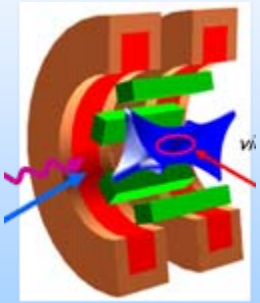
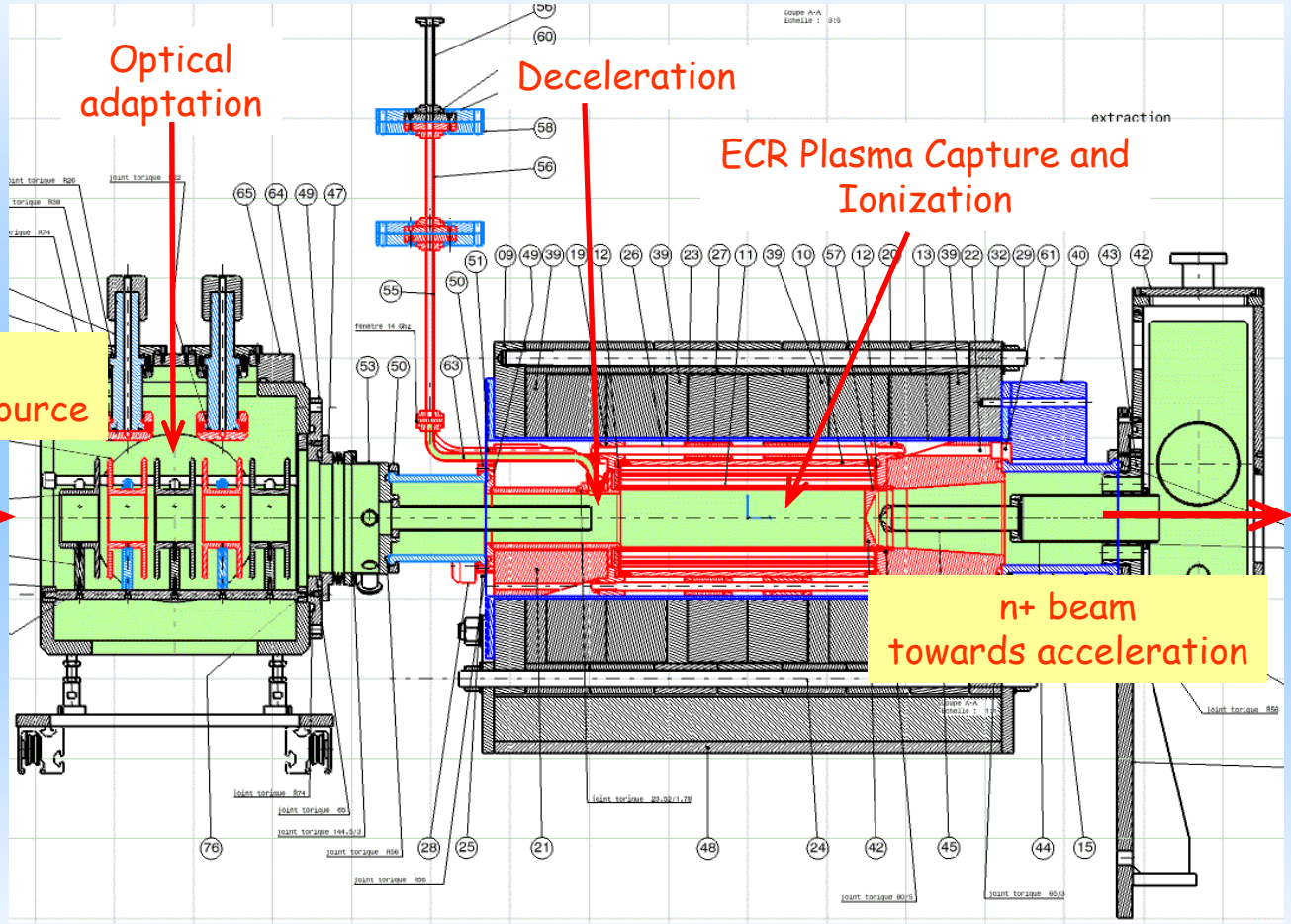
Latest Developments in ECR charge breeders

T. Lamy
LPSC, UJF, CNRS/IN2P3, INPG, Grenoble, France

Basic principles

Method developed since 1992 at ISN-LPSC





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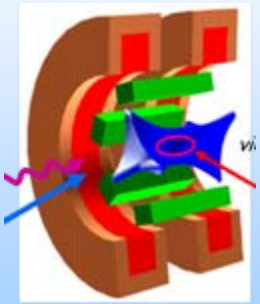


SIMION 3D Calculations

Charge breeder requirements

Efficient

$$\eta_q = \frac{I(q+)}{q \times I(1+)} \qquad \eta_G = \sum_q \eta_q$$

one Q/A *Global capture*

Fast

The charge breeding time must be low with respect to the half-life of the Radioactive isotopes.

High intensity acceptance

Ex: SPIRAL2 - 10^{11} Kr/s delivered to experiments, ~ 100 nA 1+

Good optical characteristics (emittance)

To insure a good transport to the experiments

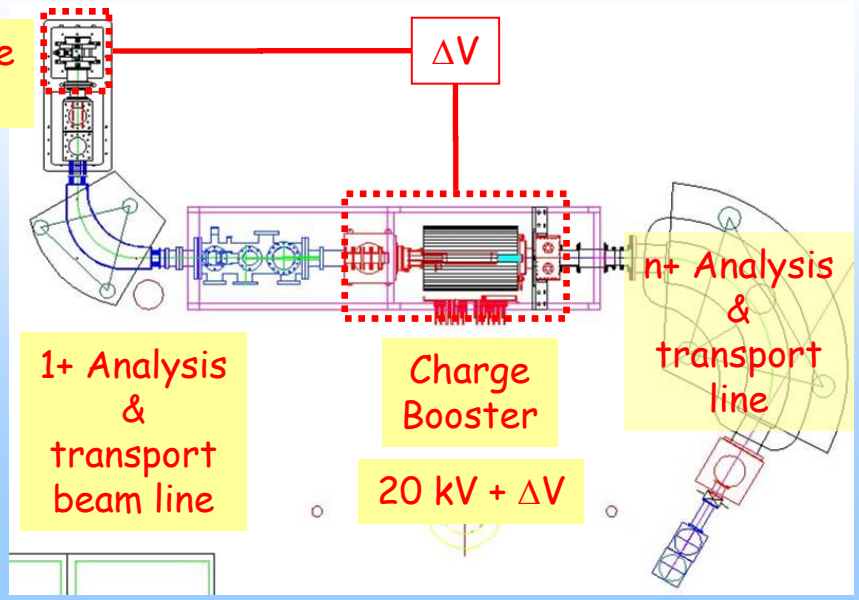
As clean as possible

Superposition of multi charged ions from support gas and impurities on a low intensity radioactive ion beam (nA)

Robust and easy troubleshoting

Due to the radioactive environment, limit the human intervention time

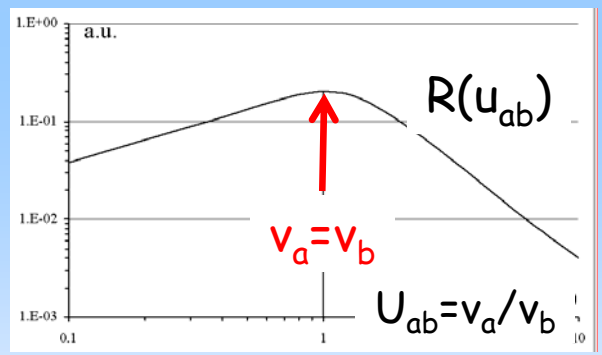
LPSC 1+/n+ experimental setup



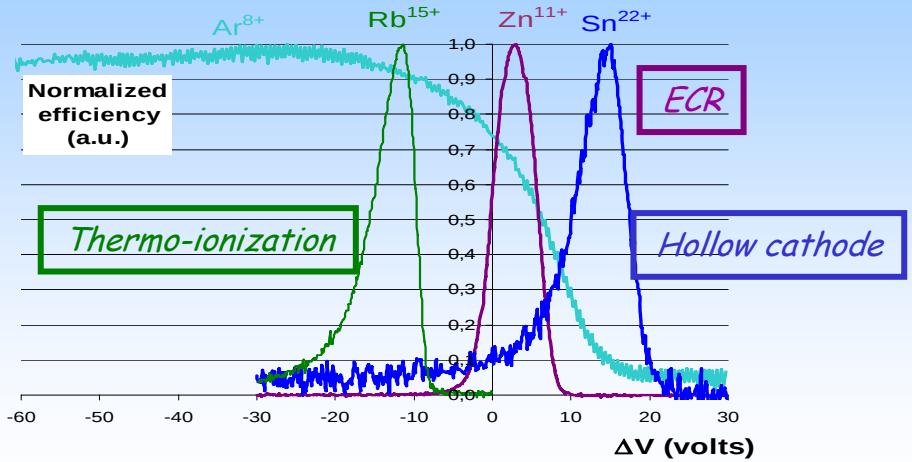
1+ Capture optimization + classical ECR tuning

Capture : 90 degrees deviation issued from successive small long range interactions

$$\frac{\langle \Delta w_{a//} \rangle_b}{\Delta t} \propto n_b \left[\frac{Z_a Z_b}{m_a \overline{w}_b} \right]^2 \left(1 + \frac{m_a}{m_b} \right) R(u_{ab})$$



Knob to tune va/vb
ΔV between 1+ and n+ sources



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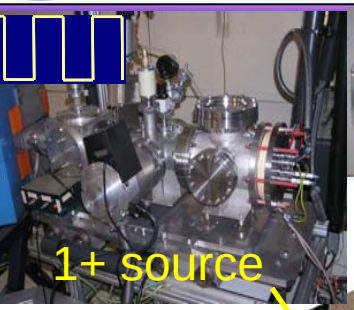
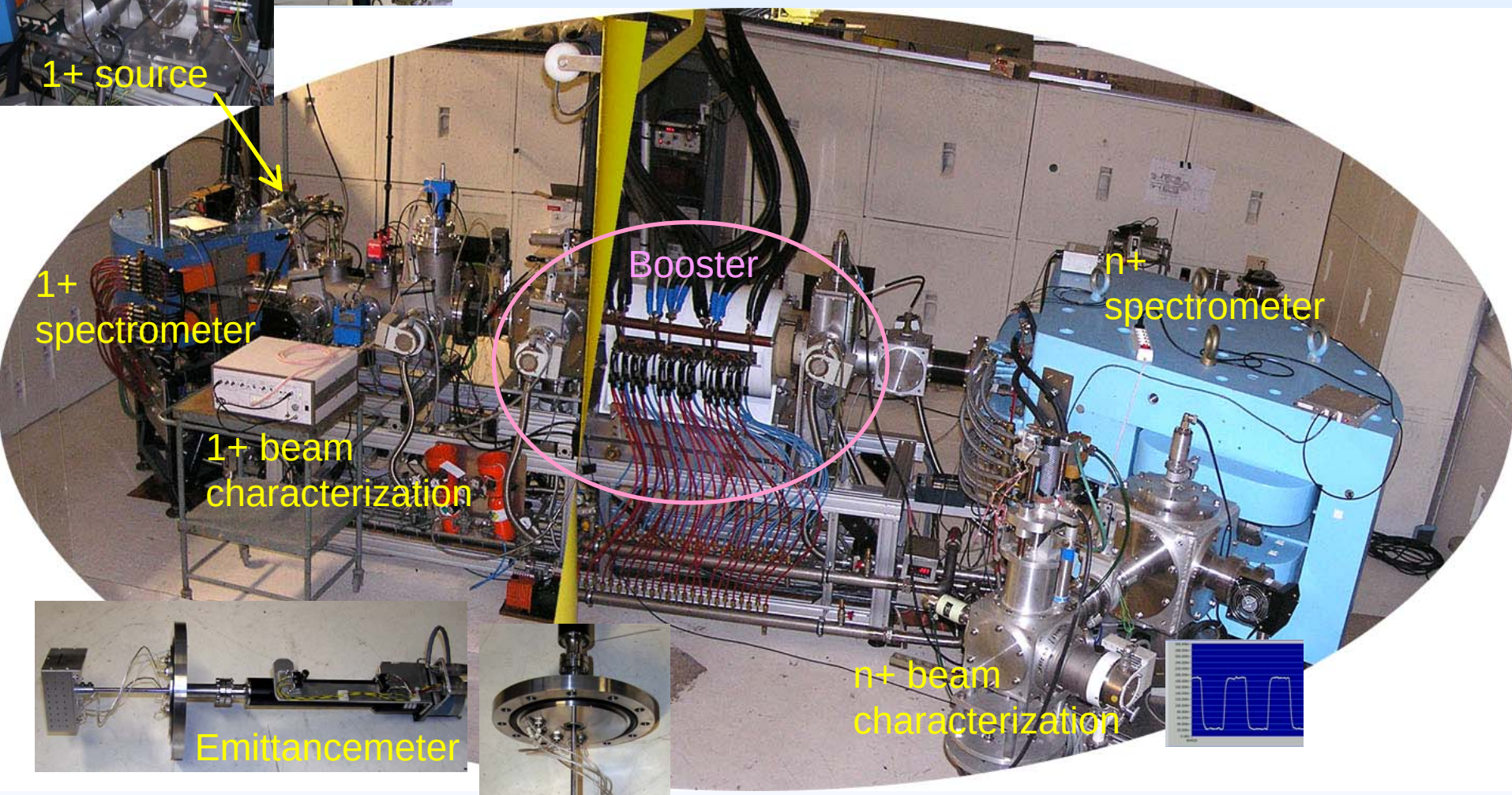




