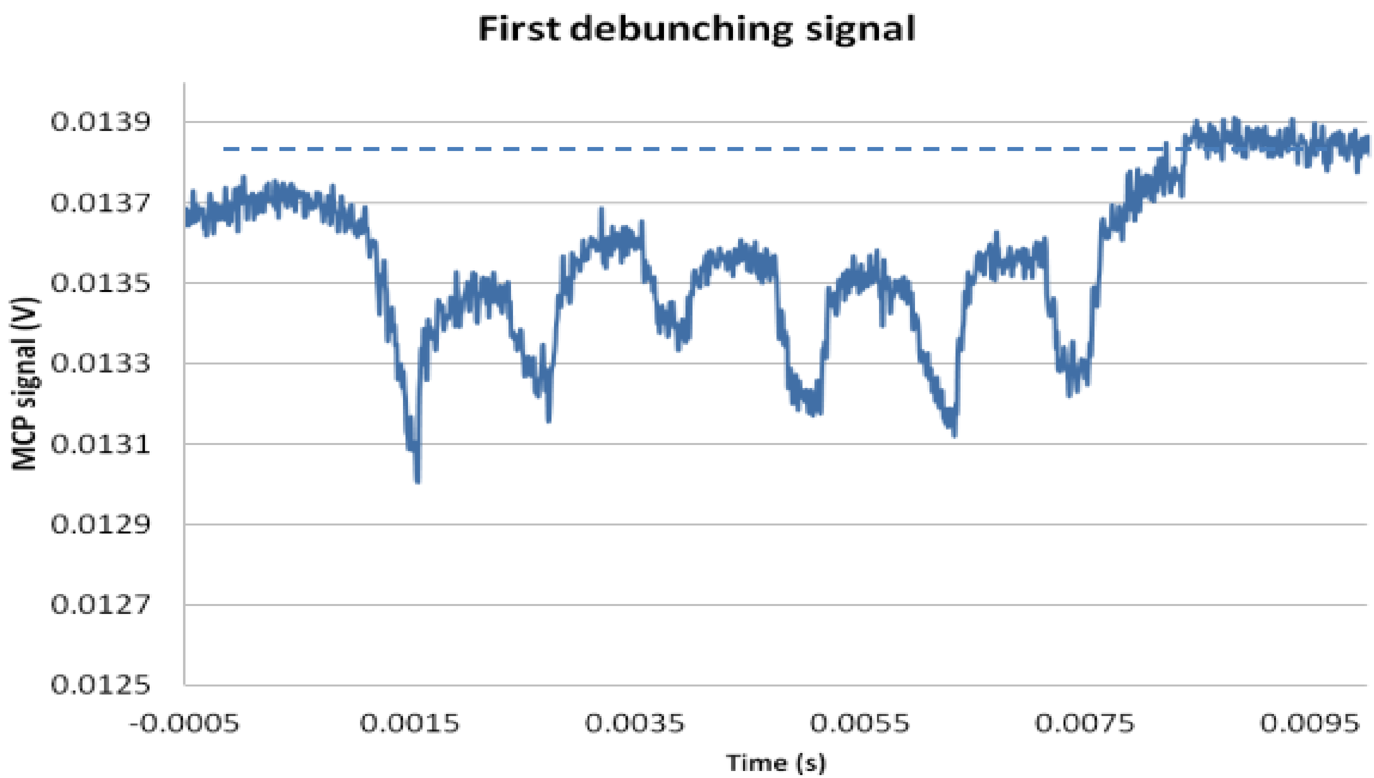
**DC for axial + RF for radial trapping**



# First on-line results

- Transmission though the trap (no bunching): >90%
- Trapping half-life: >100ms ($Na^+$) > 1s ($Cs^+$)

