Charge breeding studies at ISOLDE

Pierre Delahaye, ISOLDE

F. Wenander, M. Marie-Jeanne, R. Savreux and R. Scrivens

For the

ISOLDE, REX-ISOLDE

and IS397

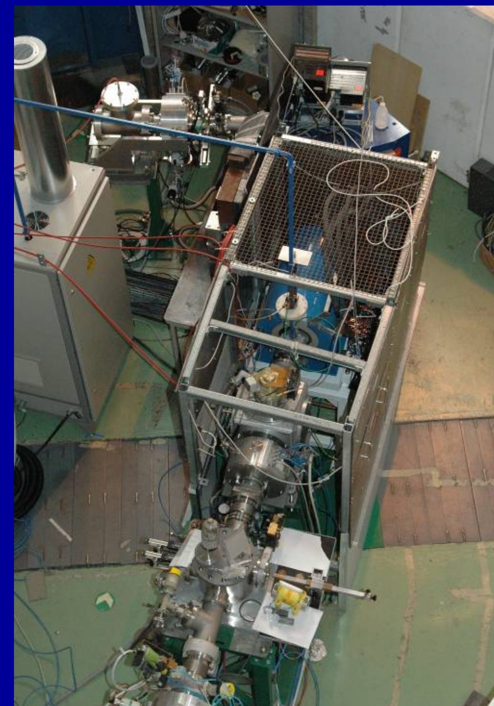
collaborations

EURISOL Town meeting, GANIL, 28/11/05, CAEN

The REXEBIS and the Phoenix booster

REX-EBIS

Operational at REX-ISOLDE



Phoenix ECRIS 14GHz

Test stand at ISOLDE

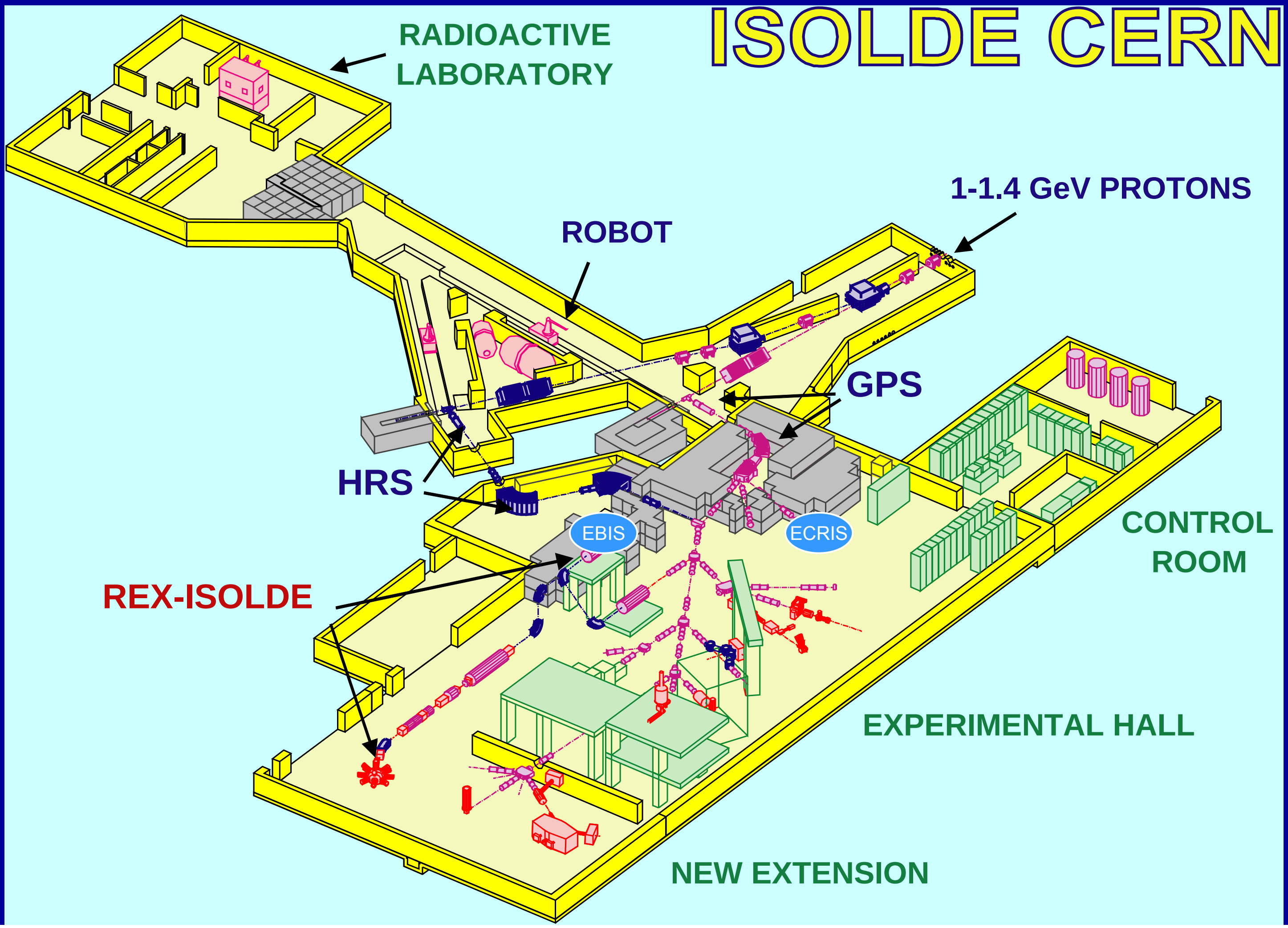
Singly charged ions →n+ ions transformation

- More post-accelerated beams available
- More radioactive isotopes available
- Better purity in some cases

Molecular sidebands from the ISOLDE targets (applies to the two items above)

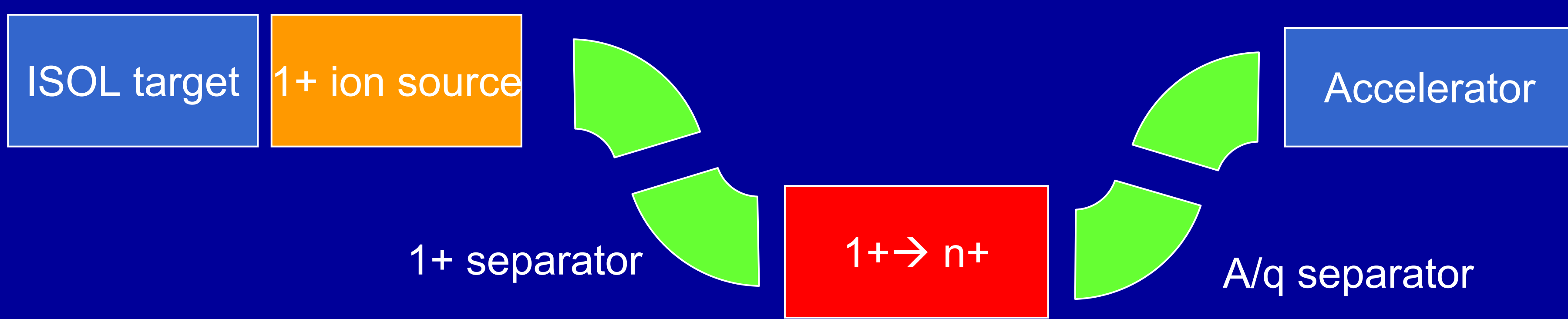
- Some applications for physics experiments of charge bred beams
- Efficiency: 1 - 20% in one charge state depending on Z

The two charge breeders at ISOLDE



The 1+→n+ scenario for ISOL post-accelerators

- In the frame of EURISOL, this scenario is studied for the reduction of the cost of the postaccelerator



Charge breeding activities at ISOLDE

- The REXEBIS as an operational machine
  - Constant improvement of operation and performances with the requested beams - EURISOL
  - A few studies of advanced charge breeding techniques - EURONS
  - Several upgrades foreseen – HIE ISOLDE
- The Phoenix ECR charge on its test stand
  - A dedicated setup for the tests and optimization of the performances of the charge breeder - EURISOL
  - Different upgrades of the test bench are foreseen - EURONS
  - Some potential application to physics experiments – HIE ISOLDE