ECR charge breeder : Elements studied

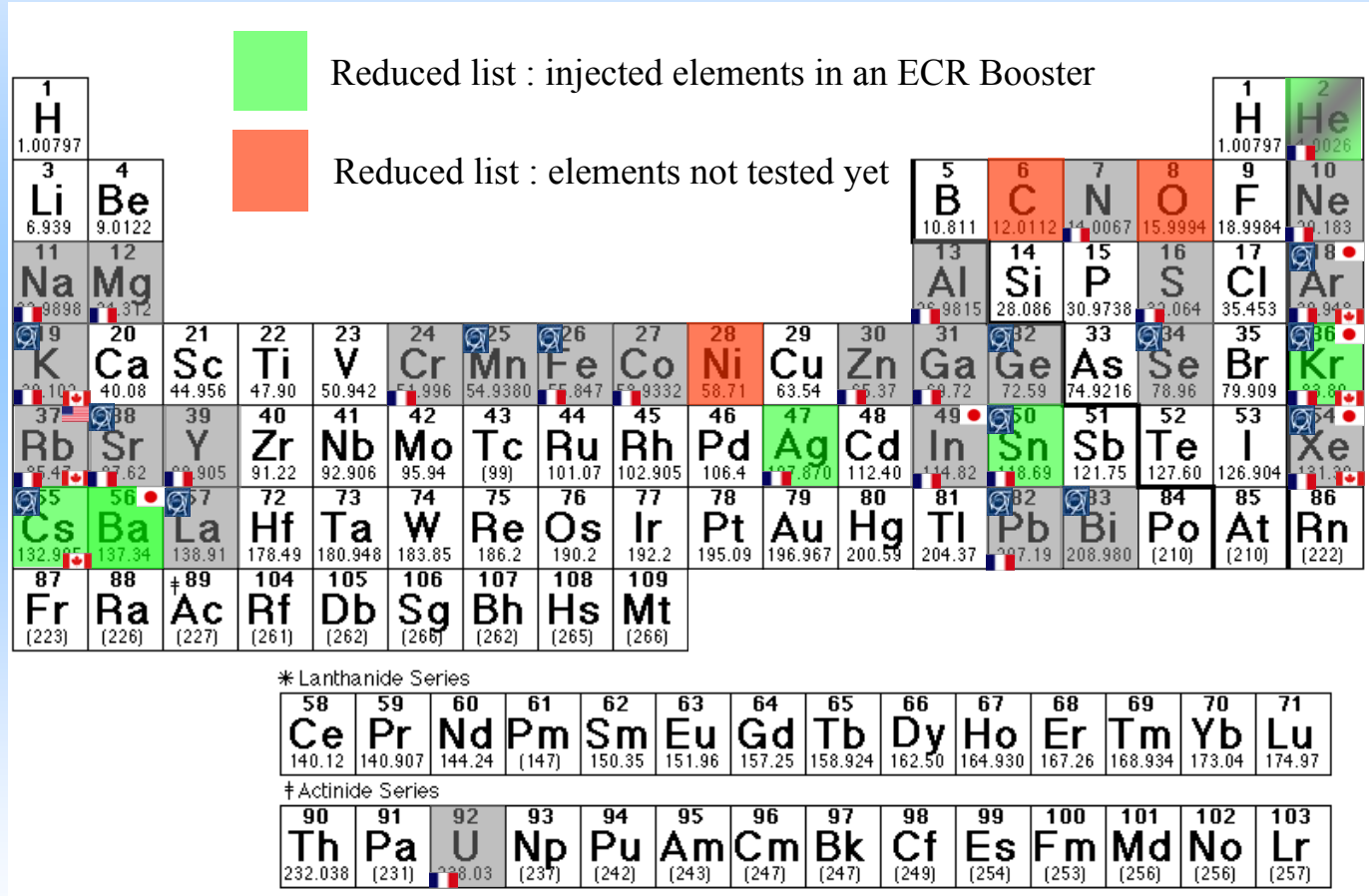
Efficiencies: 31 different elements injected, 22 at LPSC

LPSC | TRIUMF ISAC2 | IS397 ISOLDE | KEK TRIAC | ANL CARIBU

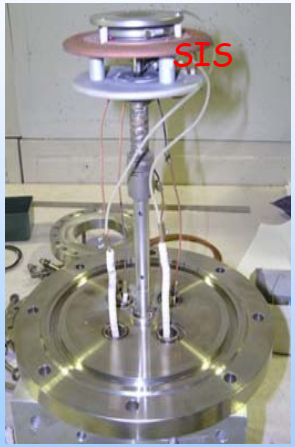
Efficiency on the most abundant charge

Gas
$\eta \approx 10\%$

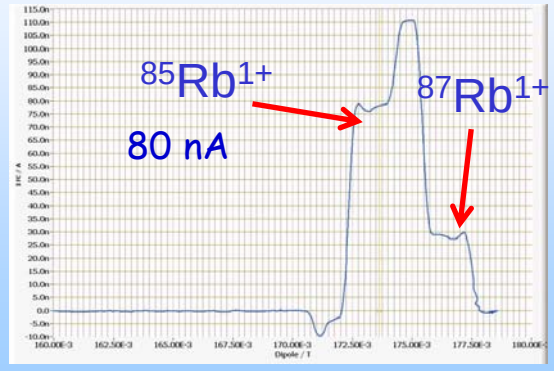
Metals and alkali
$\eta \approx 2$ to 5%



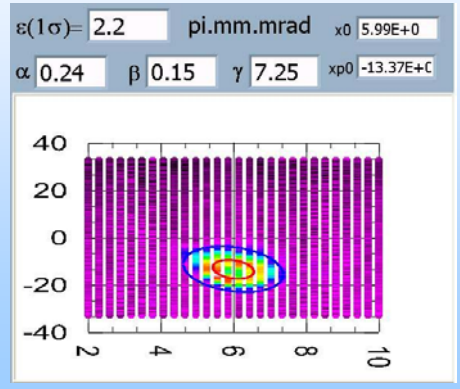
Heavy and light ions charge breeding (Rb)



Rb^{1+} spectrum



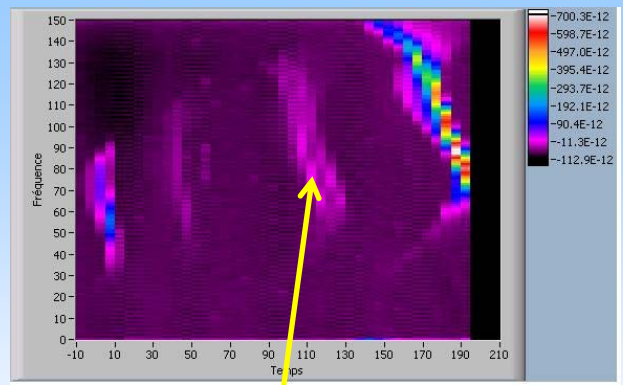
$^{85}Rb^{1+}$ X emittance



$^{85}Rb^{15+}$ (+ O2 gas) 3.6 % 70 ms, (We had before, 5 %, 225 ms)

The tuning of the booster may depend on the isotope half life

^{74}Rb 64.9 ms
^{82}Rb 76 s



$^{17}O^{3+}$, $^{34}S^{6+}$, $^{68}Zn^{12+}$...

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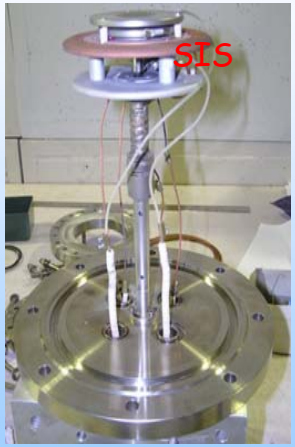

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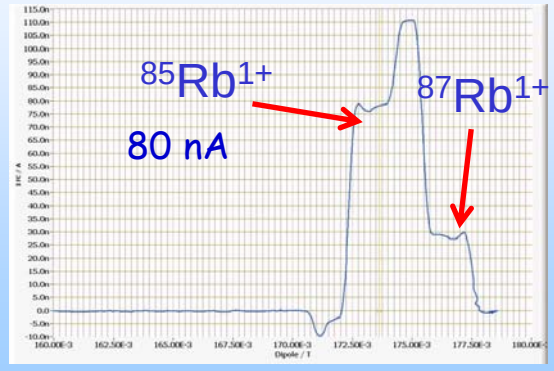

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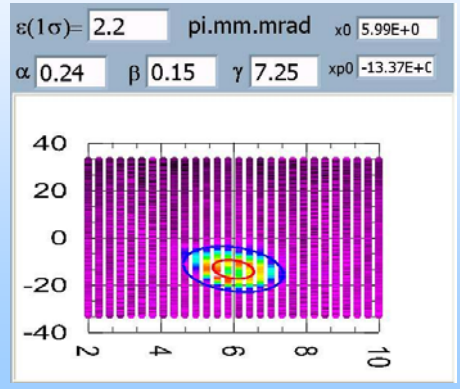

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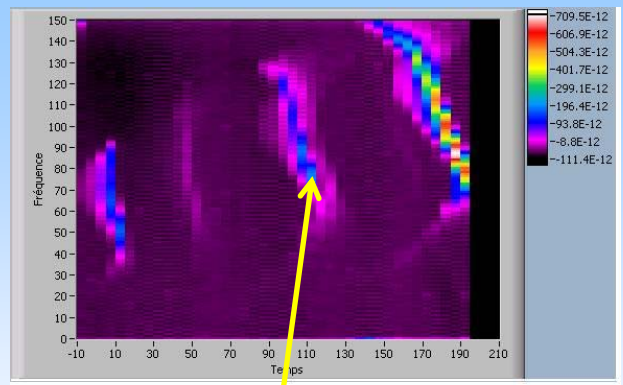

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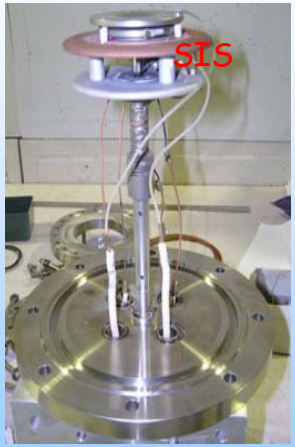

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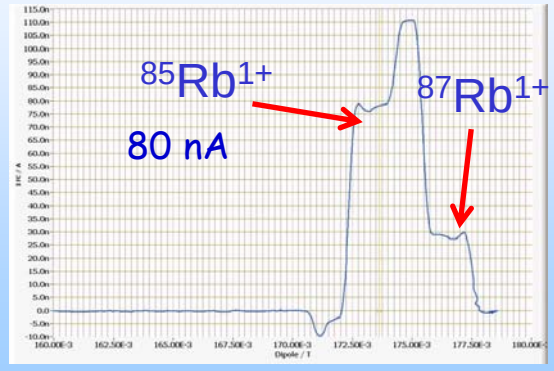

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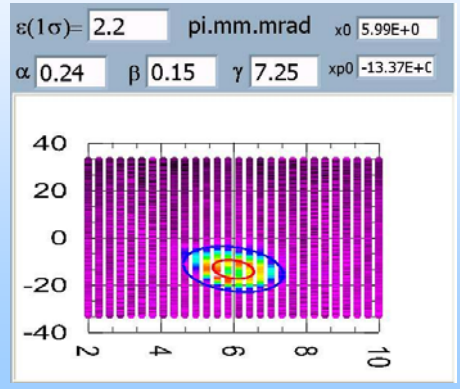

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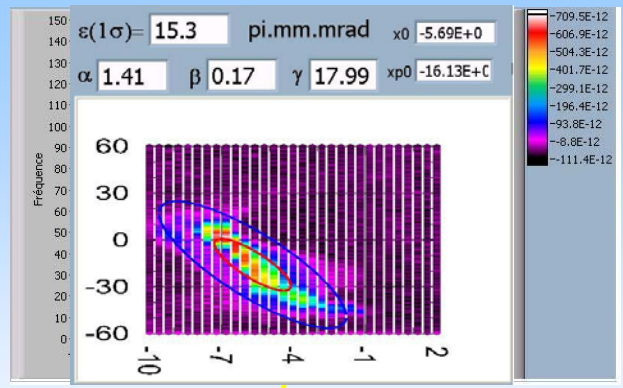

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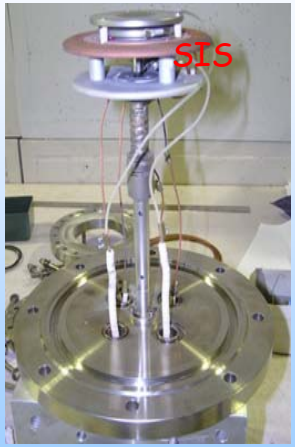

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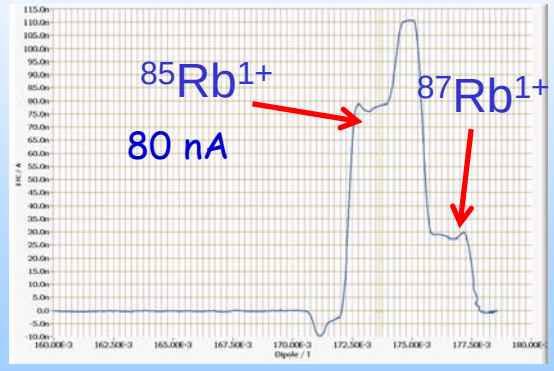

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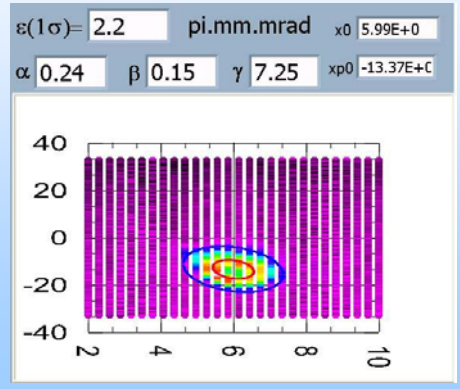