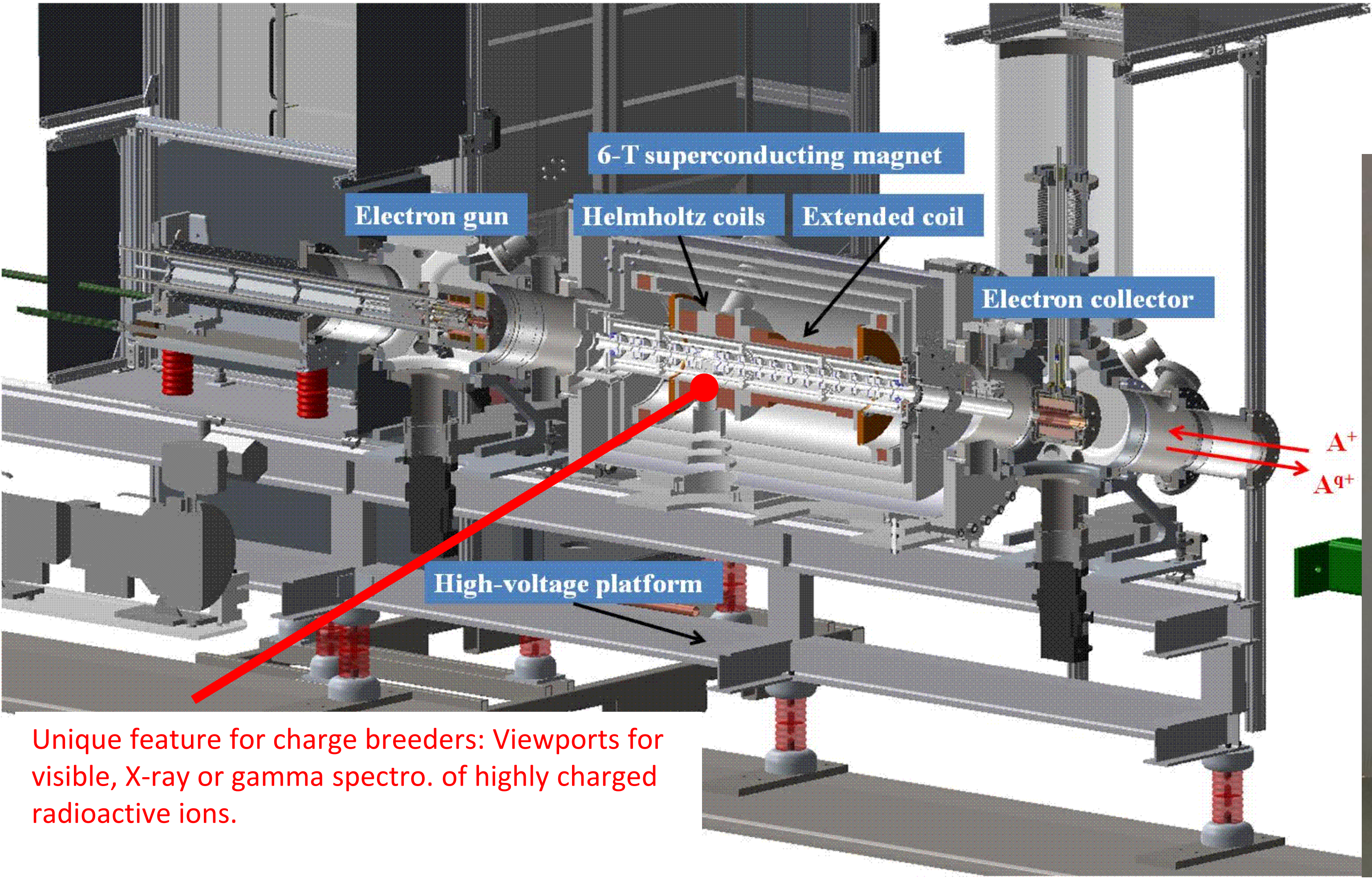
Injected $Na^+$ bunches



# Slow extraction from ReA EBIT at NSCL

***Courtesy A. Lapierre***

# The ReA EBIT




Unique feature for charge breeders: Viewports for visible, X-ray or gamma spectro. of highly charged radioactive ions.

**Trap structure**

* 1.2 m long
* 23 Ti electrodes

## Main requirements of a CB for ReA:

- Breeding time < 50 ms (for short-lived isotopes)