ISOLDE CERN

I3 EURONS

REX-ISOLDE

EURISOL Design Study

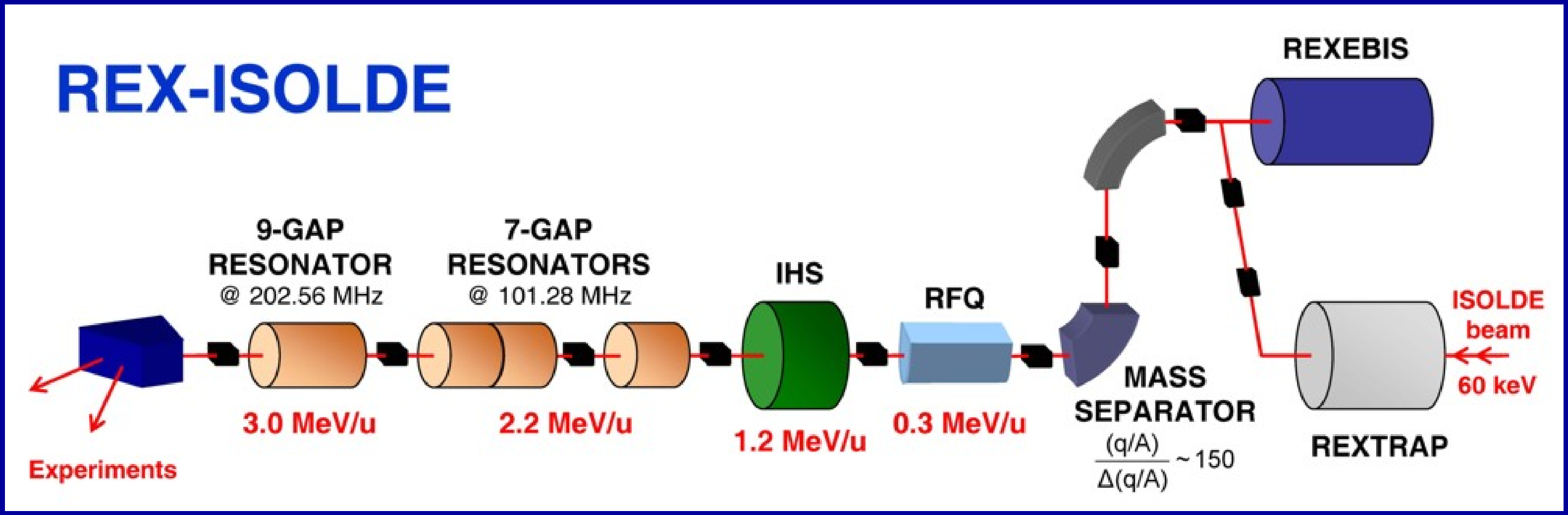
CERN

The REXEBIS as an operational charge breeder

F. Wenander et al., in print by Rev. Sci. Instrum.
ICIS 05 Proceedings

The REX-ISOLDE post-accelerator

- 10% duty cycle LINAC
- 3<A/q<*4.5*
- From 5keV/u up to 3MeV/u



ISOLDE CERN

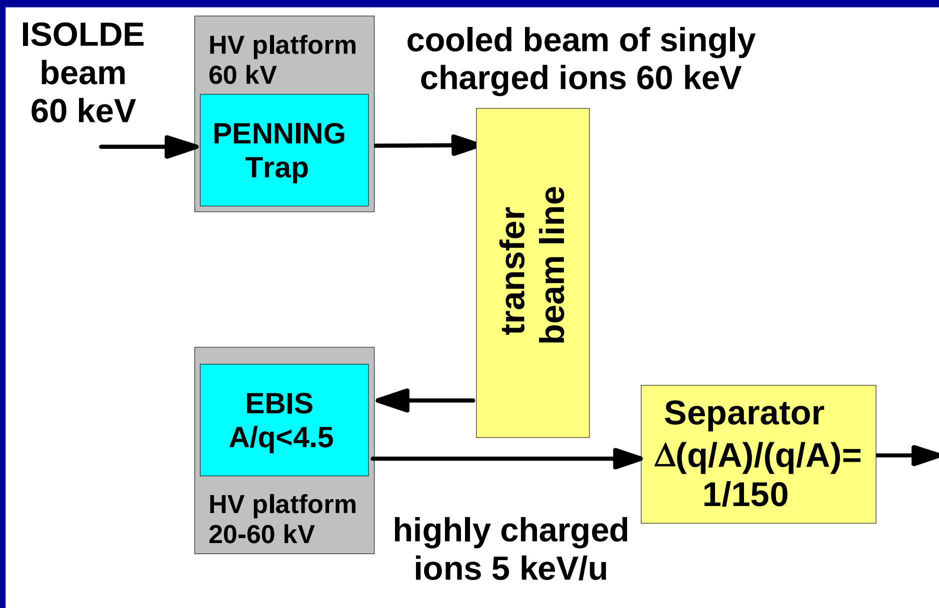
I3 EURONS

REX-ISOLDE

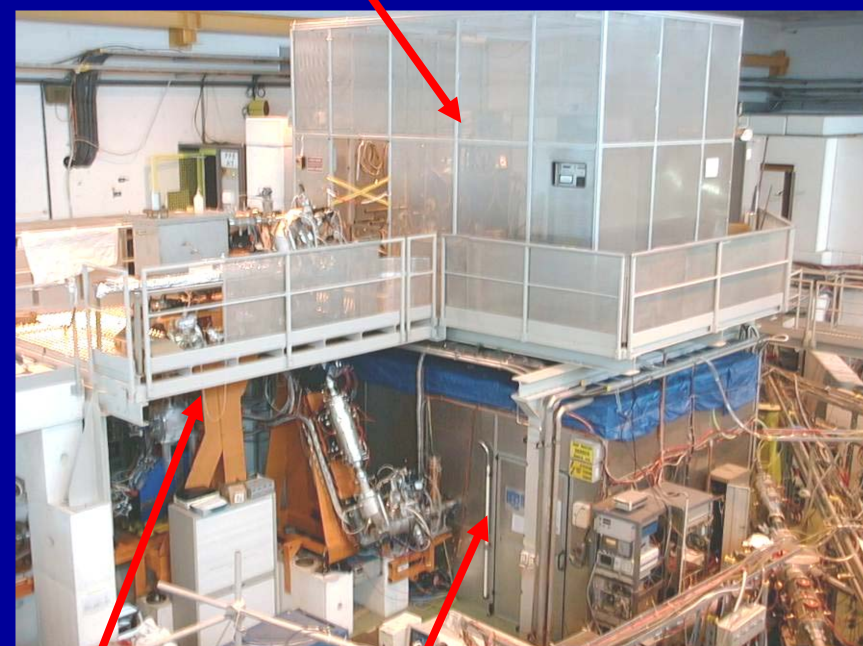
EURISOL Design Study

CERN

The low energy stage



REX EBIS



q/A-selector

REXTRAP

breeding time (A/q < 4.5)	20 ms
beam intensities	$< 10^{10}$ /s
ions in one charge state	< 30%
injection efficiency into EBIS	>80%
efficiency REXTRAP	50%

Limited by space charge effects above 10^8-10^9 ions/ cycle

ISOLDE CERN

I3 EURONS

REX-ISOLDE

EURISOL Design Study

CERN

REXEBIS Efficiencies

Element	Charge state	Radioactive	Breeding time (ms)	Efficiency %
^{7}Li	2+	No	5	**13**
^{7}Li	3+	No	18	**12**
^{23}Na	7+	No	15	**18**
^{26}Na	7+	Yes	18	**11**
^{28}Mg	9+	Yes	18	**17.5**
^{39}K	10+	No	14	**22**
^{68}Ni	19+	Yes	98	**>7**
^{68}Cu	19+	Yes	98	**>17**
^{66}Zn	20+	No	78	**3**
^{70}Se*	19+ → Injected as $SeCO^{+}$		58	**6.5**
^{108}Sn	30+	Yes	198	**6**
^{110}Sn	27+	Yes	98	**9**
^{128}Xe	32+	No	330	**4**
^{133}Cs	27+	No	38	**14**
^{133}Cs	32+	No	158	**7.5**