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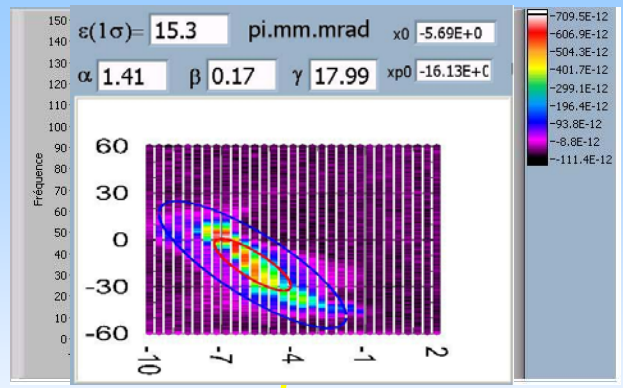

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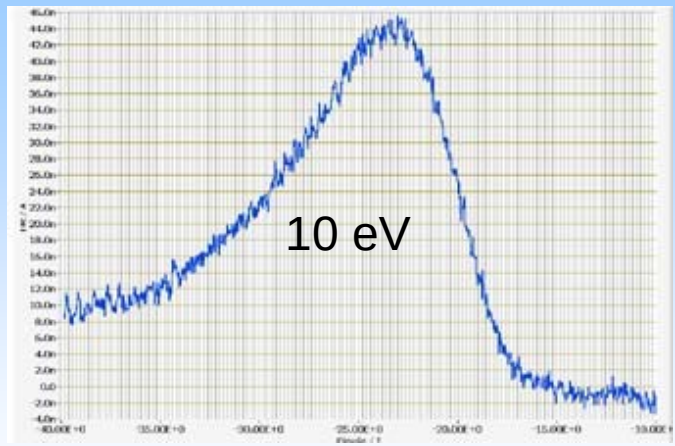
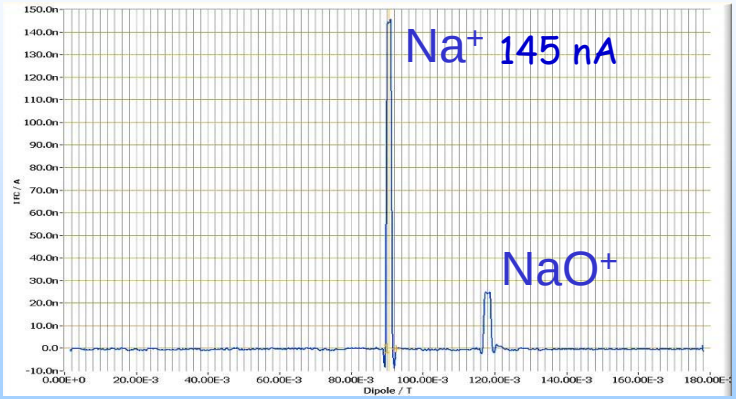
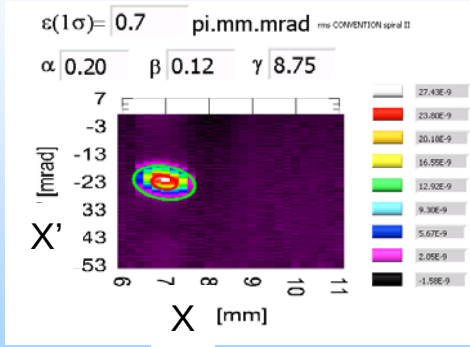
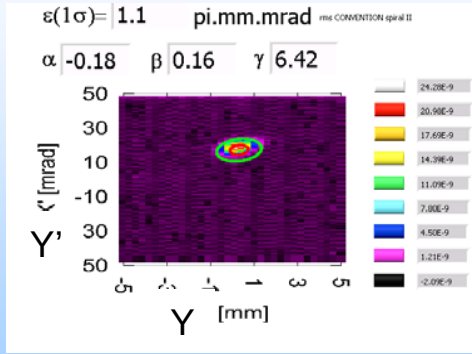


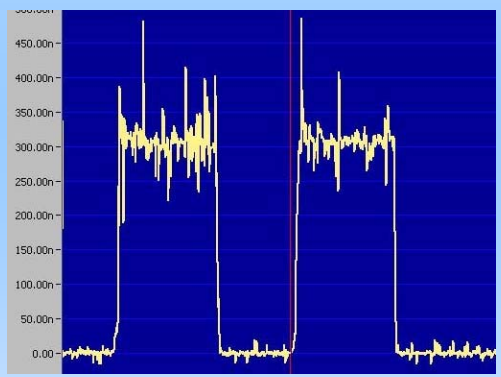
Each radioactive beam is a development by itself

Heavy and light ions charge breeding (Na)







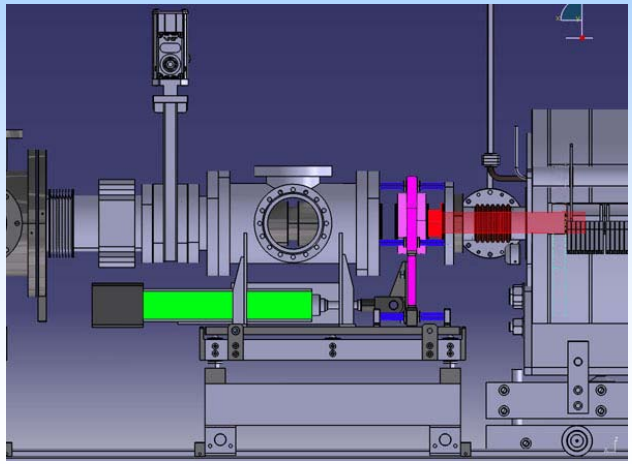


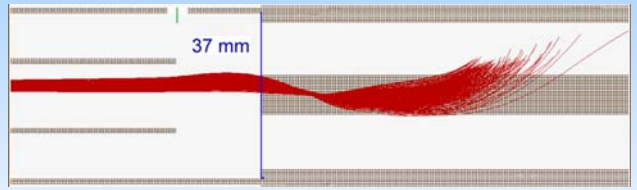
$^{23}Na^{6+}$ (+ He gas) 1.4 % 50 ms, $^{23}Na^{7+}$ 1.14%

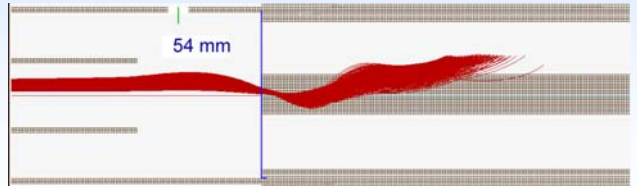
When injecting NaO^{+}, the Na^{6+} production efficiency increases to 1.9 %

Another way
Movement of the grounded tube

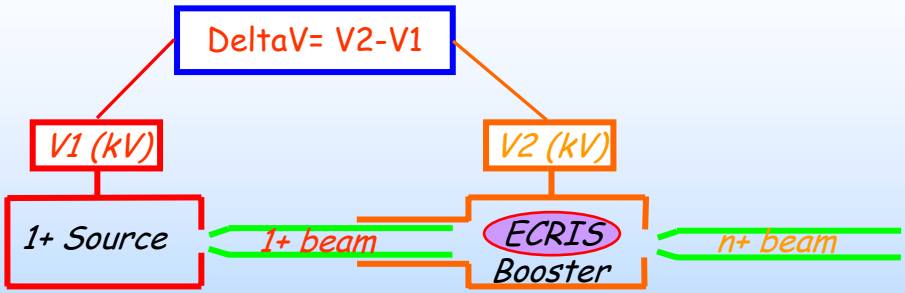
May be an effect on light ions
Capture
Should be checked…

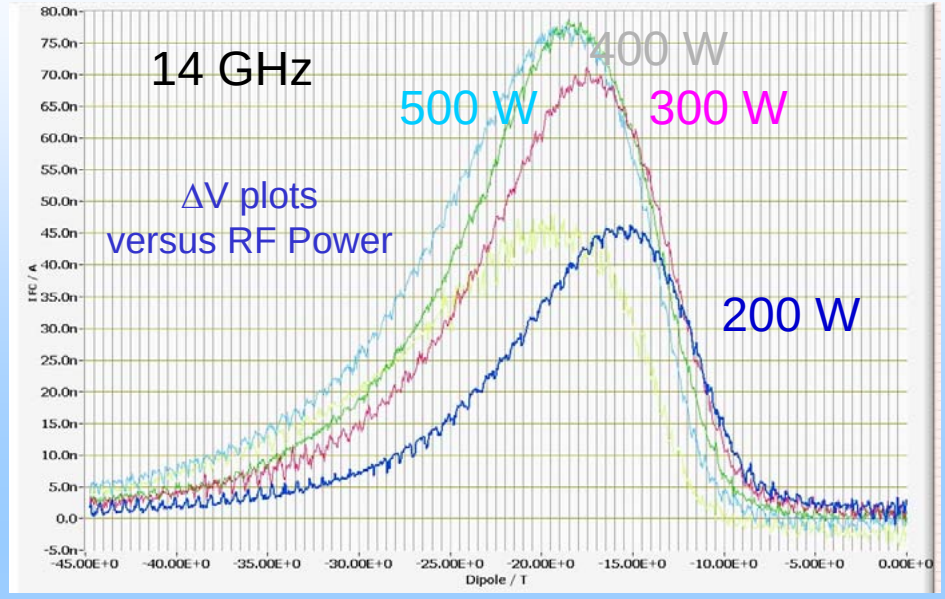






DeltaV sensitivity





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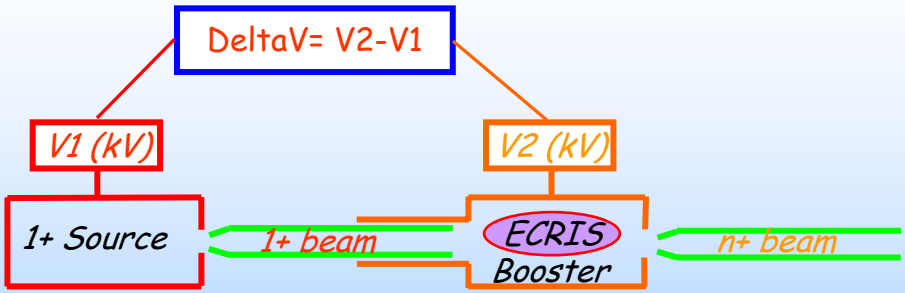