- Efficiency in single charge states: 20% - 50 %
- Charge capacity: up to $10^{10}$ positive charges
- Low contamination level.

## ReA EBIT key parameters:

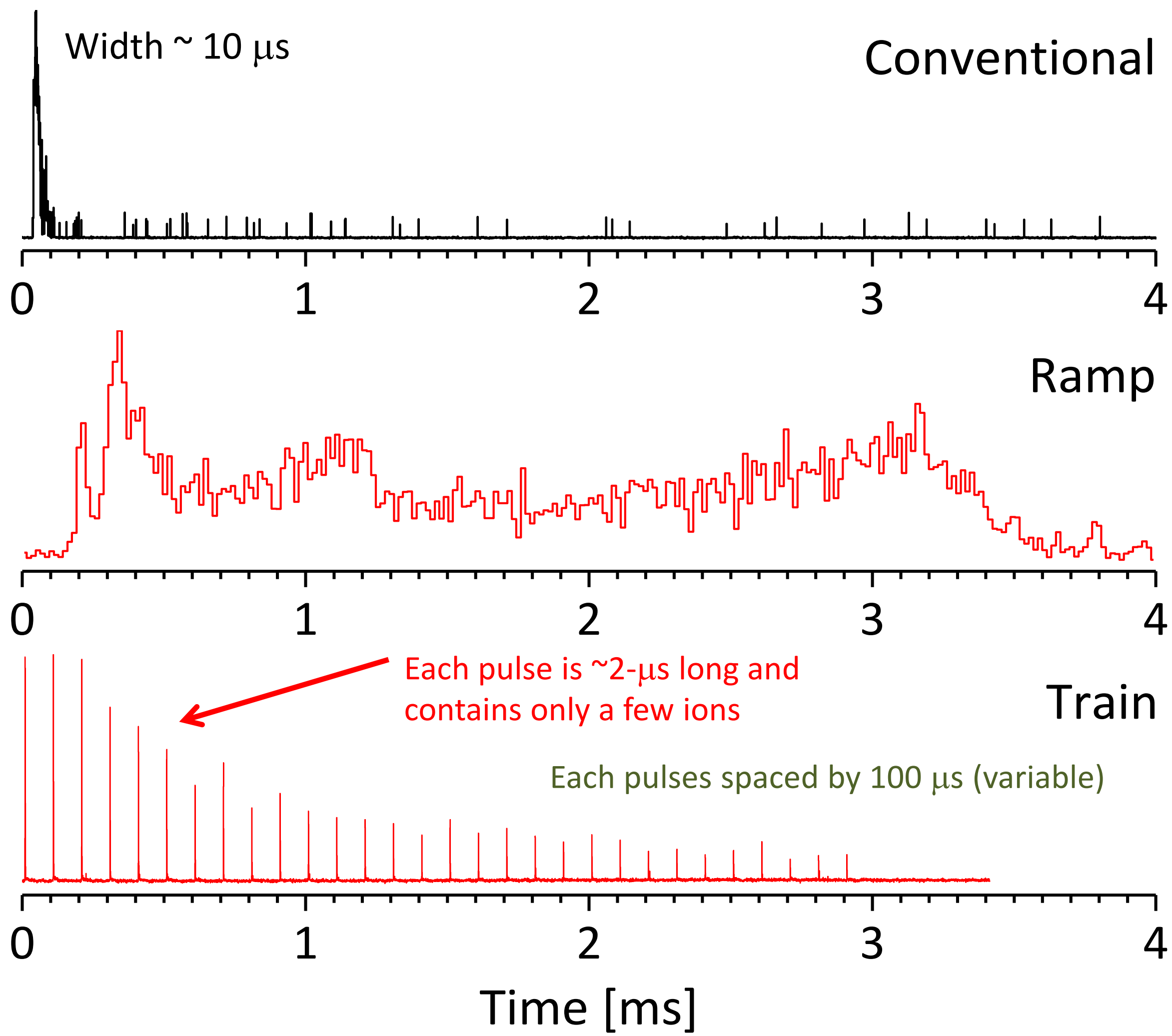
- High electron current: 1.4 A thru a 4T
- E-beam energy < 30 keV (e.g., Ne-like $U^{82+}$)
- Current density (750mA/4T): ~500 A/cm$^2$
- Reduced contamination: 4-K trap structure