ISOLDE CERN

I3 EURONS

REX-ISOLDE

EURISOL Design Study

CERN

Pushing the limits

Conditions

Tried a higher I_e current of 325 mA (normally 190-250 mA)

higher current density -> faster breeding
larger transverse acceptance/emittance
higher trap capacity

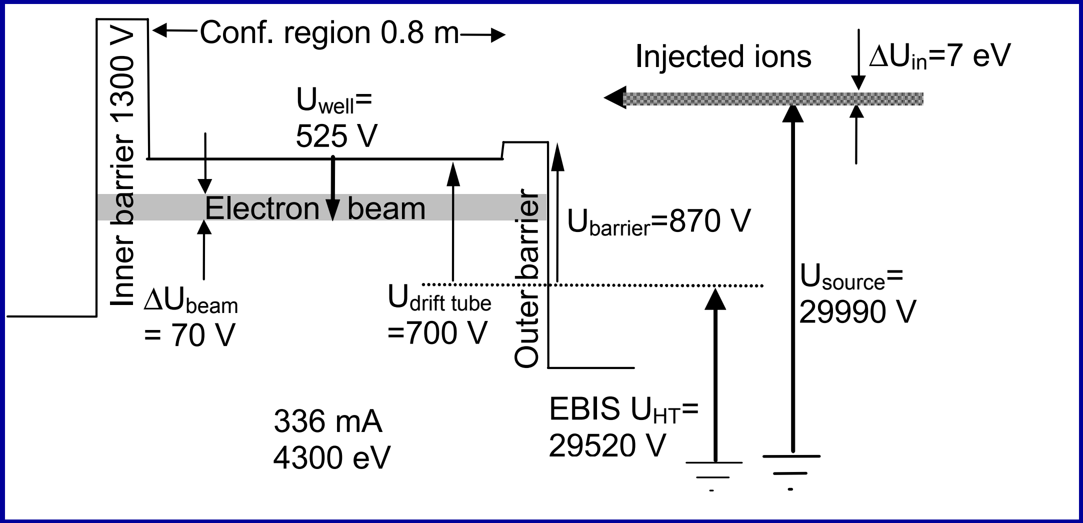
Results

* EBIS eff for 100 Hz operation
  26.6% for K^{9+} (5 ms t_{breed})
  19.5% for K^{10+} (8 ms t_{breed})

* Similar efficiencies for 50 Hz
-> satisfying ion cooling in trap at 100 Hz
* Equally high efficiency as for low Ie
* Optimal t_{breed} 8 ms instead of 12 ms for 10+

advanced charge breeding techniques

- Accu mode or continuous injection mode



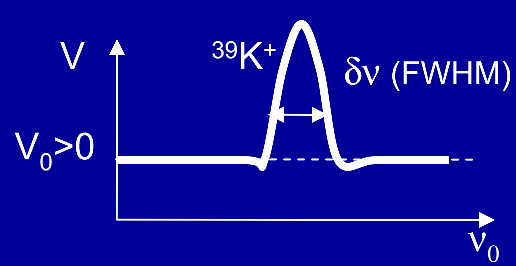
Up to 4% efficiency with $^{39}K^{9+}$

The Penning trap is not necessary

Tested also with $^{39}K^{+}$ and $^{23}Na^{+}$ from HRS

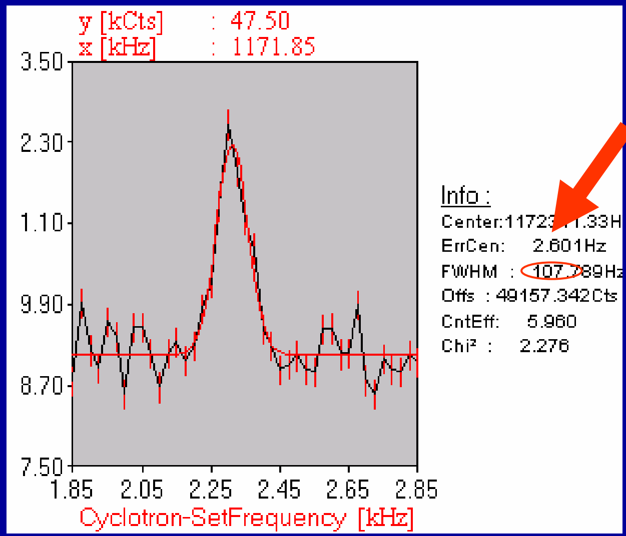
- Mass selective cooling

Refining the mass resolving power of REXTRAP
Preliminary tests show that a resolving power of 10^4 might be possible