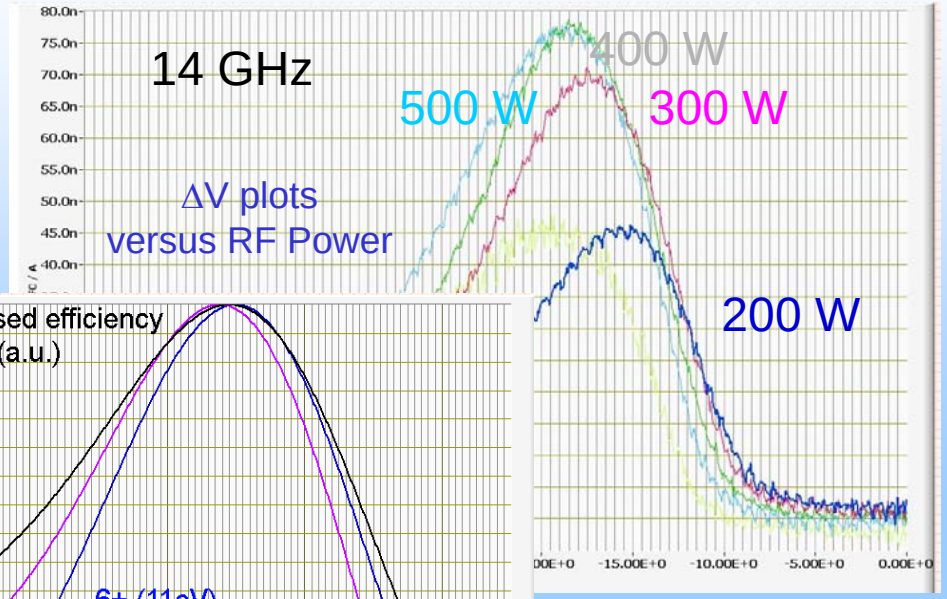

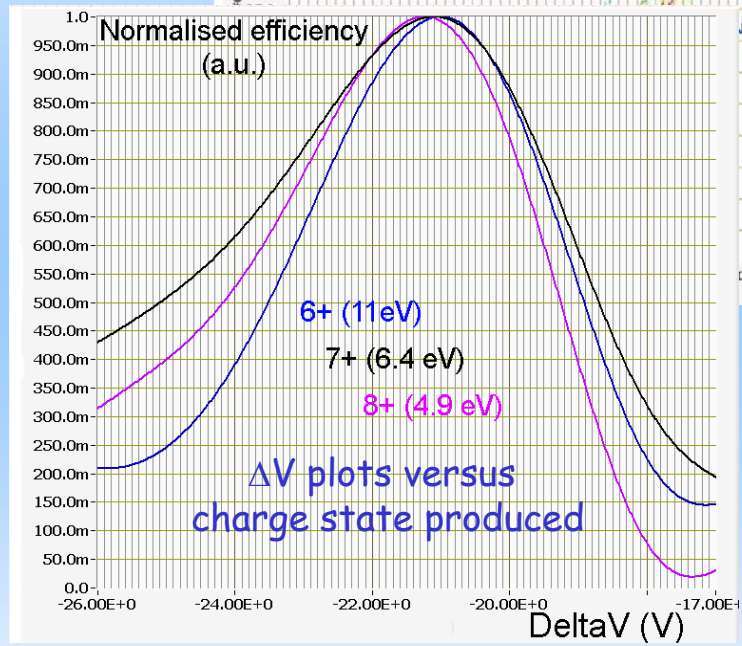

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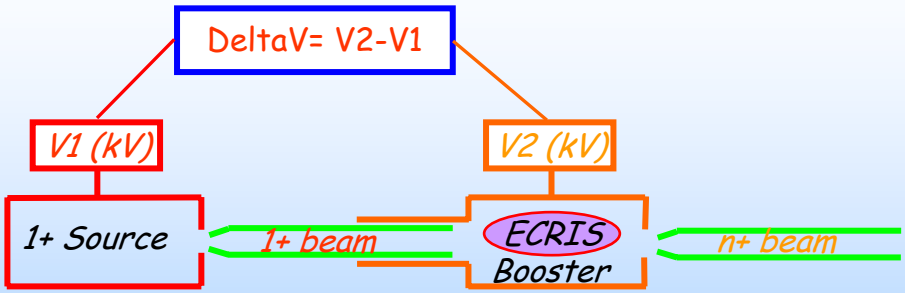
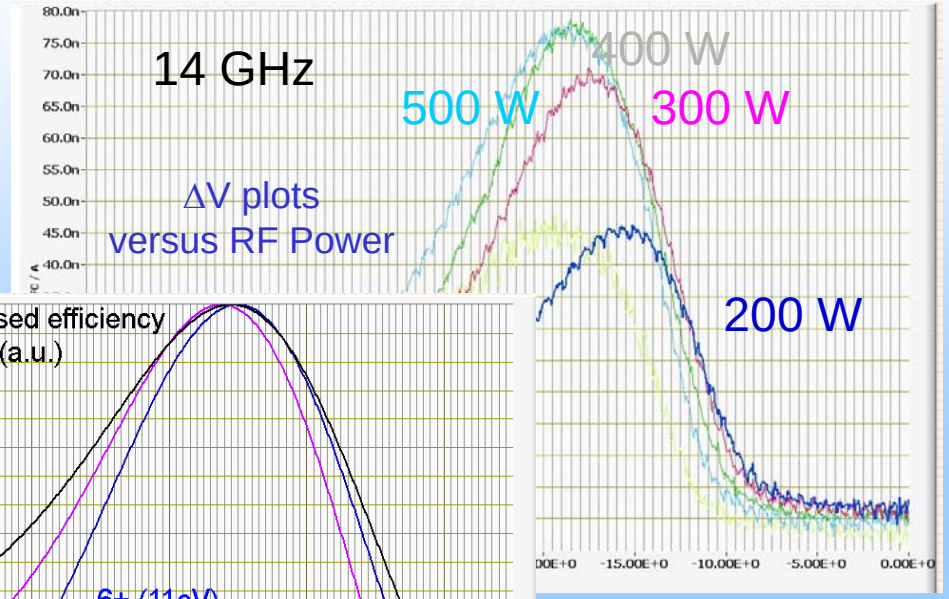
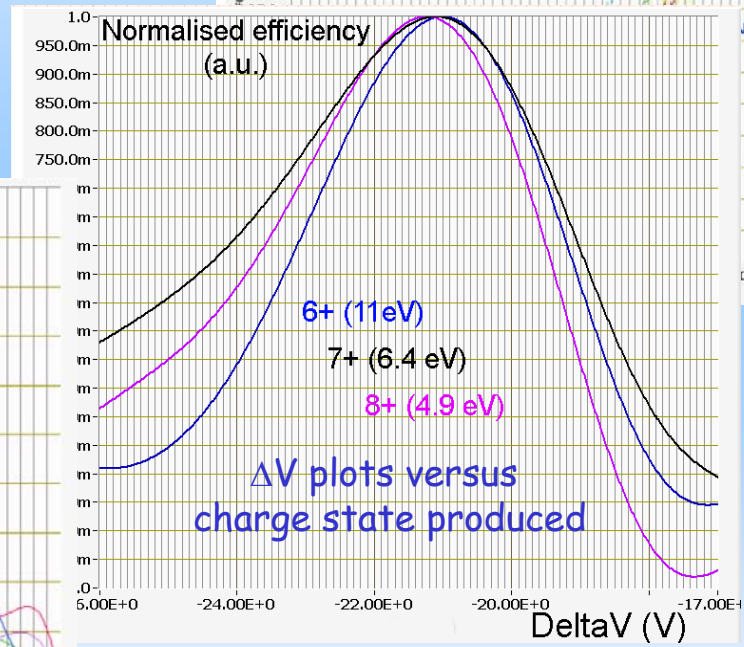
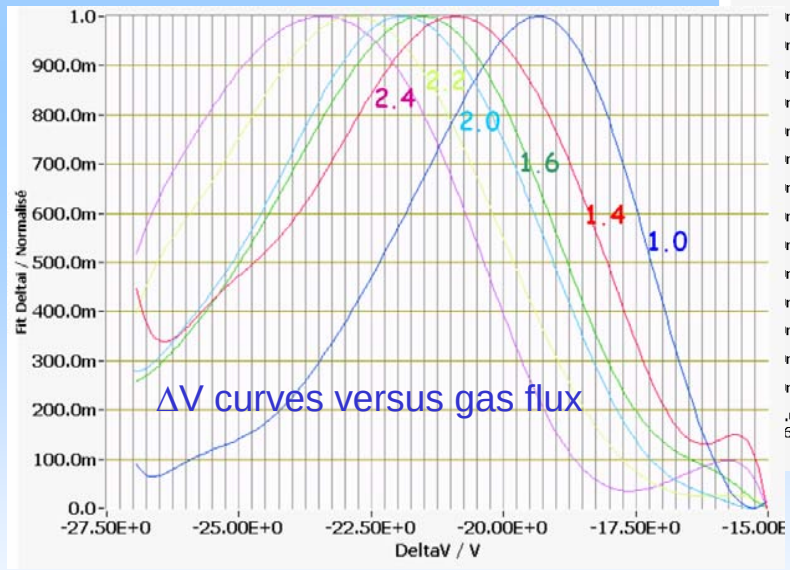






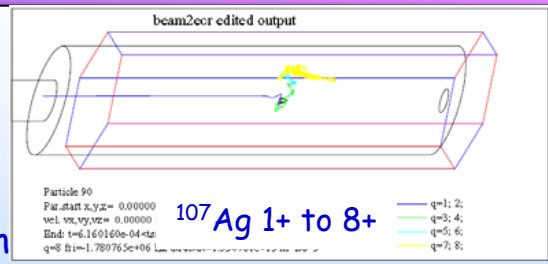


Pressure and gas flux should be precisely controlled

Accelerator operation: tuning parameters characterization and reproducibility are fundamental

Theoretical studies

Model of accumulation, multi-ionization and extraction of ions in ECR Ion Sources
M. Cavenago et *al.* Rev. Sci. Instr. Vol. 73, (2002) 537-540
Simulations of beam injection and extraction into ion Sources
M. Cavenago, Proc. PAC'05, Knoxville, Tennessee



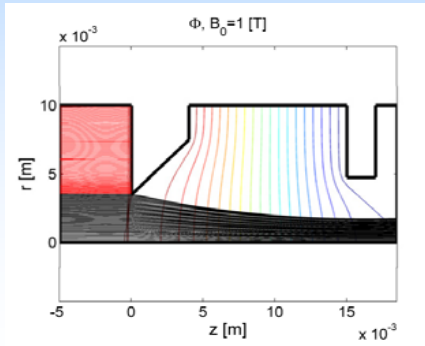
Monte Carlo simulation, 3d random kicks each time step simulates the collision from the background, includes:
Ionization and recombination models; 3d magnetic fields: axial and radial, 3d ambipolar potential: radial, axial width, pre-sheath (at inj. & Extr.), hexapole distortion

Stopping efficiency of an ECR charge breeder for axially injected ions
S. C. Jeong et al., Rev. Sci. Instrum., 73 (2), 803-805 (2002)

Stopping process is considered as a separate step followed by subsequent ionization
plasma homogenous, uniformly distributed over the volume with a density of 5 10^{11}/cm3.
Ti= 1 eV, incident energy of injected ions 10 eV
Results: stopping efficiency, (counting ions moving in the plasma volume without splats)

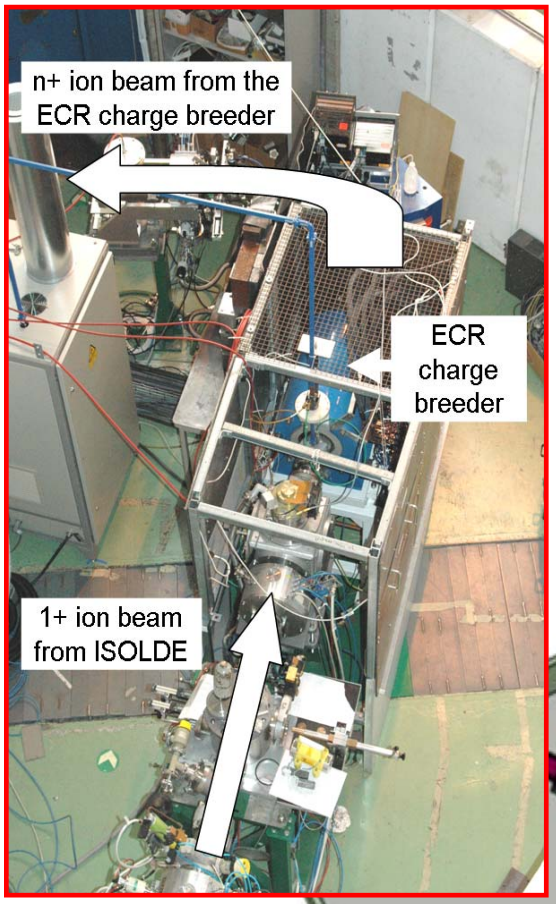
Electron cyclotron resonance charge breeder ion source simulation by MCBC and GEM
J.S. Kim et al., Rev. Sci. Instrum. 79, 02B906 (2008)
Status of far-tech's electron-cyclotron-resonance charge-breeder simulation toolset; MCBC GEM and IONEX; J.S. Kim et al., TUCO-C04 Proceedings of ECRIS08, Chicago, IL USA

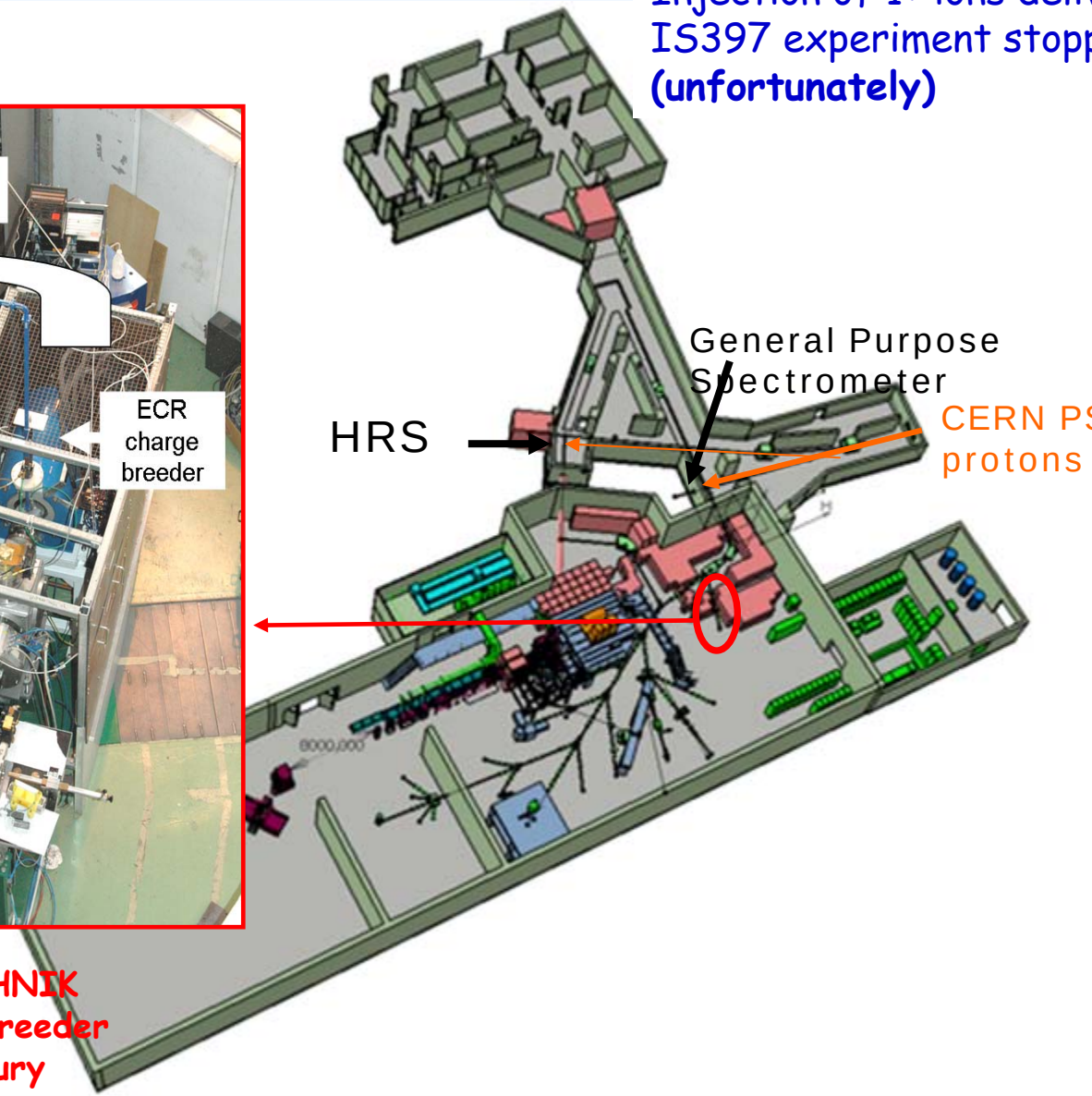
Suite of codes:
Monte Carlo Beam Capture (MCBC), the Generalized ECRIS Modeling (GEM) and the Ion Extraction (IonEx) code using innovative numerical technique, Particle-In-Cloud-Of-Points (PICOP)



CERN - ISOLDE

Injection of 1+ ions delivered by ISOLDE
IS397 experiment stopped last year
(unfortunately)