*Courtesy A. Lapierre*

# Time stretching of EBIT extracted pulses

**Measured with a microchannel plate after the Q/A separator**

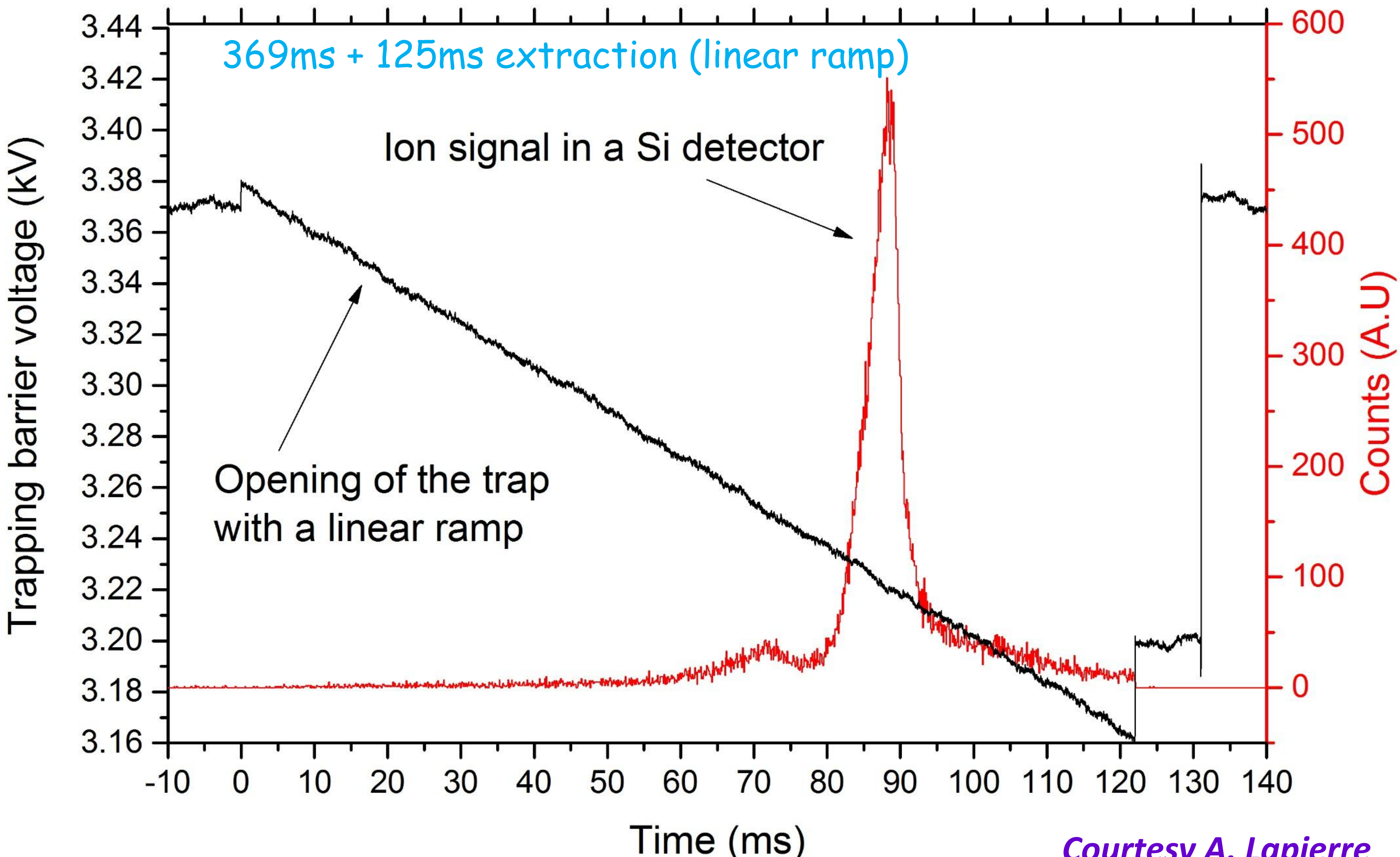
Peak intensities normalized to 1




***Courtesy A. Lapierre***

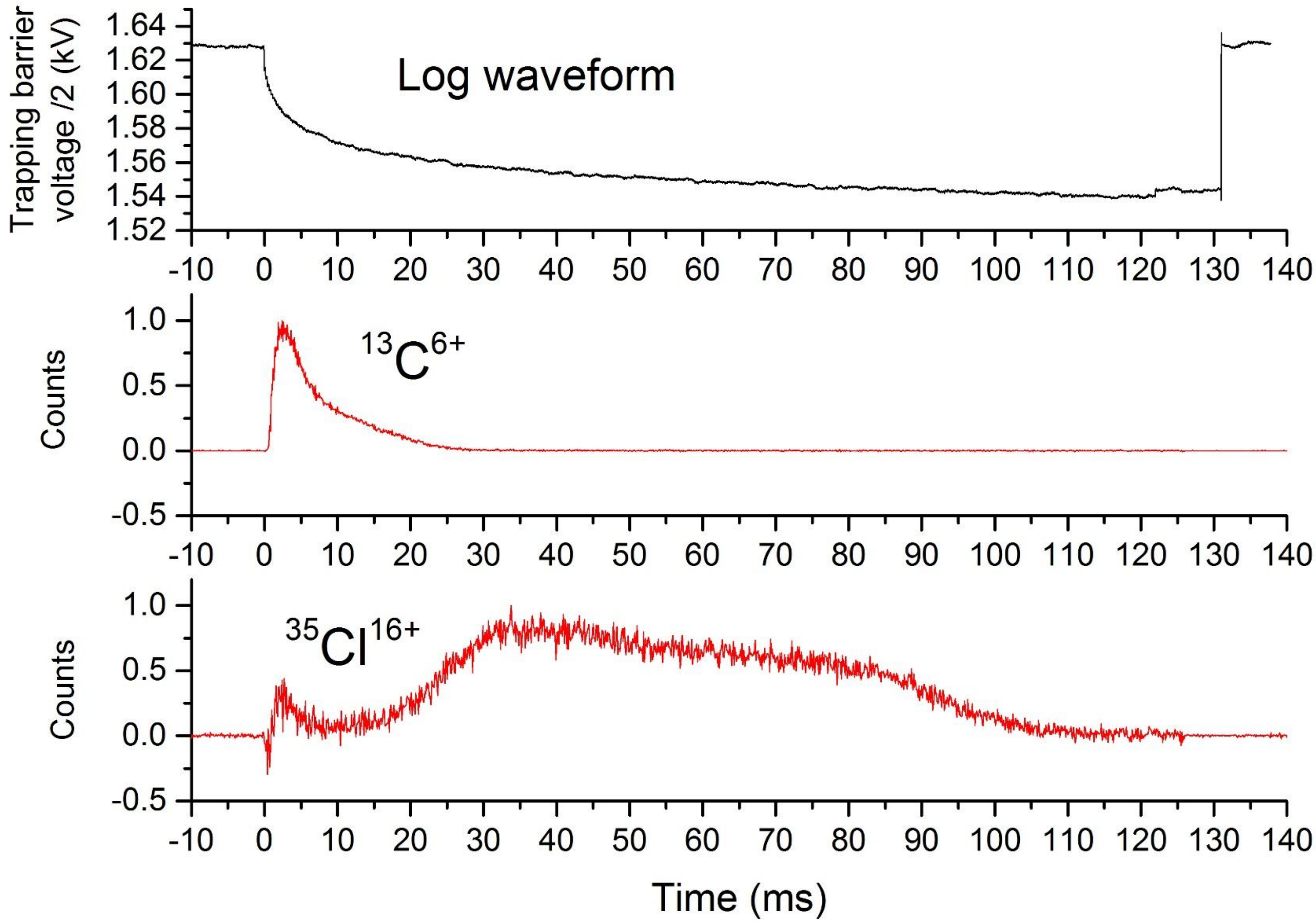
T. Baumann, A. Lapierre, S. Schwarz, *et al.* AIP Conf. Proceedings (EBIST2014 International Symposium), to be published (2015)