* Without magnetron excitation
* Low pressure and amplitude of excitation

$\nu_0/\delta\nu \sim 10^4$



!! 107 Hz !!
ν_0=1172311 Hz

Gas: 5.2 V,
RF amplitude 040,
collect. time 8 ms,
cooling time 40 ms

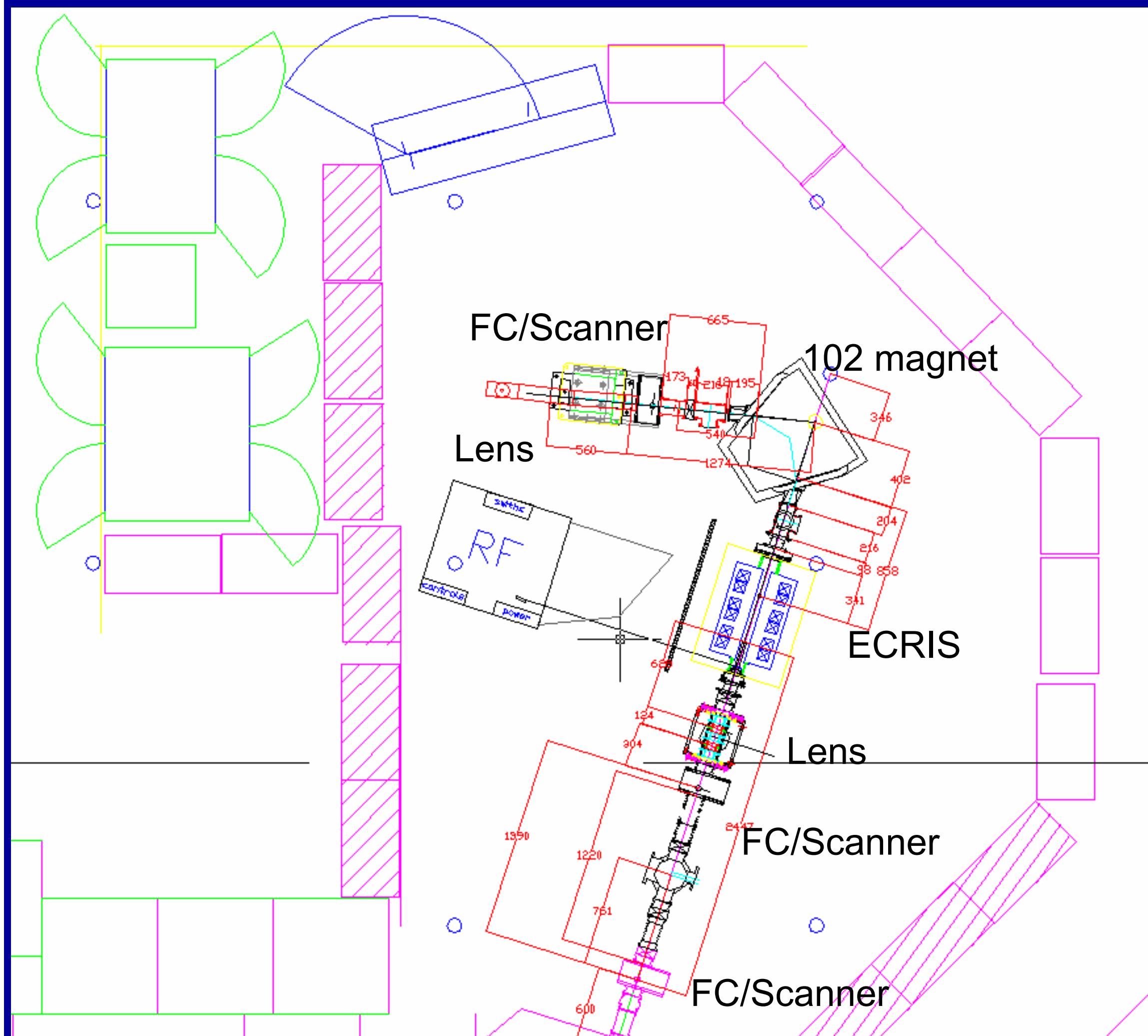
Asa Skulladottir and Sven Sturm

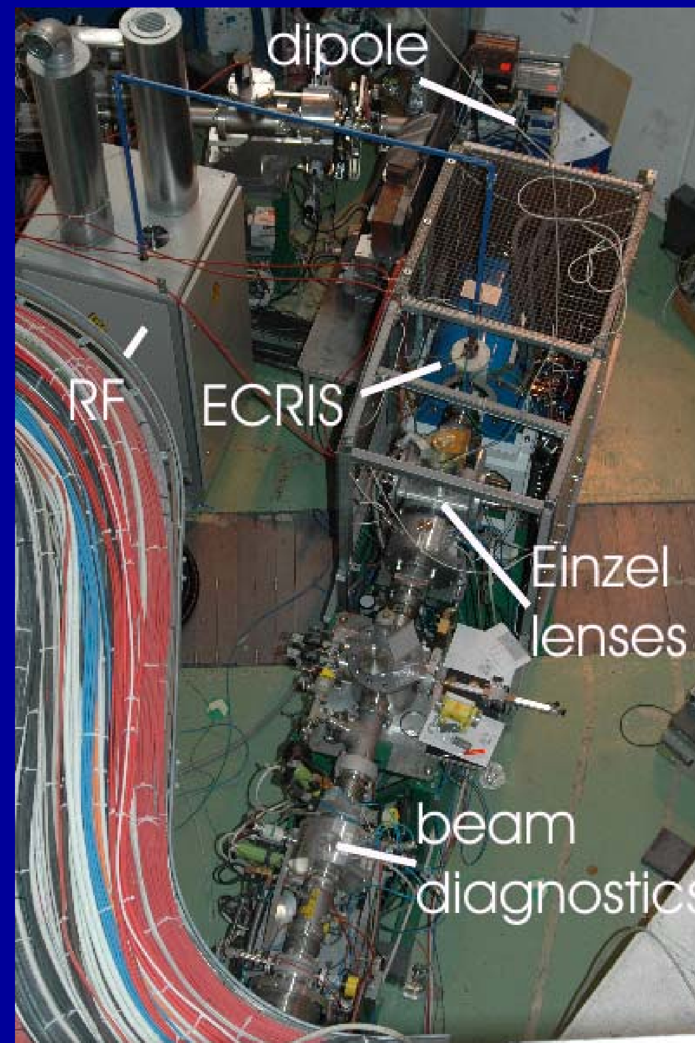
- Shell closure effects $^{39}K^{17+}$ $^{69}Ga^{21+}$
- Ion-Ion cooling techniques (injection of H –He)

The Phoenix booster on its test bench

Pierre Delahaye et al., in print by Rev. Sci. Instrum.
ICIS 05 Proceedings

Experimental setup





ISOLDE CERN

I3 EURONS

REX-ISOLDE

EURISOL Design Study

CERN

Continuous mode results

From 100pA to 10nA of beam injected

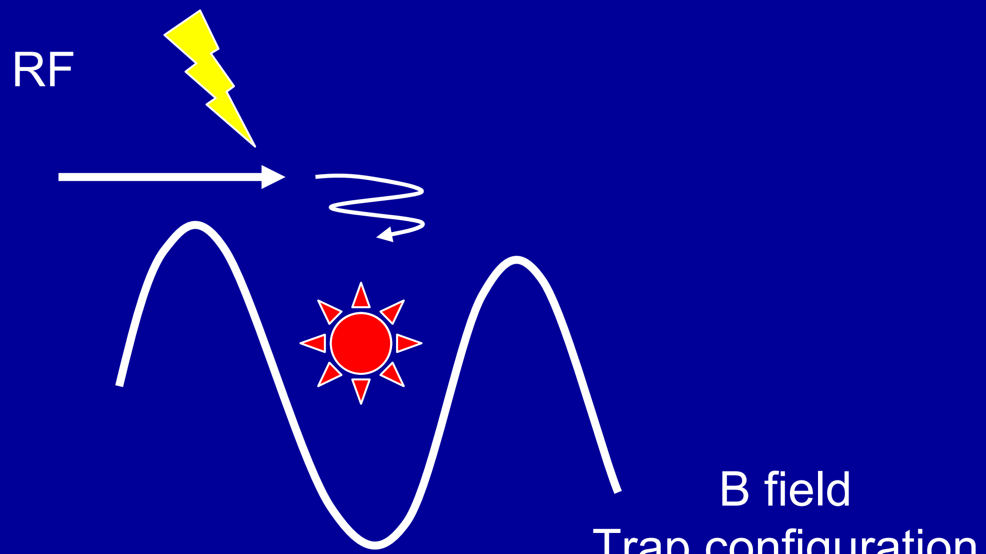
Three ISOLDE target ion – source used:

- LaO target+RILIS: ^{139}La, ^{116}Sn
- Pb/Bi target + hot plasma source: ^{208}Pb, ^{209}Bi, ^{86}Kr, ^{132}Xe
- Ta(W) target: ^{39}K, ^{133}Cs *bad injection conditions!*

1+ ion	N+ ion	$\eta(\Delta\eta)$ %	$\tau_{cb}(\Delta\tau_{cb})$ (ms)	q_{max}	A/q_{max}
$^{39}K^{+}$	$^{39}K^{10+}$	1.7(0.2)	100(50)	10	3.9
$^{116}Sn^{+}$	$^{116}Sn^{21+}$	6.3(2.8)	200(50)	21	5.52
$^{132}Xe^{+}$	$^{132}Xe^{21+}$	6.2(0.7)	230(30)	>21	<6.29
$^{133}Cs^{+}$	$^{133}Cs^{26+}$	1.7(0.2)	200(50)	26	5.12
$^{139}La^{+}$	$^{139}La^{23+}$	2.4(0.3)	200(50)	>23	<6.04
$^{208}Pb^{+}$	$^{208}Pb^{25+}$	3.4(0.7)	-	25	8.32
$^{209}Bi^{+}$	$^{209}Bi^{28+}$	2.3(0.2)	330(50)	28	7.46

Pulsed mode tests

- The ECR charge breeder used as an "ECRIT"
- The current of the extraction coil is ramped up for a trap configuration of the magnetic field
- The RF is pulsed. During the RF gate the ions are accumulated and trapped
- They are released with the plasma during the "afterglow pulse"