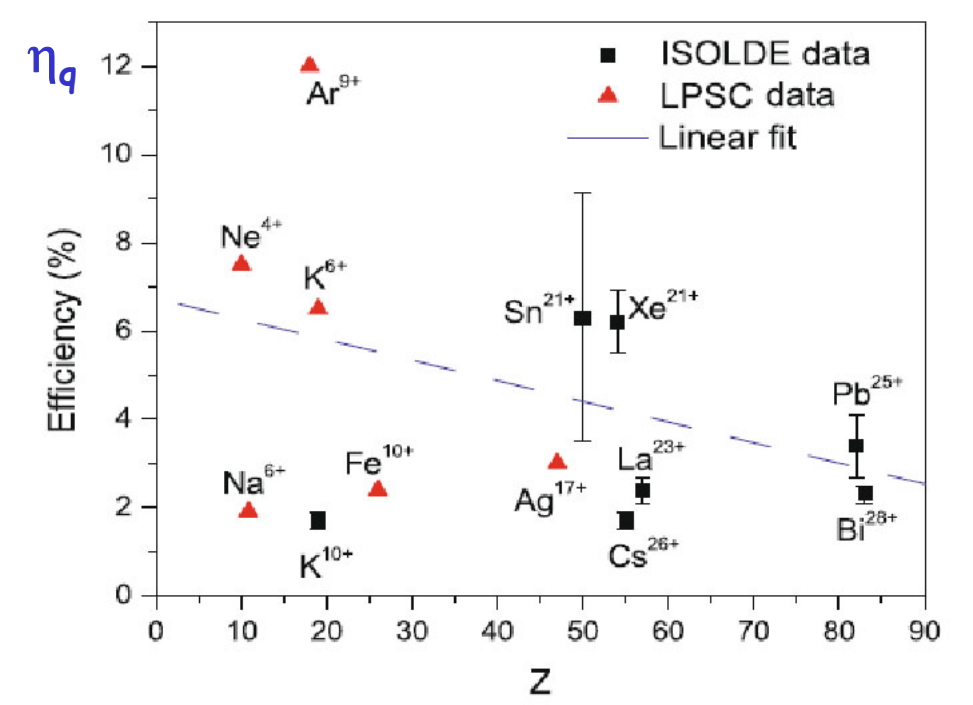


LPSC-PANTECHNIK
Phoenix charge breeder
CRLC Daresbury
14.5 GHz

Experimental and operational ECR charge breeders worldwide

CERN - ISOLDE PhD Mélanie Marie-Jeanne

Stable and radioactive ions, CSB cw or pulsed operation



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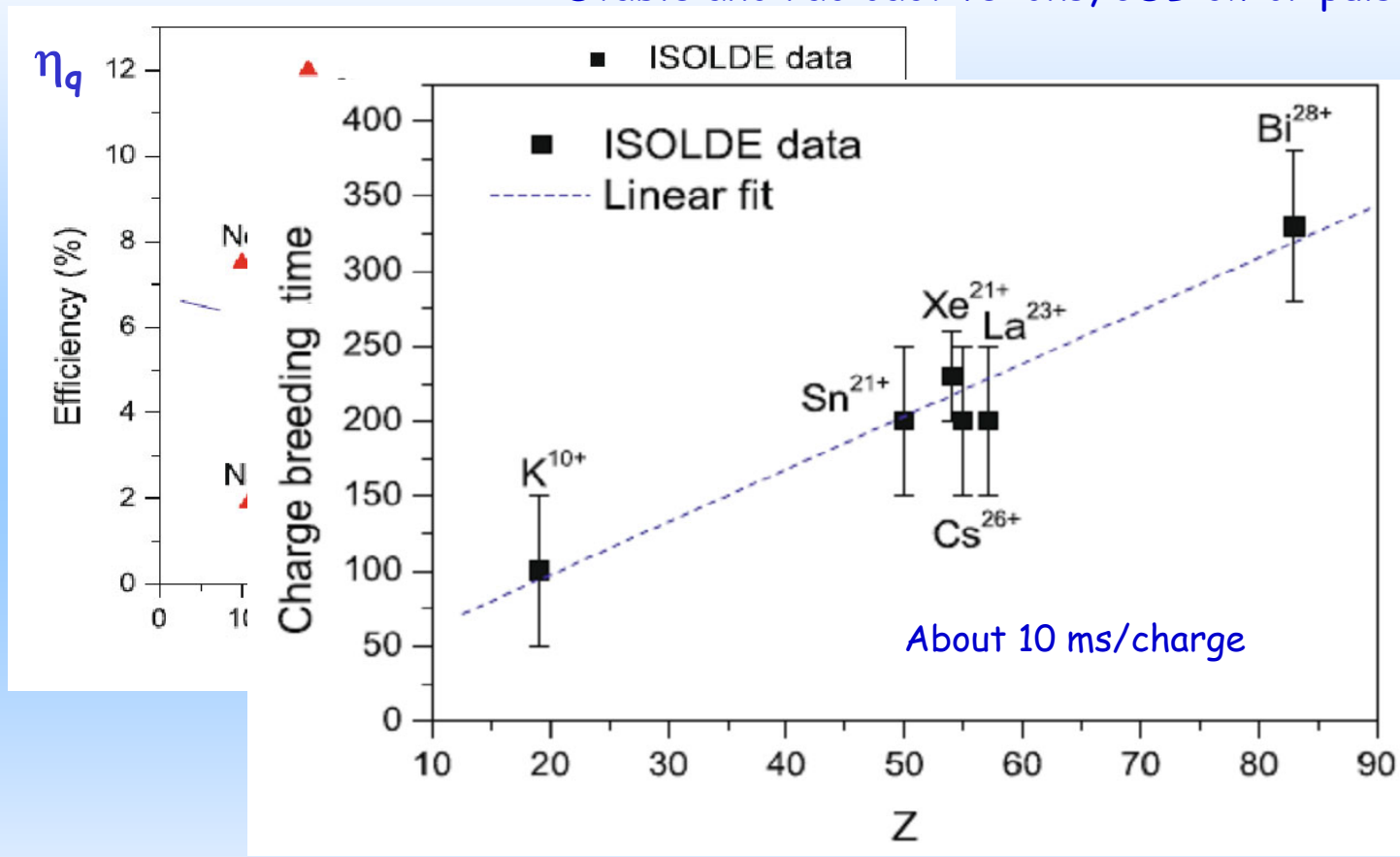

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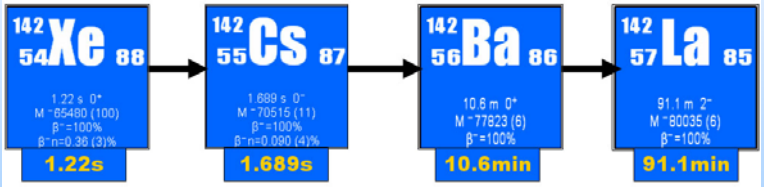
Stable and radioactive ions, CSB cw or pulsed operation

Injection of coktail beams delivered by one ion source



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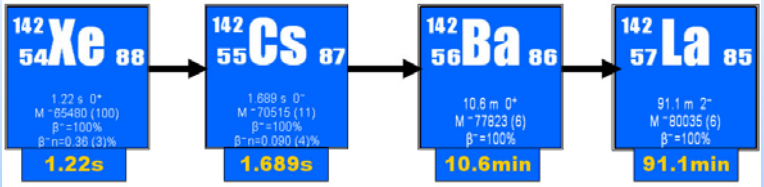
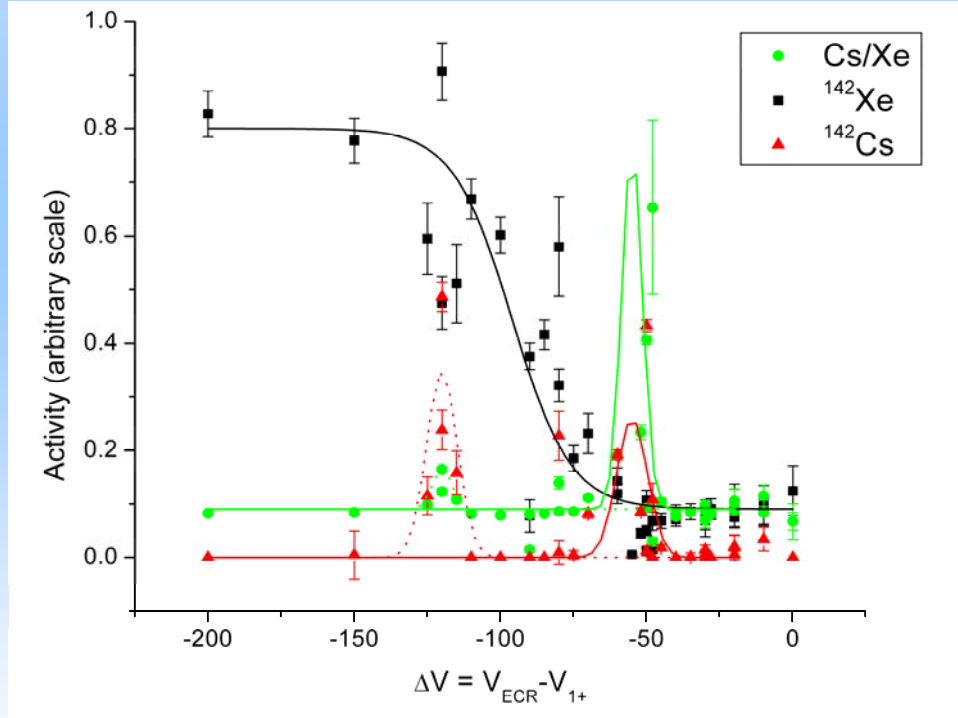
Stable and radioactive ions, CSB cw or pulsed operation

Injection of coktail beams delivered by one ion source





Cs peak observed (capture confirmation)

Experimental and operational ECR charge breeders worldwide

CERN - ISOLDE PhD Mélanie Marie-Jeanne

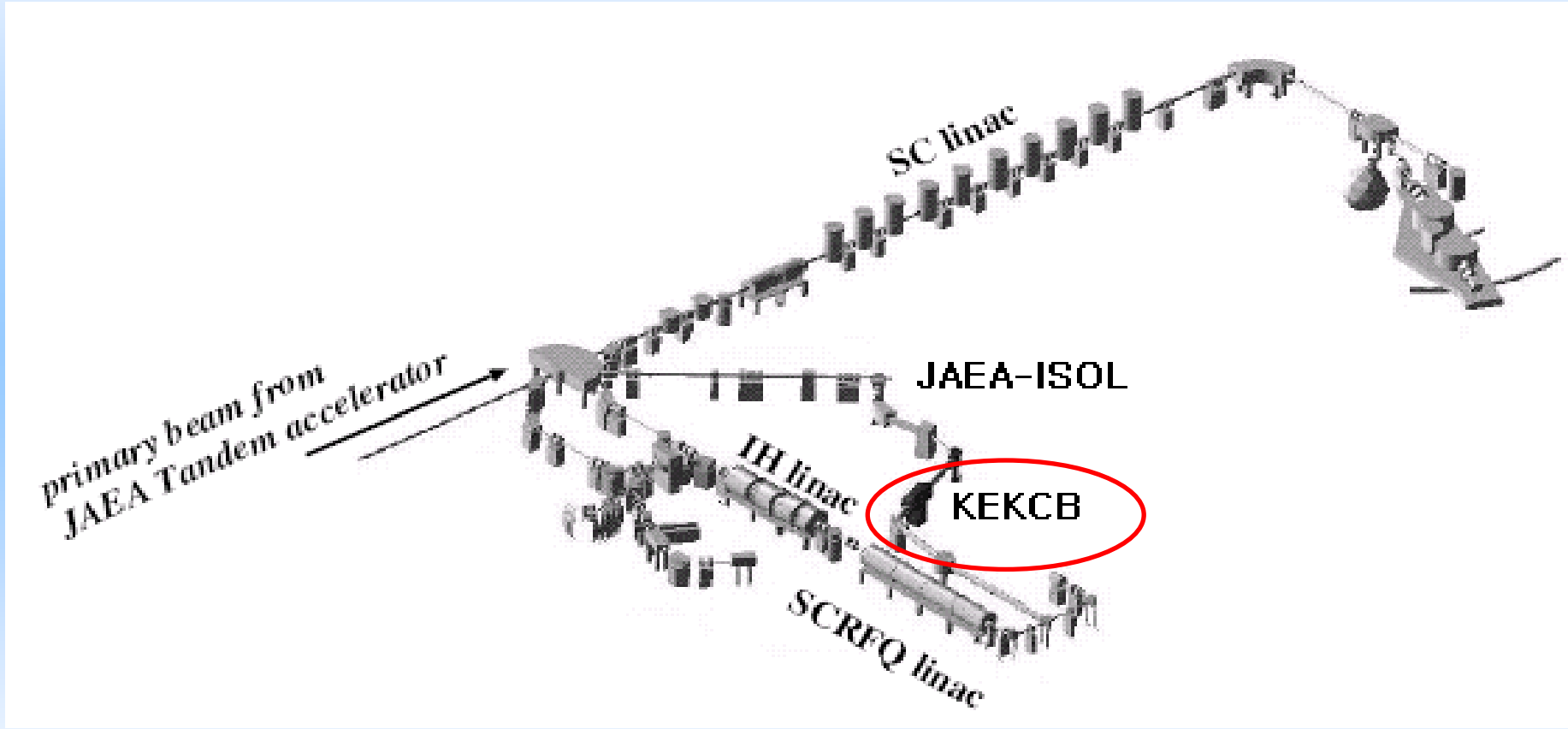
Stable and radioactive ions, CSB cw or pulsed operation