# $^{46}K^{18+}$ reaccelerated and delivered to a ReA3 experiment




*Courtesy A. Lapierre*

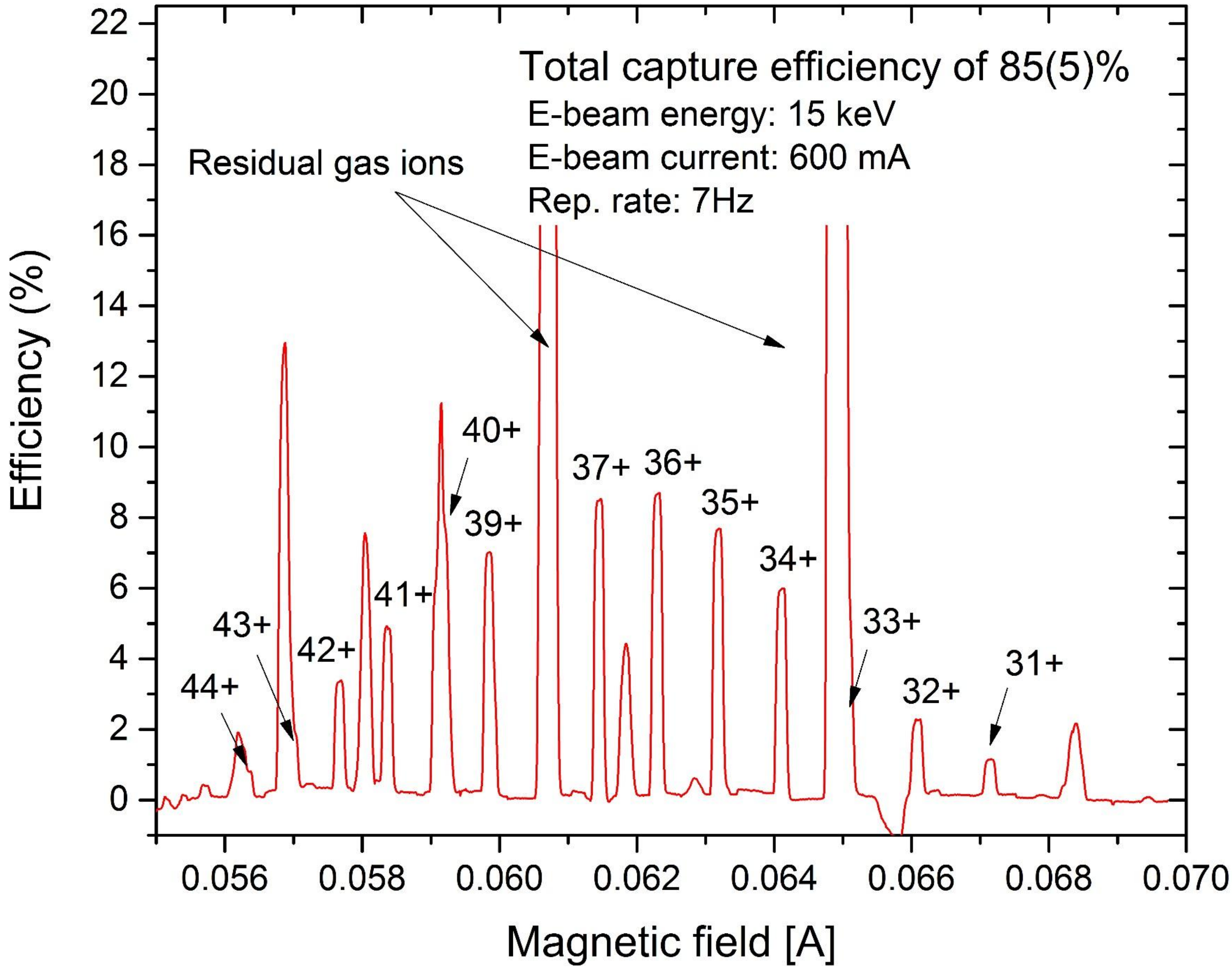
# ReA3 EBIST time-structure optimization studies with an MCP after Q/A separator




**The low charge states as they are loosely bound in the trapping potential exit first after opening the trap; this can be a means to eliminate or reduce beam contaminants delivered to users.**