ISOLDE CERN

I3 EURONS

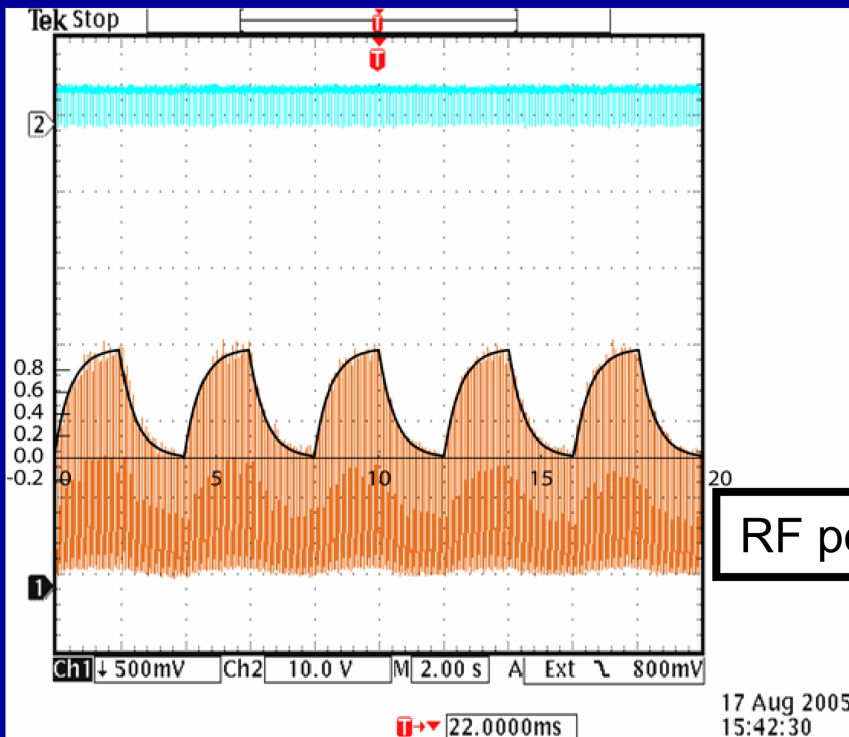
REX-ISOLDE

EURISOL Design Study

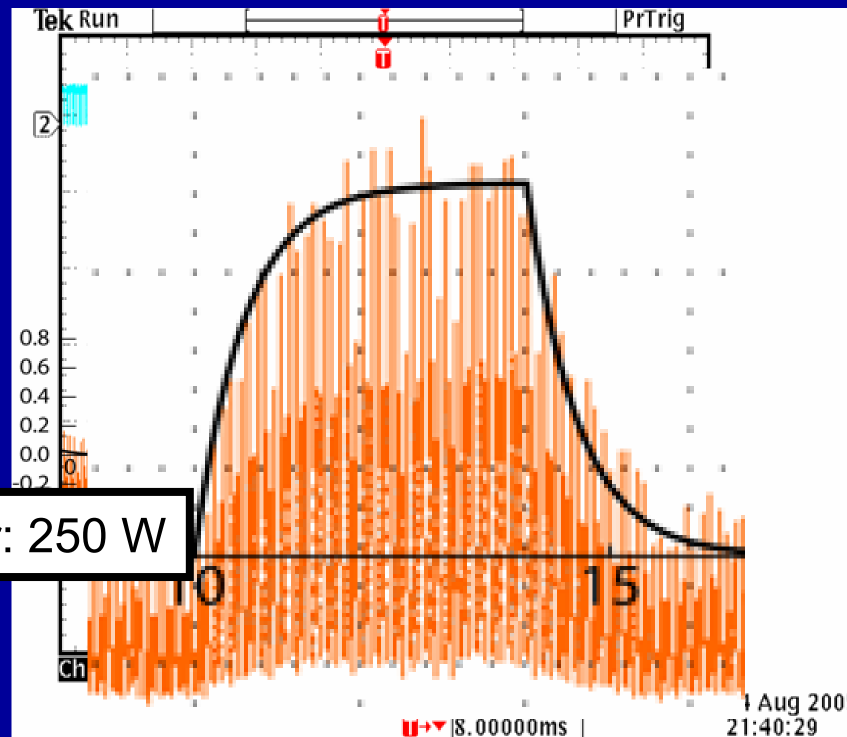
CERN

Pulsed mode preliminary results

- ^{132}Xe and ^{86}Kr beams
- On – off injection cycles for efficiency measurements



RF power: 250 W



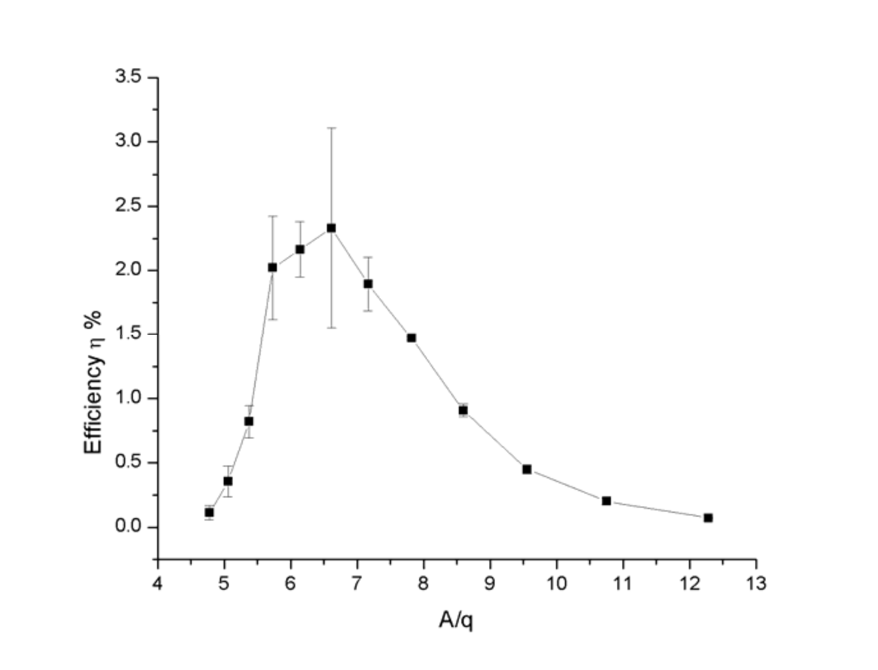
^{86}Kr: 500(100) ms rise time!

^{132}Xe: 600(100) ms rise time!

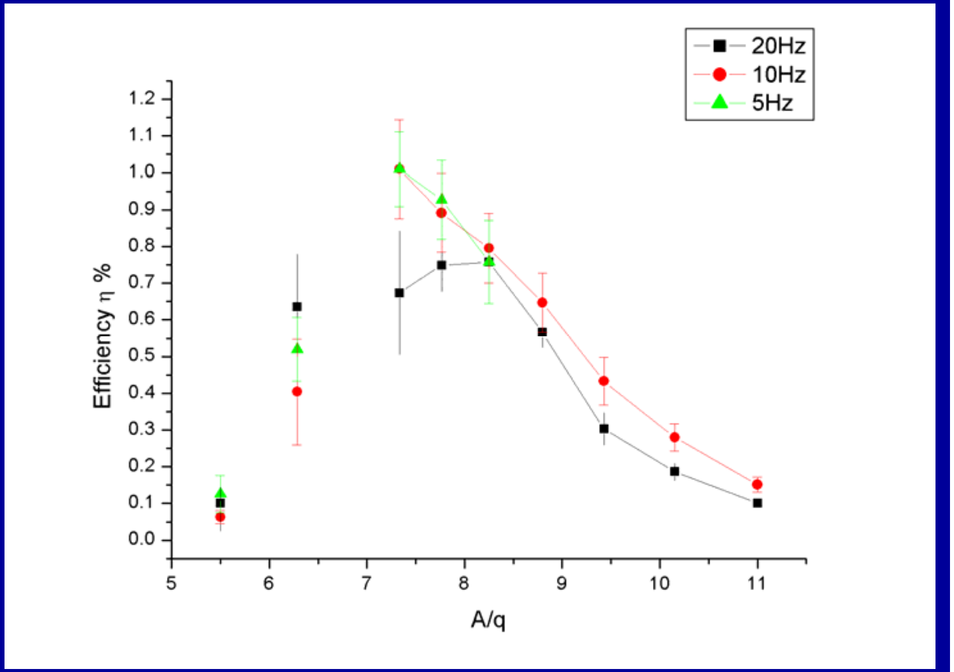
Either middle coil not fully optimized – not good trapping conditions, effusion time or too low power used (**250W**)

Measured efficiencies

^{86}Kr



^{132}Xe



2.2% Kr^{13+}

1% Xe^{18+}

Some more optimization possible! N. Chauvin et al., NIM A **419,** 185 (1998)

Ongoing developments

- Reduction of the background:
  - improvement of the vacuum
  - 2 steps separator
  - UHV source development in c … h LPSC Grenoble
- Extension of the charge breeding towards light ions A<40 with LPSC Grenoble
- Refinement of the pulsed (afterglow) mode
- Molecular beam injection: LaO^+, CO^+

up to 2.7% for $^{139}La^{23+}$ A/q=6.04

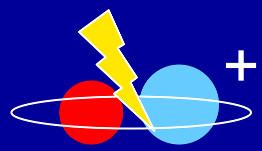
Newly bought from Lund!!