Molecular breakup of molecules

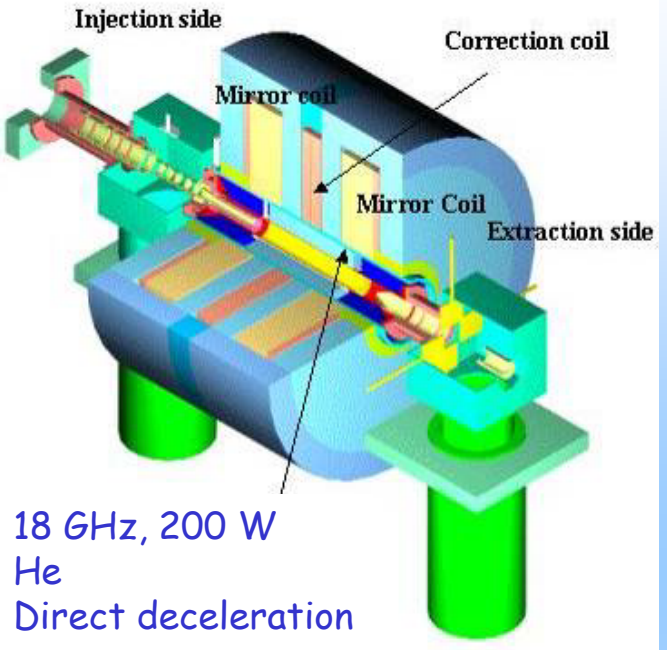
Breakup of LaO^{+} --> 3.5% of $^{139}La^{23+}$

Experimental and operational ECR charge breeders worldwide

KEK - TRIAC

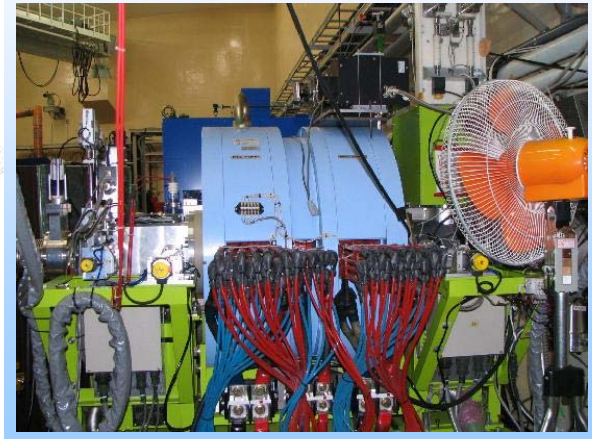


Experimental and operational ECR charge breeders worldwide



18 GHz, 200 W
He
Direct deceleration

KEK - TRIAC



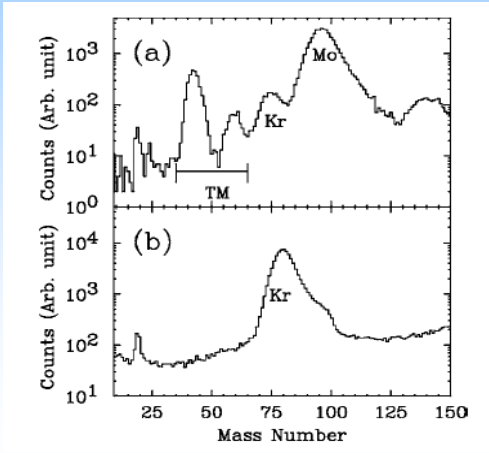
Ion	η_q
$^{92}Kr^{12+}$ (1.8 s)	8.2%
$^{123}In^{16+}$ (1.5 s)	1.6%
$^{142}Ba^{21+}$ (10.6 m)	1.5%
$^{143}Ba^{21+}$ (14 s)	1.3%

Gaseous element, η_q ~7-10 %
Non-gaseous elements, η_q~1-2%

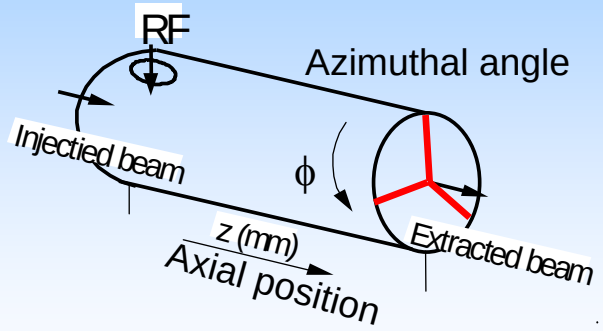
S.C. Jeong *et al.*, NIMB266(2008)4411

Reduction of background ions
N. Imai *et al.*, Rev. Sci. Instr. 79 (2008), 02A906

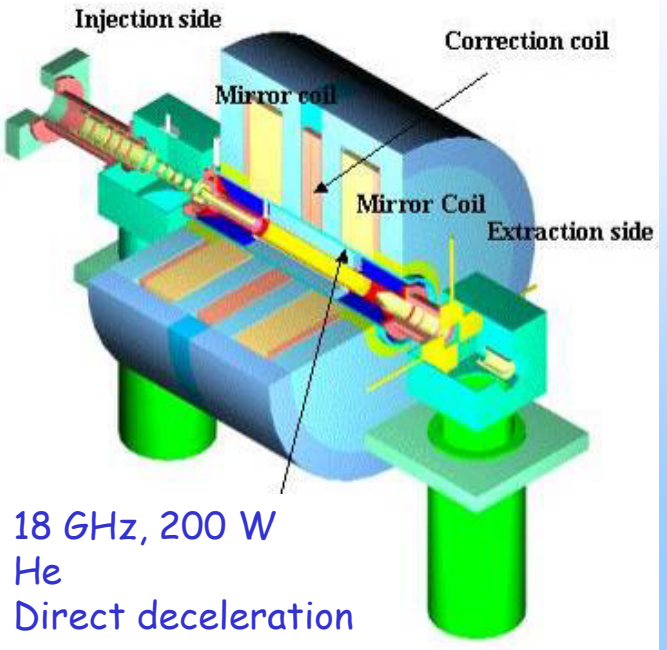
Sand and
high-pressure water
jet blasting
Al liner cleaning



Tracking beam loss in plasma chamber
M. Oyaizu *et al.*, AIP conf. Proc. 1120 (2009) 308



Experimental and operational ECR charge breeders worldwide



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Direct deceleration

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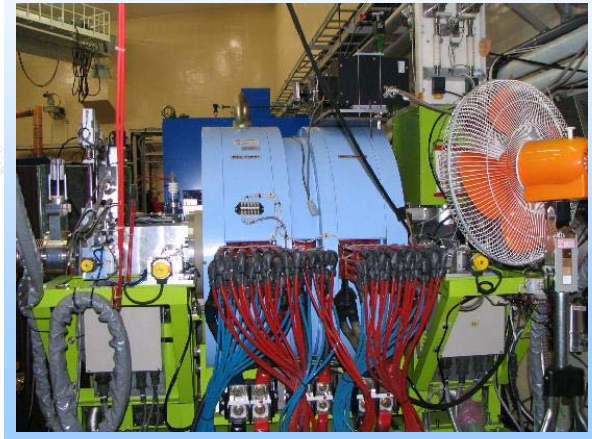

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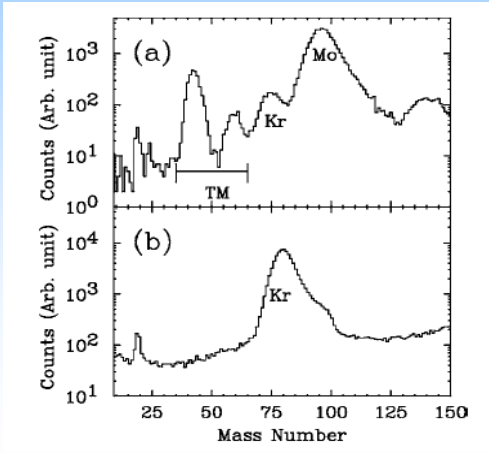

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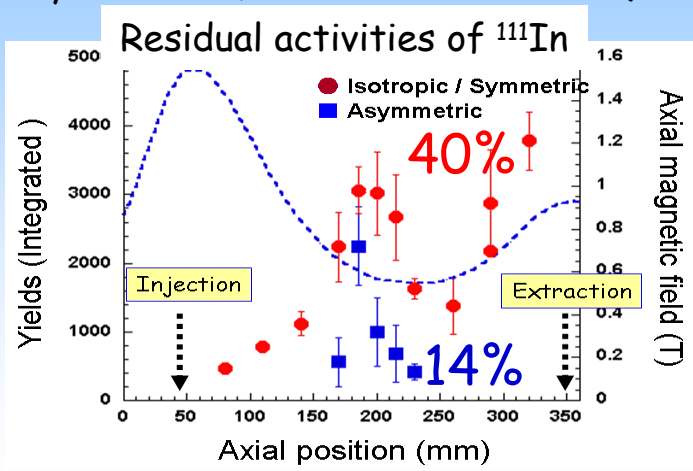
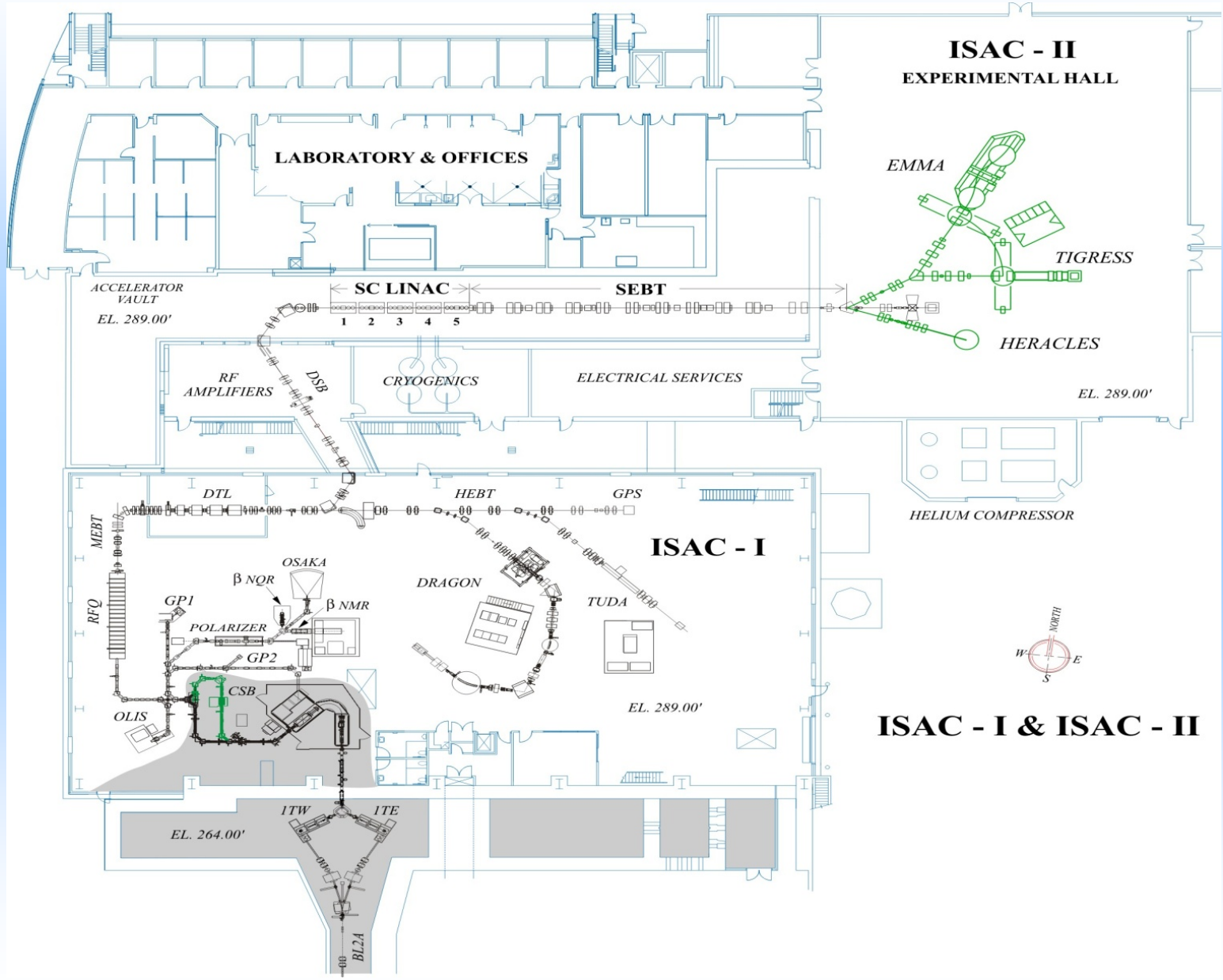


Experimental and operational ECR charge breeders worldwide

TRIUMF

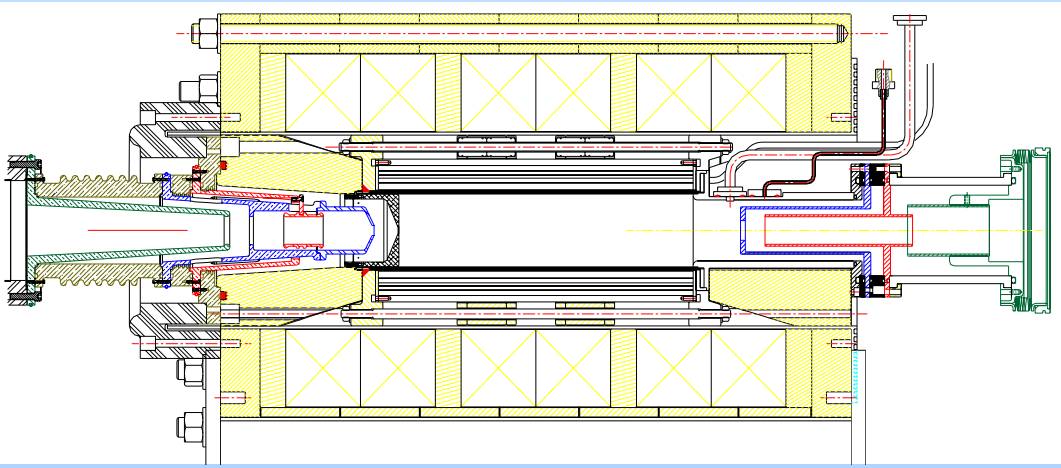


Experimental and operational ECR charge breeders worldwide

TRIUMF

Acceleration of Charge Bred Radioactive Ions at TRIUMF
F. Ames *et al.* Proc. Of the PAC09, Vancouver - May 2009