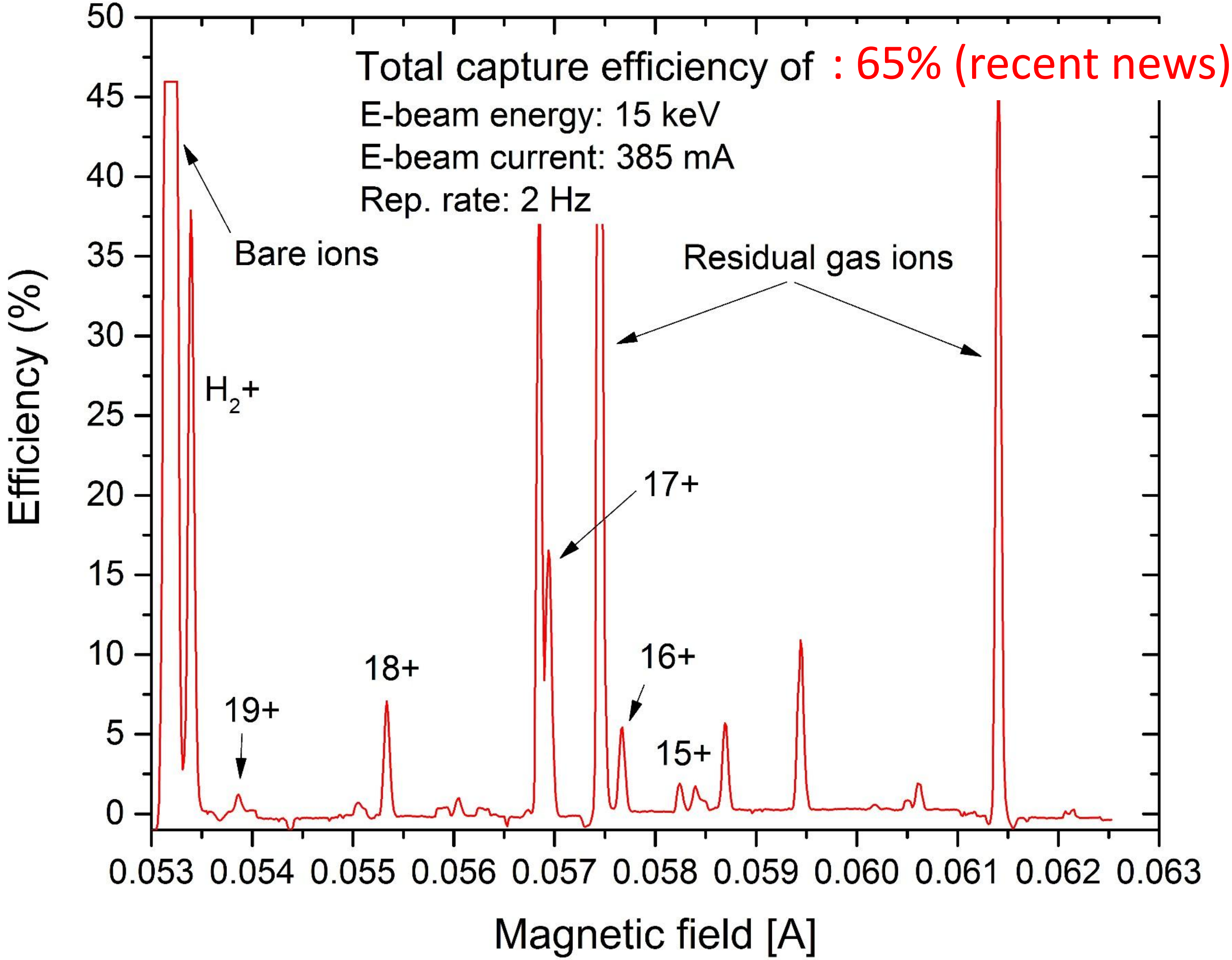
***Courtesy A. Lapierre***

# Charge breeding efficiency of injected 133-Cs stable beam




*Courtesy A. Lapierre*

# Charge breeding efficiency of injected K stable beam



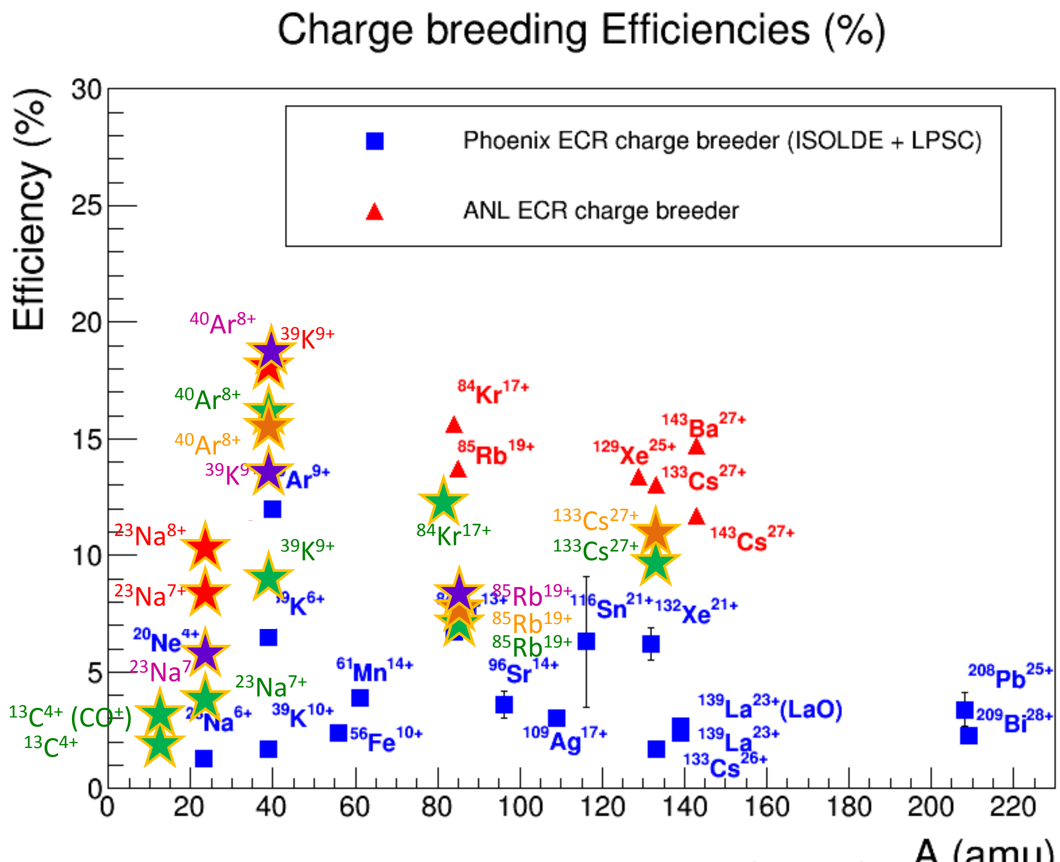

*Courtesy A. Lapierre*

# **EMILIE** objectives

- **EBIS debuncher**
  - Simulation, Construction and test of a novel concept of EBIS beam debuncher

- **Optimization of the performances of ECR charge breeders of Phoenix type**
  - Gaining understanding in the 1+ n+ technique
  - Optimization of performances

# Improvement of charge breeding efficiencies




P. Delahaye, NIM B 317(2013) ,
J. Angot et al, THYO02, ECRIS 2012

H. Koivisto et al, RSI 85 (2014)
L. Maunoury et al, RSI 85 02A504 (2014)
**T. Lamy et al, ECRIS 2014**

1) Injection of molecules
2) Vaccuum improvement
   - Lower residual pressure
3) Magnetic field improvements:
   - symmetrization at injection
   - axial field optimization
4) Double frequency heating