Molecule breakup!

- LaO^+ injected

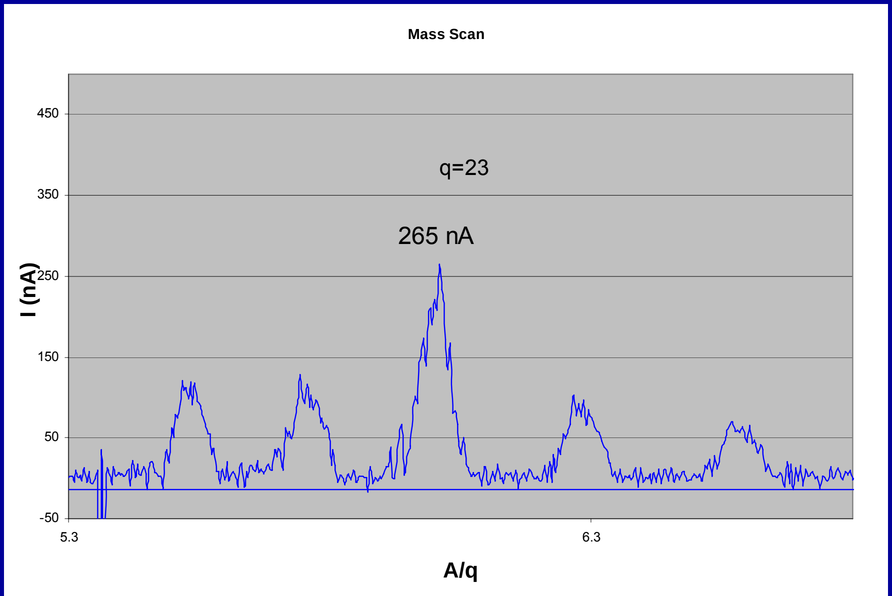
420 nA injected
Background substracted

$^{139}LaO^+$ molecule breakup



$0{,}1+ \rightarrow 23+$

up to 2.7% for $^{139}La^{23+}$ A/q=6.04



Brief Summary Shutdown 2005- 2006

	REXEBIS+REXTRAP	PHOENIX booster
Efficiency	15→2%	7→ 2% ≈ for same Z
τ_{cb}	From 13 to 300ms depending on A	<300ms 100 ms ~ Confinement time
A/q	3.5 - 5	5 – 8
A	No real limitation	Injection difficult A<40
Mode	Pulsed	Continuous or pulsed
Imax	A few 10nA	> 1 μA
Backgrd	If no gas peak <0.1pA	Usually >2nA
Reliability	Cathode is fragile	Robust

Conclusion

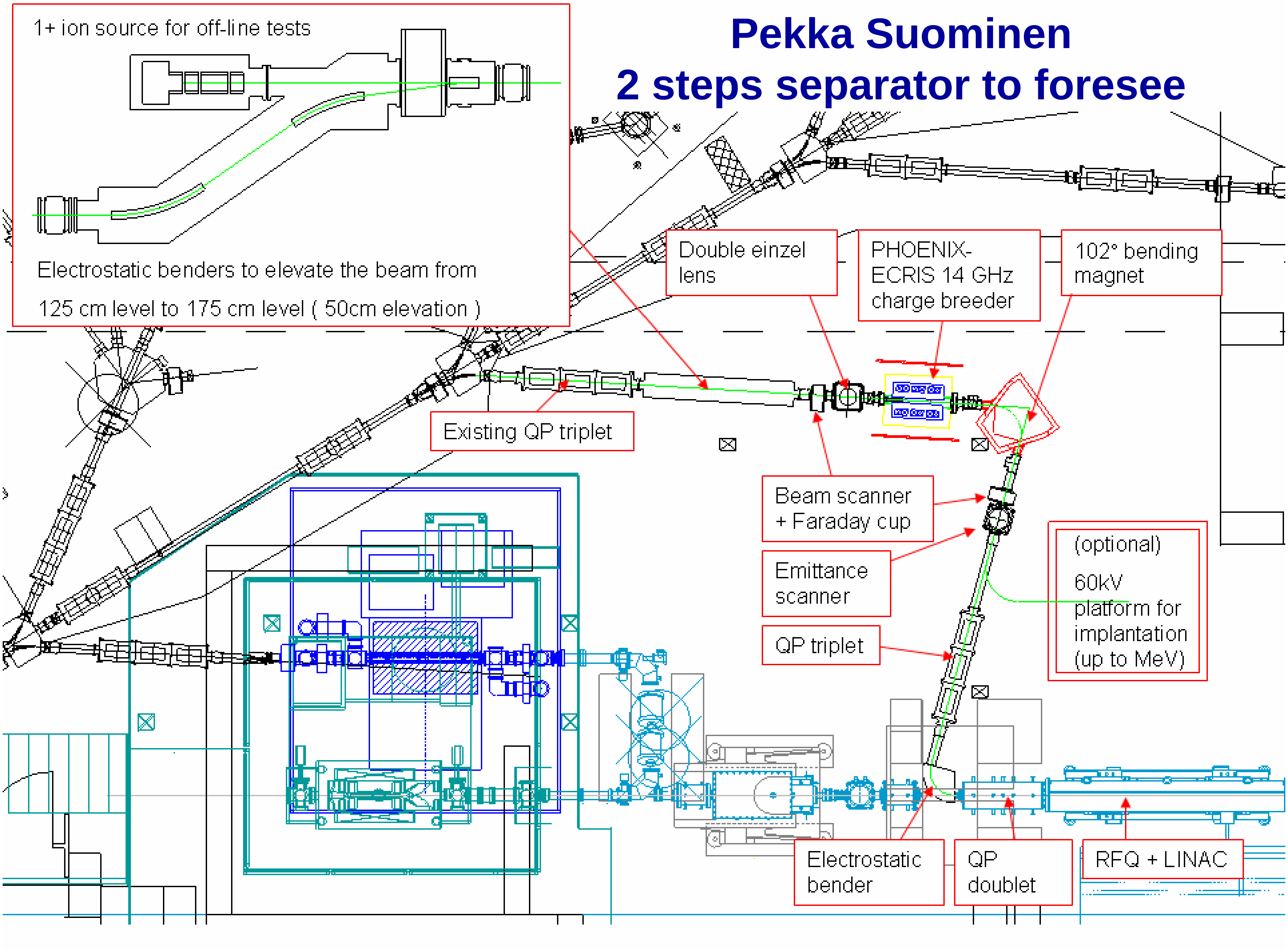
- Both booster have advantages, an obvious high complementarity is shown
- More tests need to be done, especially for the Phoenix ECR (IS397 experiment)
- The ongoing developments might hopefully lead to improved performances
  - Phoenix booster: UHV ECR breeder, 2 steps separator, light ion injection, …
  - REXEBIS: New gun design, higher Intensity of ebeam 10A?!, …

Outlook

- Possible use of the ECR charge breeder for physics experiments
  - Sometimes a useful tool for **beam purification** using the charge state distribution (T. Fritioff, J. Cederkall, L. Weissman et al., NIM A **556** (2006) 31
  - **Molecular sidebands:** spectroscopy of exotic nuclides difficult to produce
  - **ECR charge breeder + HV platform** – beams of a few MeV total energy to be used for astrophysics and /or solid states

- Upgrade of REX-ISOLDE: upgrade of the REXEBIS
- ECR booster and EBIS in parallel ?