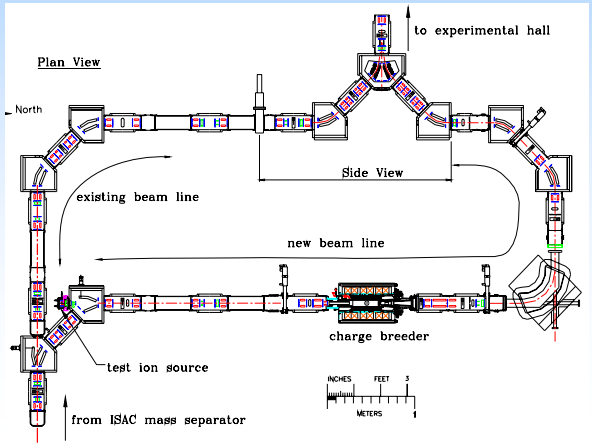
Modified LPSC-PANTECHNIK Phoenix charge breeder
14.5 GHz
He
Two steps deceleration and extraction



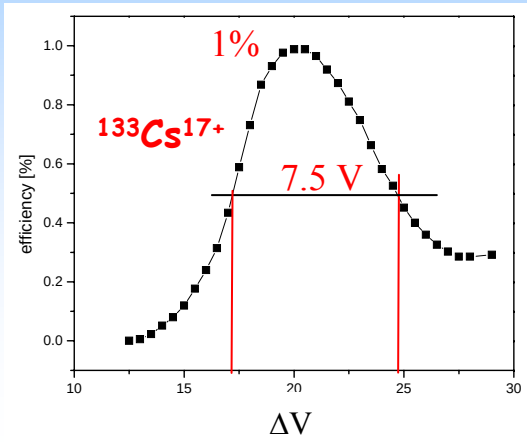
Test stand results

Ion	η_q (%)	rise time (ms)
$^{40}Ar^{8+}$	5.5	102
$^{84}Kr^{12+}$	6.3	401
$^{129}Xe^{17+}$	4.8	432
$^{39}K^{9+}$	2.1	
$^{85}Rb^{13+}$	3	230
$^{133}Cs^{20+}$	3.5	300

Installation at ISAC



Test beam time November 2008



First acceleration of radioactive charge bred $^{80}Rb^{14+}$ ions

$^{80}Rb^{14+}$ (γ radiation)
1.1 10^5 pps after CSB (1%)
3.5 10^4 pps after accel.

33 % accelerator transmission

Experimental and operational ECR charge breeders worldwide

ANL - CARIBU

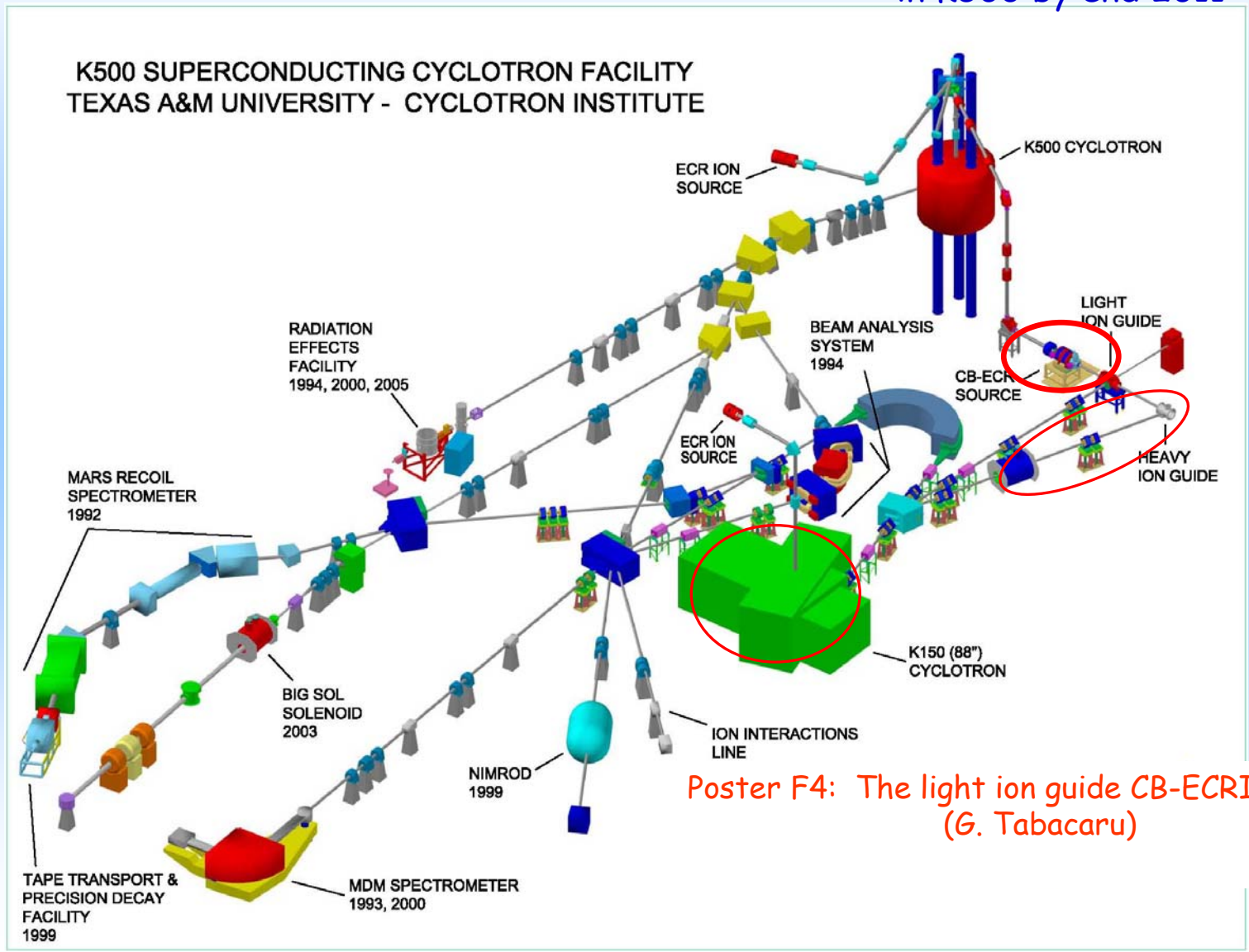
Impressive work has been performed (in time…)
Nice results confirm last ECRIS'08 ones

I'm not a thief…
Listen to the next excellent talk from Rick Vondrasek !

Experimental and operational ECR charge breeders worldwide

TEXAS A & M University (R. Tribble)

Reaccelerate light and heavy ion guide RIB's in K500 by end 2011



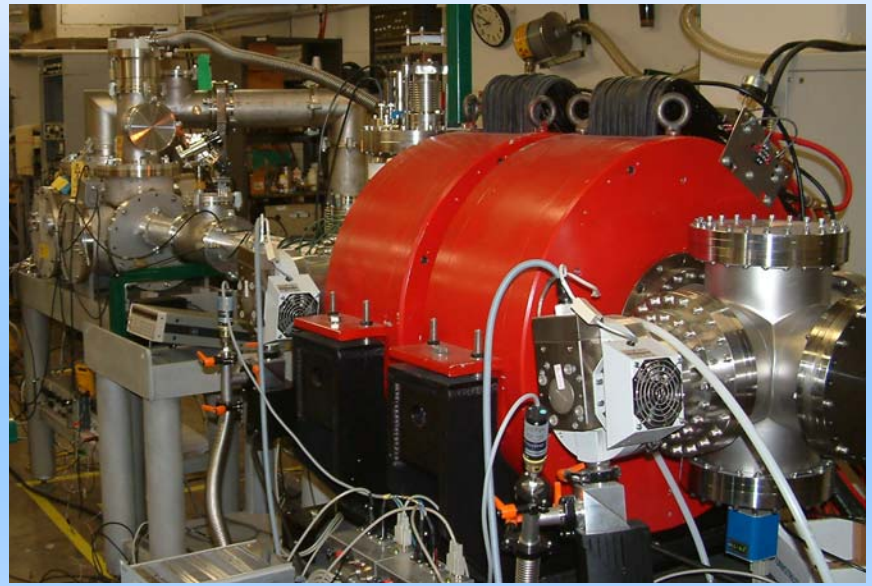
Poster F4: The light ion guide CB-ECRIS project (G. Tabacaru)

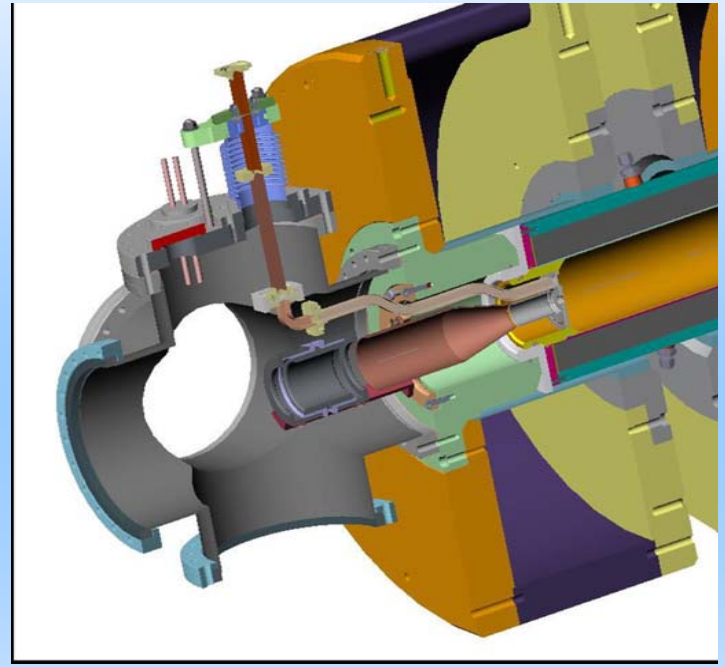
Experimental and operational ECR charge breeders worldwide

TEXAS A & M University

Design of a Charge-Breeder Ion Source for Texas A&M University
W. D. Cornelius Proc. of ECRIS08, Chicago, IL USA

Scientific Solutions, San Diego CA USA





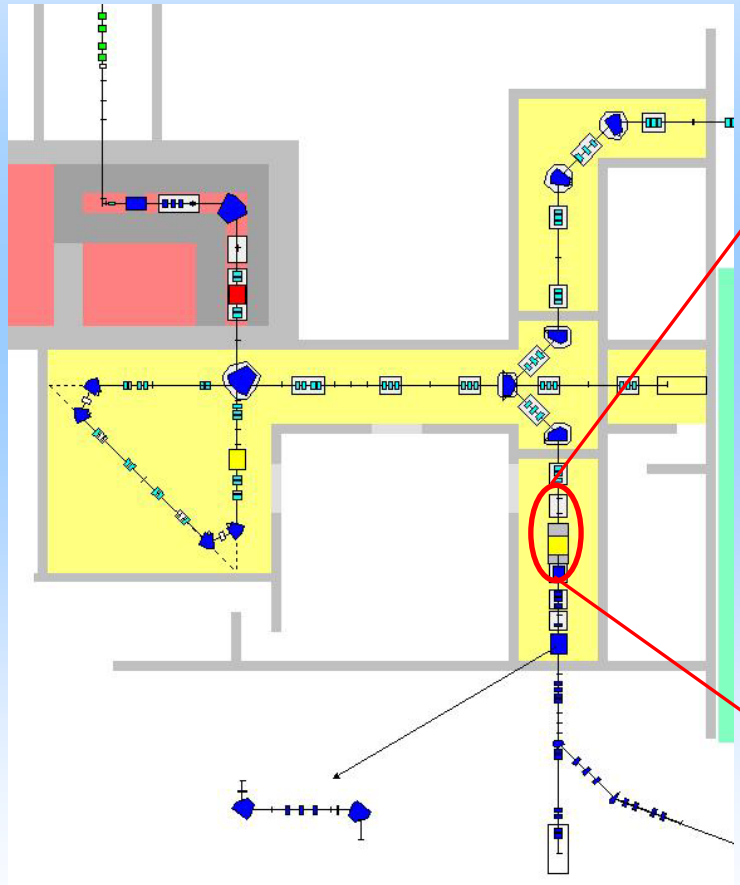
'Classical' ECR CSB @ 14.5 GHz
AECR-U solenoid magnets design

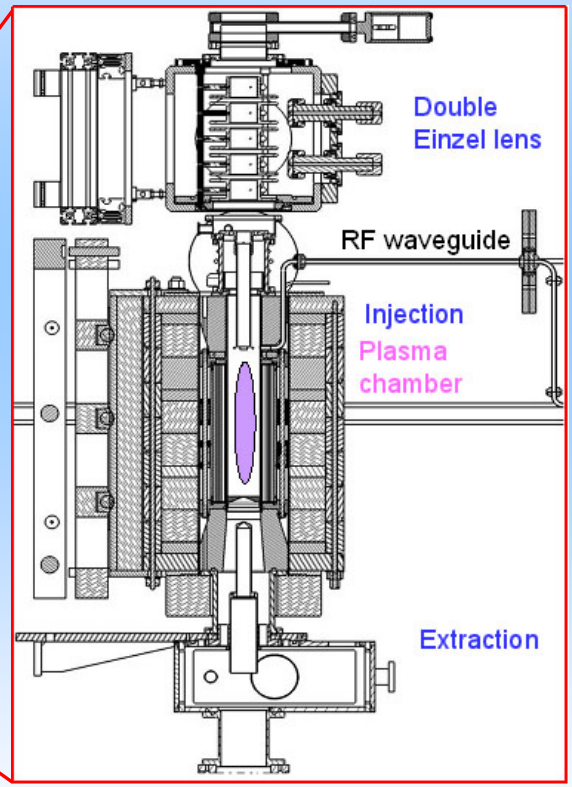
But Innovative concepts for:
1+ injection through little hole,
Axial HF input,
Closure of the plasma chamber,
Internal HV insulation

First plasma ignited recently (low power)
Charge breeding experiments by the end of this year, waiting for exciting results, surely!