**EMILIE 2012-2014**

★ ANL charge breeder
★ LPSC charge breeder

**EMILIE 2015**

★ SPIRAL charge breeder
★ SPES charge breeder

**See Talks Laurent Maunoury and Alessio Galatà**

# EMILIE perspectives

- Experiments to be proposed
- ICBT in ENSAR2/EURISOL

# ICBT – Innovative Charge Breeding Techniques

***"The aim is to perform very fast charge breeding, production of fully stripped ions and cw beams using Electron Beam Ion Breeders and to improve the efficiency of ECR ion source breeders."***

A. Shornikov

F. Wenander

P. Delahaye

P. Gmaj

EBIS electron gun development

Faster charge breeding

Higher charge state

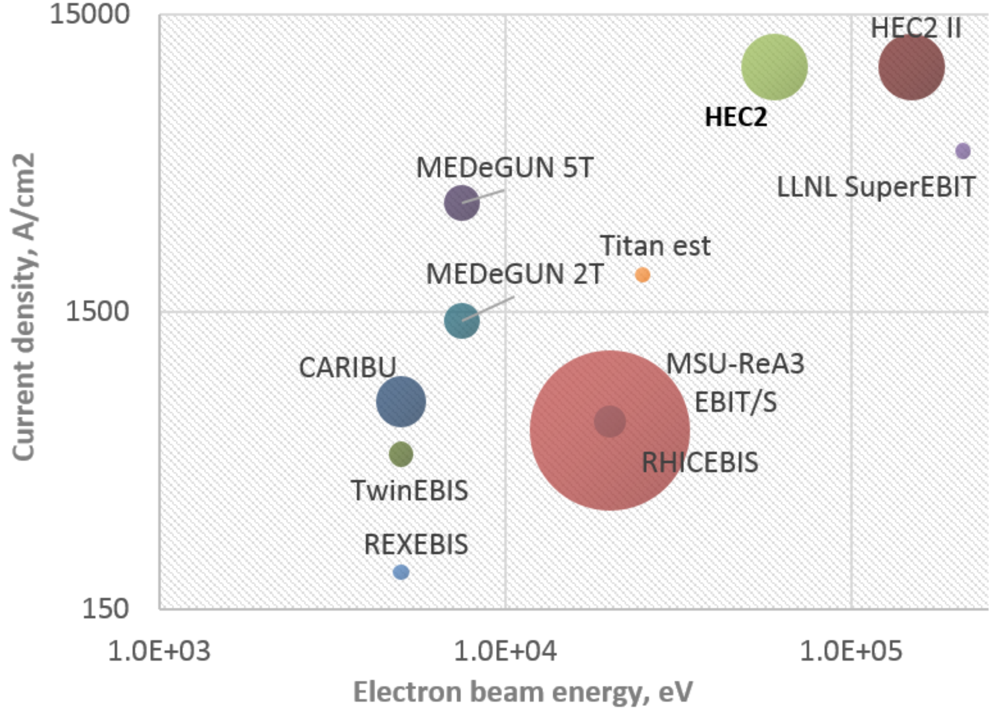
Paul trap for highly charged ions

CW beams out of EBIS/T

Tests on ECRIS

Less stable contaminants

Higher efficiency




# CERN

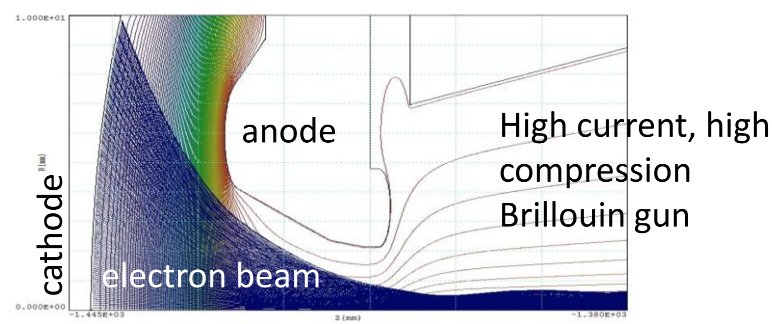
# Faster breeding requires higher electron current density

# Higher charge states requires higher electron beam energy

Try two different electron gun designs

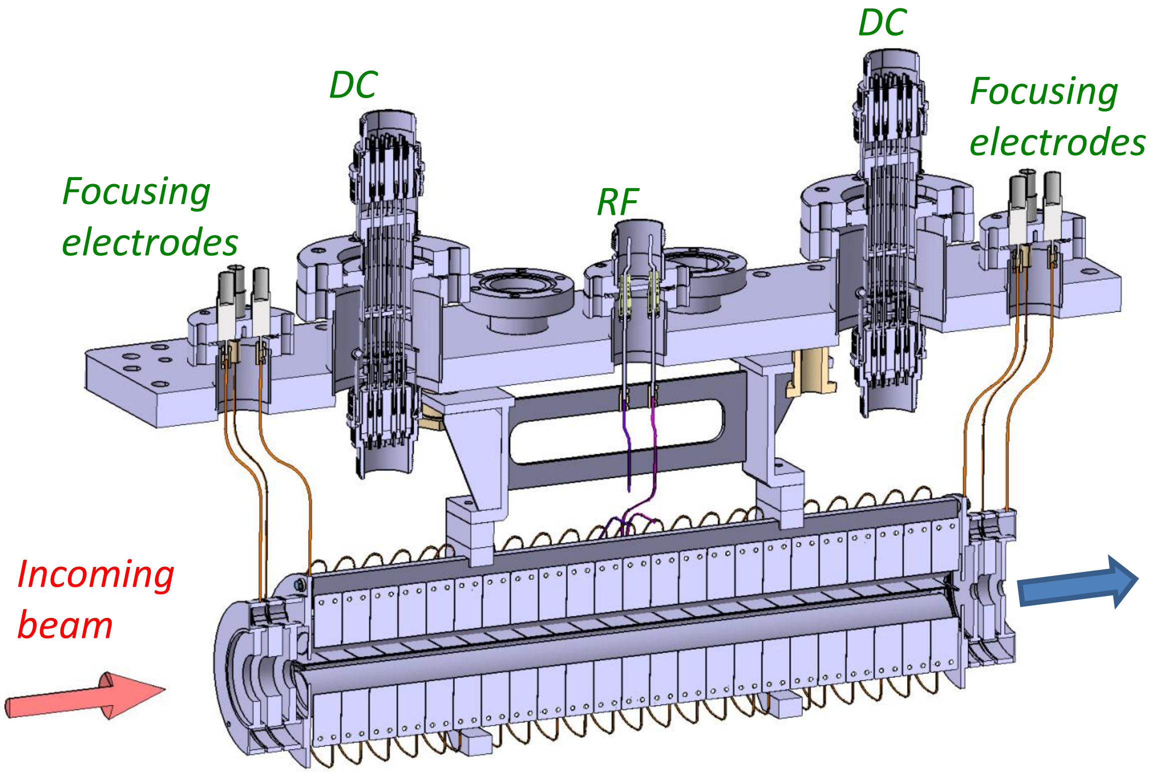
## MEDeGUN – CERN development
to be tested at TwinEBIS 2 T test-bench