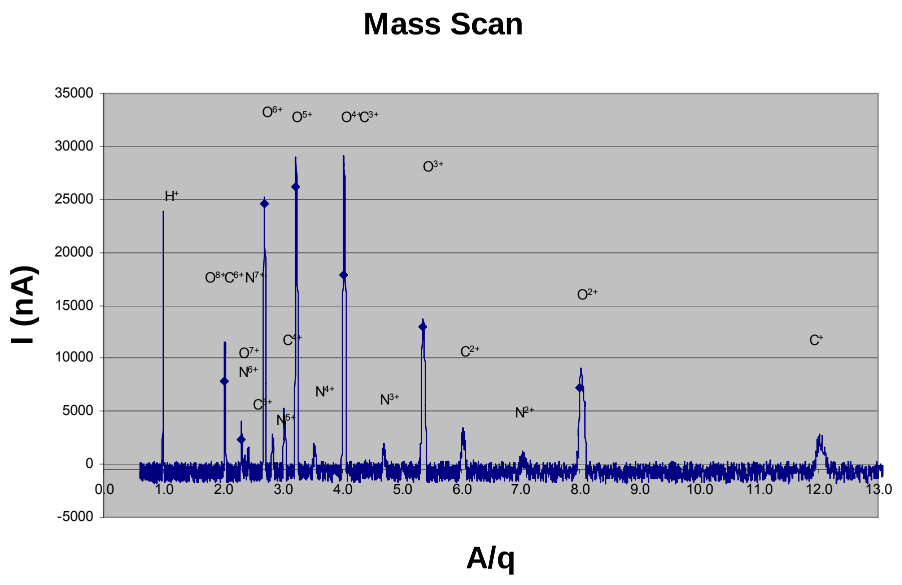
Pekka Suominen
2 steps separator to foresee

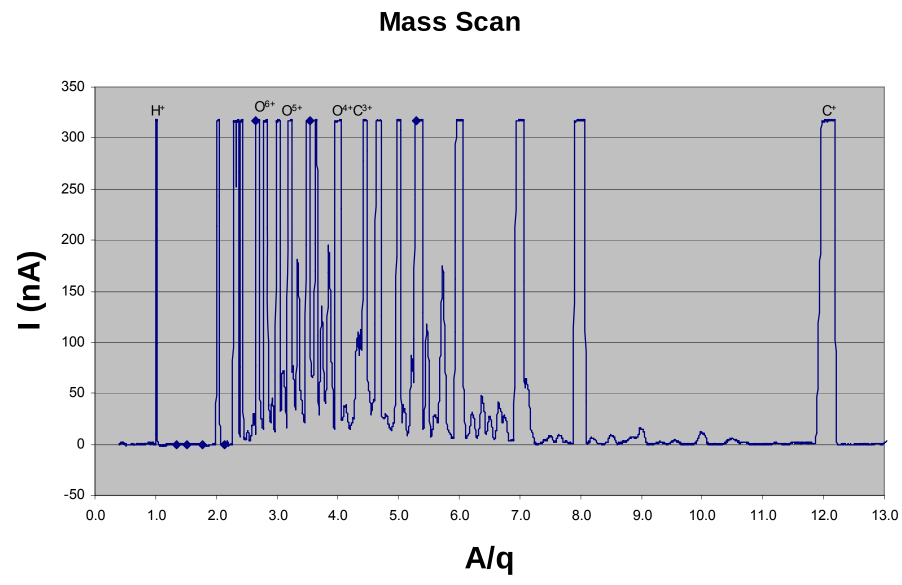


Continuous mode tests

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

Exit P=2.10^{-7}mbar

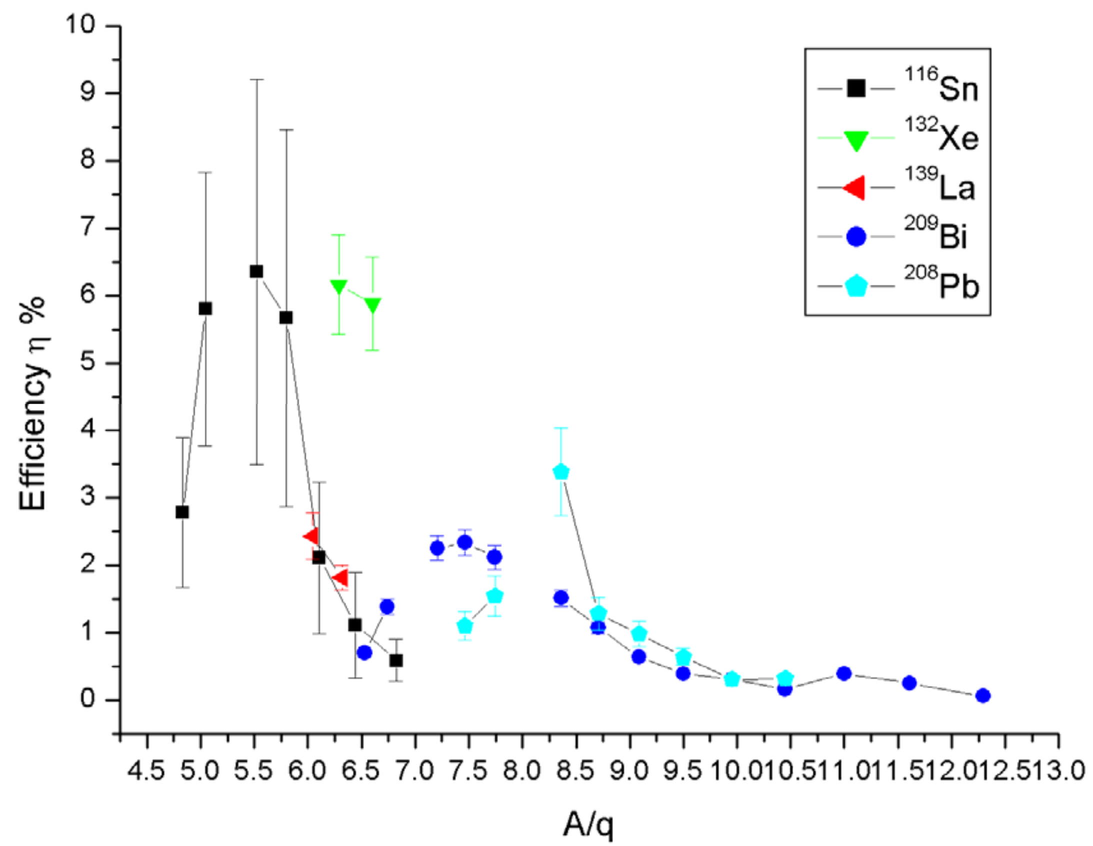




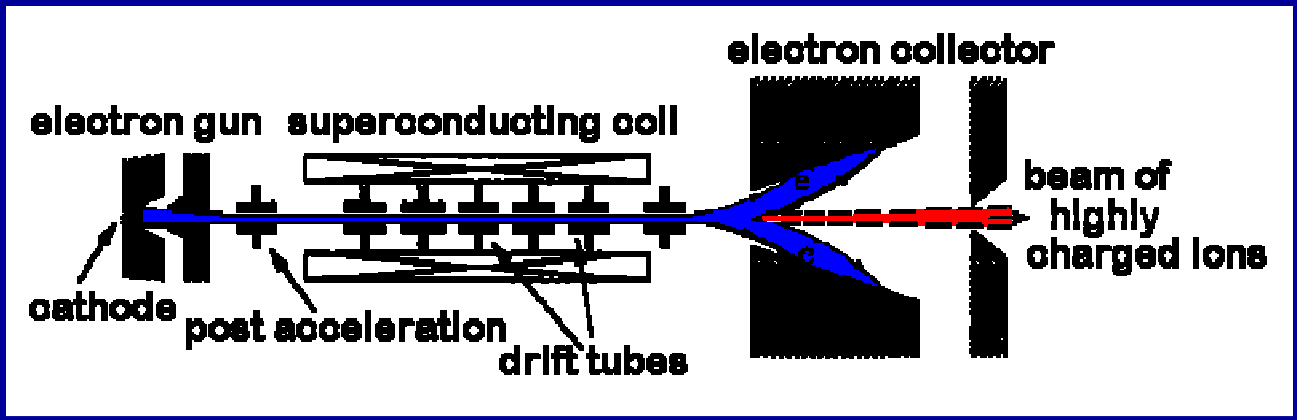
C,N,O stable components of the plasma

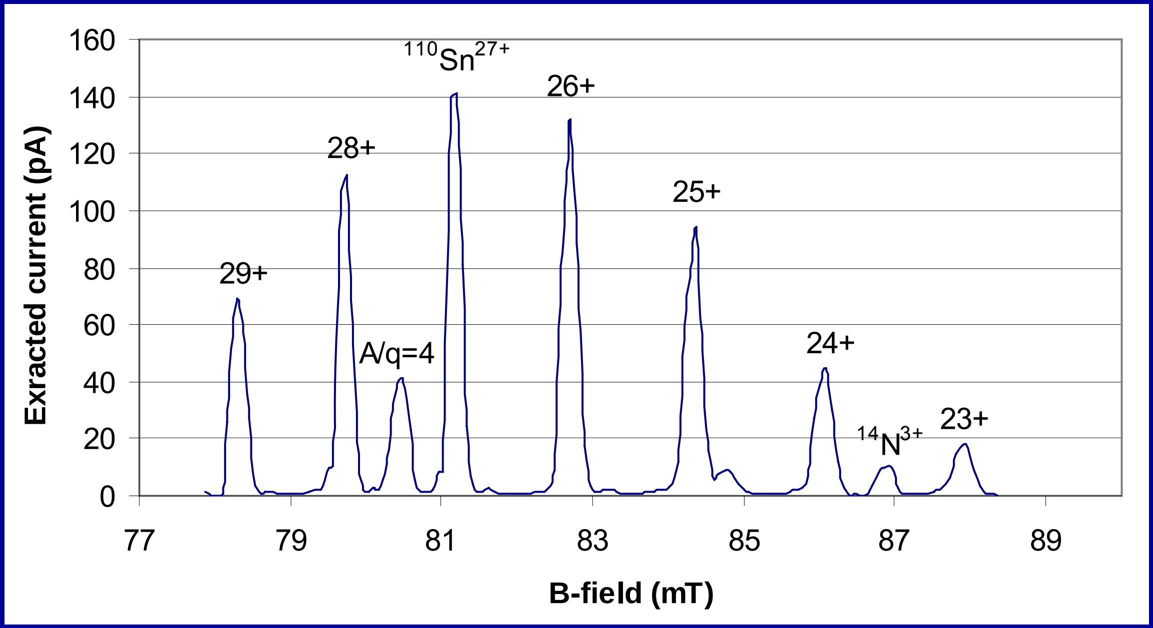
Background >10nA 2<A/q<7

Charge state distributions



The EBIS setup

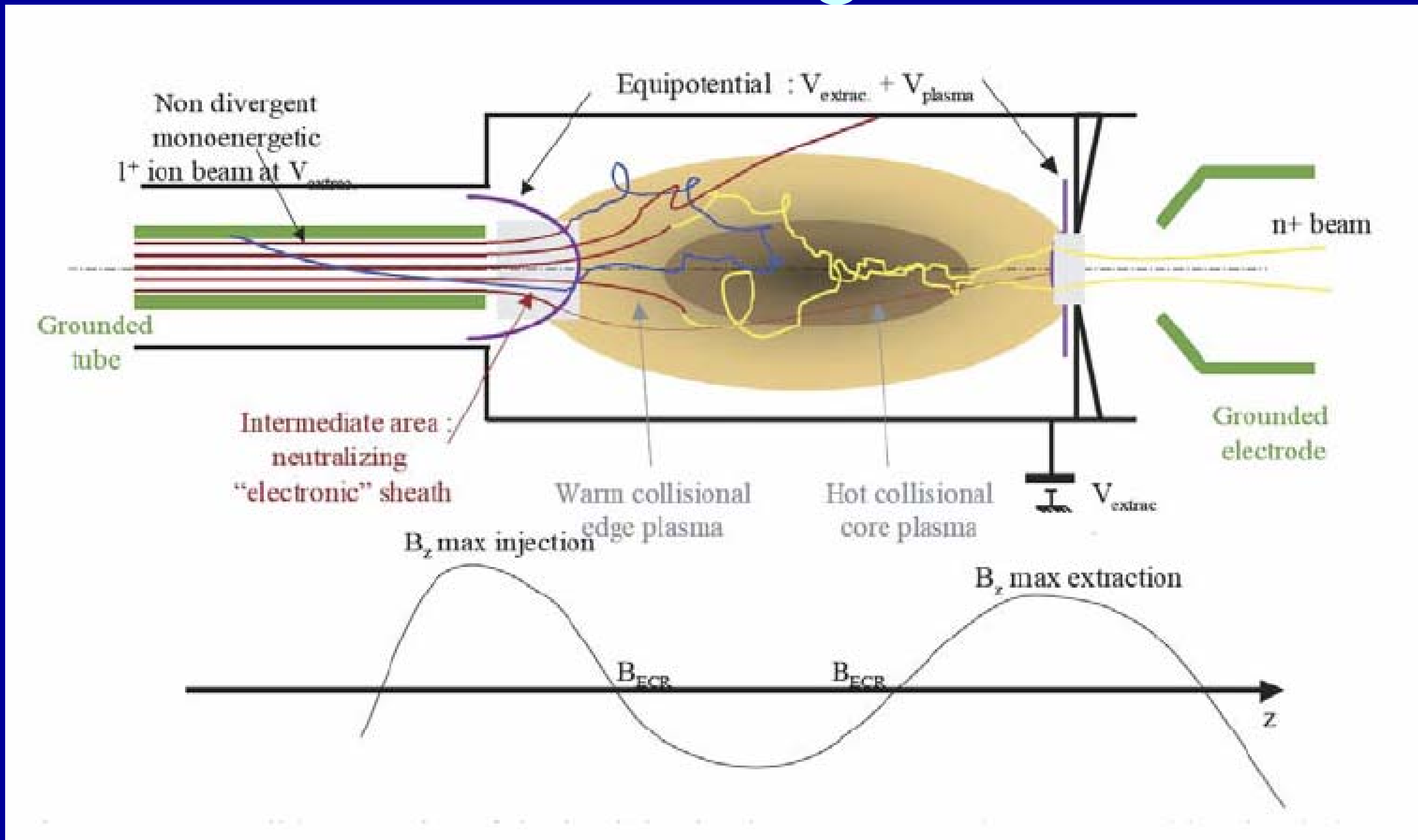




The charge state is selected with a mass separator of Nier-Spectrometer type

98 ms breeding
Radioactive $^{110}Sn^{+}$
9% breeding efficiency in 27+

The ECR charge breeder



The IS397 collaboration

Charge Breeding of Radioactive Ions in an Electron Cyclotron Resonance Ion Source(ECRIS) at ISOLDE

C. Barton[1], P. Butler[2], K. Connell[3], P. Delahaye[2], T. Fritioff[4], D. Habs[5], C. Hill[2], O. Kester[6], H. Koivisto[7], P. Jardin[8], T. Lamy[9], R. Leroy[8], M. Lindroos[2], P. Sortais[9], P. Suominen[7], G. Transtromer[10], A. Villari[8], D.D. Warner[3], F. Wenander[2]

[1] *University of York, United Kingdom*
[2] *CERN / ISOLDE, Switzerland*
[3] *CLRC Daresbury Laboratory, United Kingdom*
[4] *Stockholm University, Sweden*
[5] *Department für Physik, LMU München, Germany*
[6] *GSI, Darmstadt, Germany*
[7] *JYFL, Jyvaskulä, Finland*
[8] *GANIL, Caen, France*
[9] *LPSC, Grenoble, France*
[10] *KTH, Stockholm, Sweden*

and the EURONS charge breeding collaboration