## HEC$^2$ – BNL design, CERN collaboration
tests at BNL until summer 2016




## Based on the tests, design a charge breeder for EURISOL

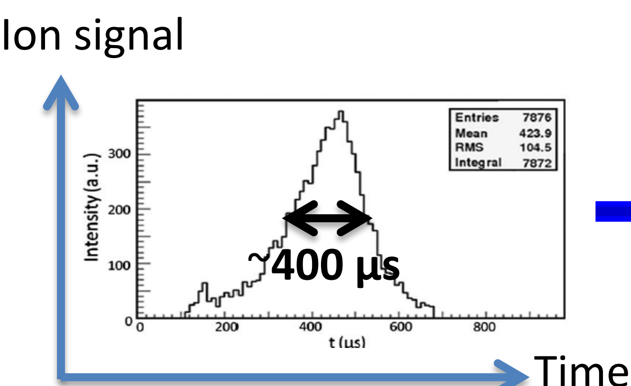
*ICBT – Innovative Charge Breeding Techniques*



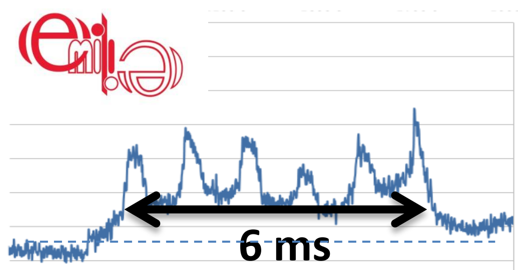

A Paul trap for debunching the EBIS beams

ICBT program:

1. Further optimization
2. Tests with n+ ions at GANIL
3. Possibly test with n+ from TwinEBIS

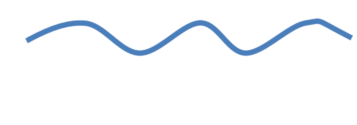



Slow extraction @ REXEBIS




EBIS beam debuncher

ICBT goal: **CW**



(with +-20% fluctuations)

EBIS beam debuncher

*ICBT – Innovative Charge Breeding Techniques*

# HIL Warsaw

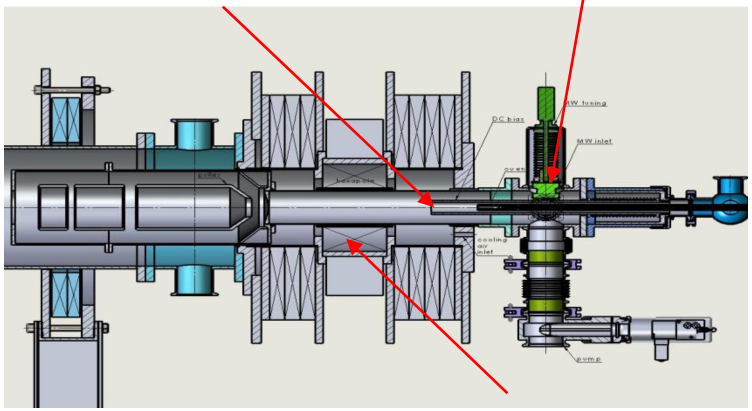
Beam purity - use rotatational hexapole to sweep the loss cones over the plasma chamber wall.

Efficiency - try non-axial injection of 1+ ions to study the impact of the injection energy and time-of-flight inside the plasma on the 1+ ion capture and breeding efficiency.

Setup – the experiments will be conducted on a for this purpose modified ECRIS test bench at HIL.

MW coupling perpendicularly to the drawing ($TE_{10}$ → TEM)

Inner rod



Hexapole

# Thanks a lot for your attention!

## Have a fruitful workshop!

**GANIL**
L. Maunoury
E. Traykov
P. Jardin
M. Dubois
P. Chauveau

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

**ANL**
R. Vondrasek

**ISOLDE**
F. Wenander
A. Shornikov

**LPSC**
T. Lamy
J. Angot

**HIL**
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G. Prete

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D. Mascali

**JYFL**
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O. Tarvainen

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