SPIRAL: F. Chautard told you yesterday, may be an ECR charge breeder to deliver metallic ion beams

SPIRAL2





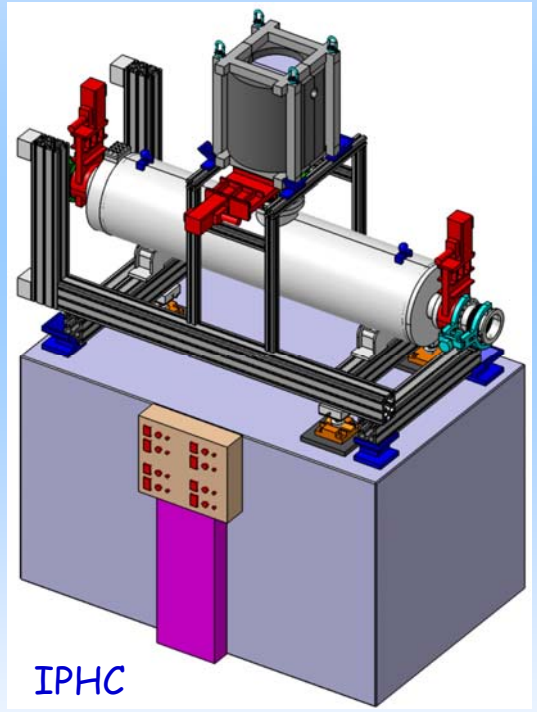
'Old' LPSC version, will be improved

CSB in yellow zone: minimize human intervention

SPIRAL2 charge state breeder 'nuclearization'

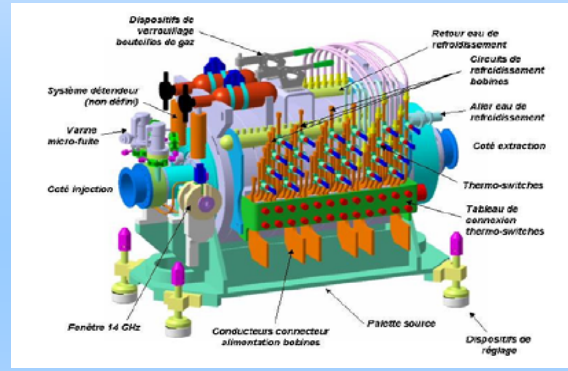
Will be based on a modular concept developed for red and yellow zones at IPHC (IN2P3 – Strasbourg), in order to have a coherence in the troubleshooting procedures on the SPIRAL2 project

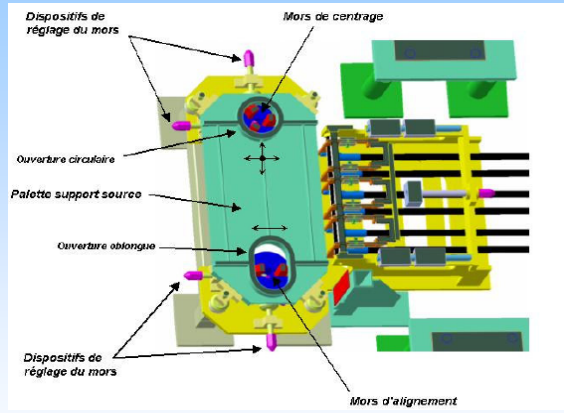
See for details, Poster F1 (Francis Osswald CNRS/IN2P3)
A secondary radioactive beam line section for the SPIRAL2 project: First step, the design study



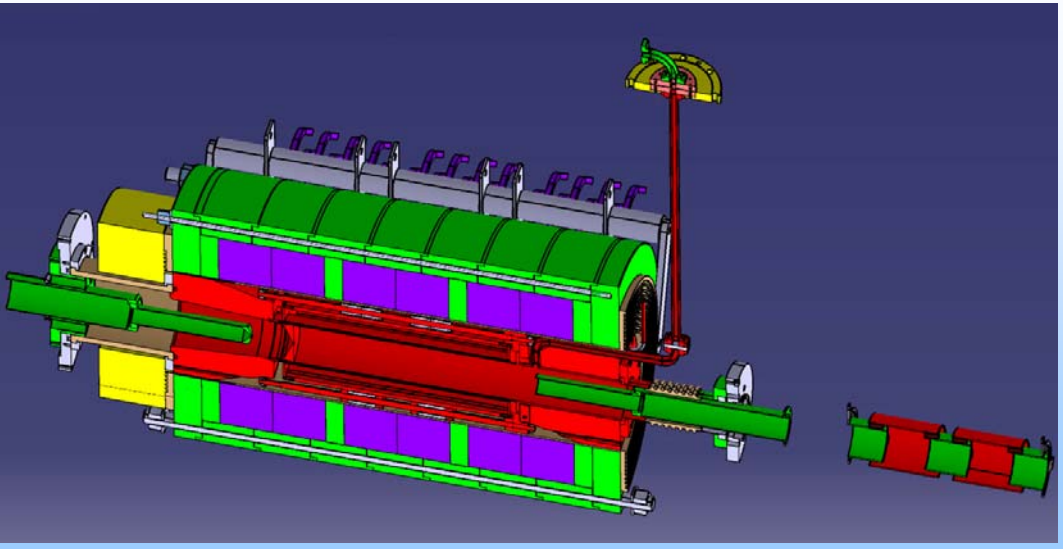
IPHC

Booster specific studies
due to specific equipment





SPIRAL2 1+ injection simplification



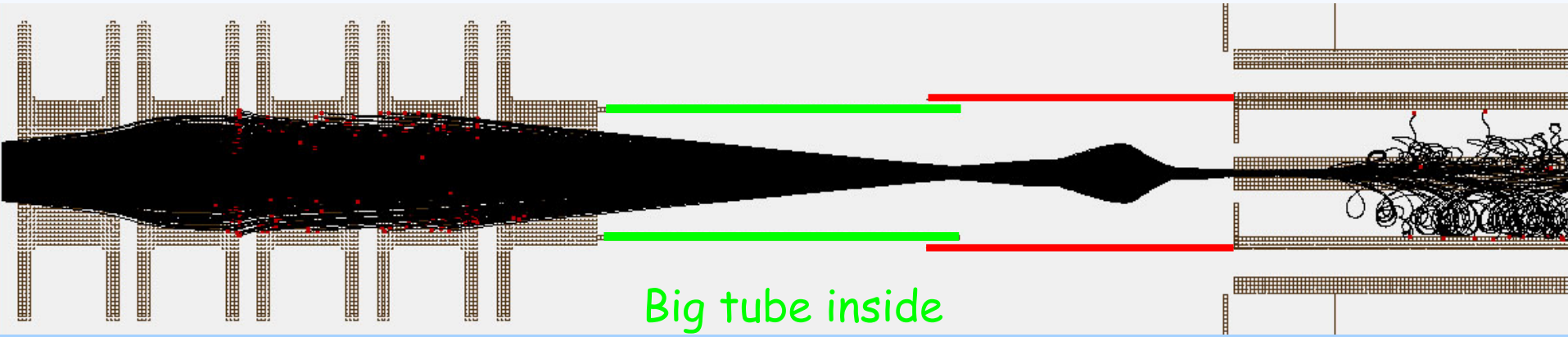
Injection and extraction tubes prevent from easily removing the CSB

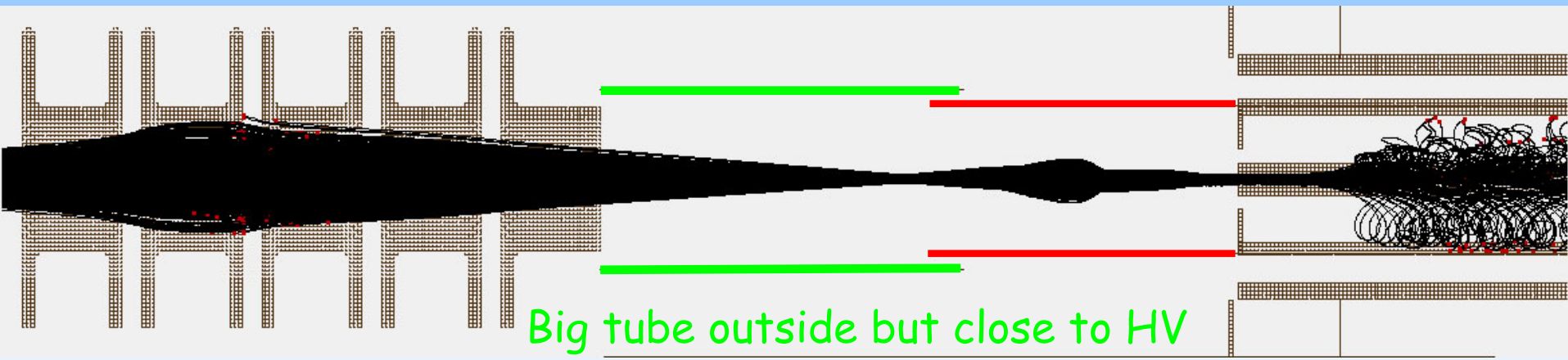
Solution: motorized tubes, not easy at injection due to optics

The deceleration tube is used to bring ground to the inside of the breeder due to HV configuration and optics.

Other solutions ?

SPIRAL2 1+ injection simplification





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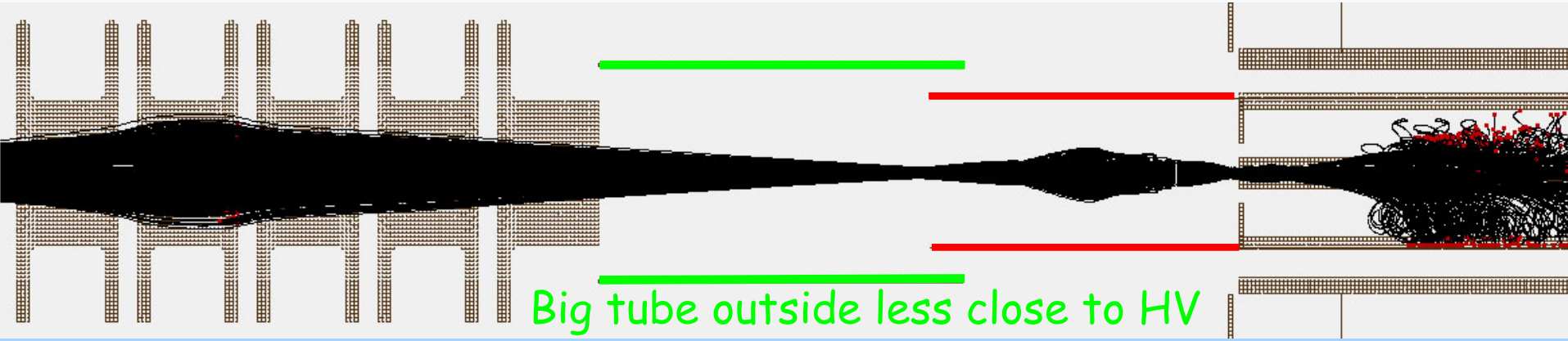
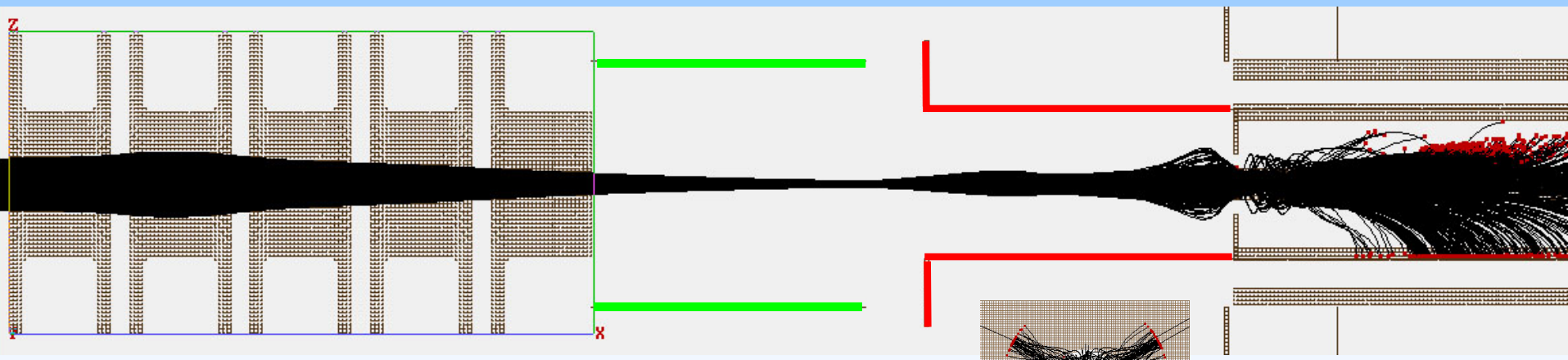


Mechanics difficult to design

Mechanics more realistic to design (insulator aroud grounded tube)



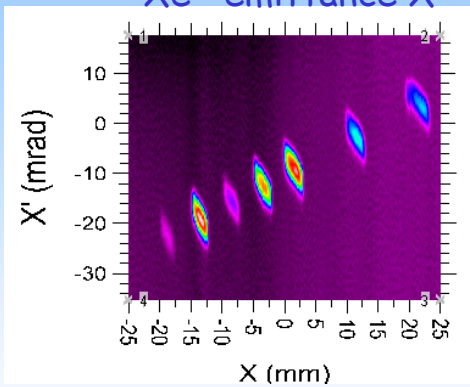
Should be tested…

1+ ion source for LPSC test stand

Purpose:
To replace the TIS (Rb, Na) by a very simple ECRIS (P. Sortais and I) producing **stable** ion beams (gas, metals), atomic and molecular ones, very low emittance and high stability ($\leq 1\mu A$)

Φ extraction 0.3 mm
15 KV
HF: 1 W, 2.45 GHz
1 μA
1 π.mm.mrad

Xe^{1+} emittance X

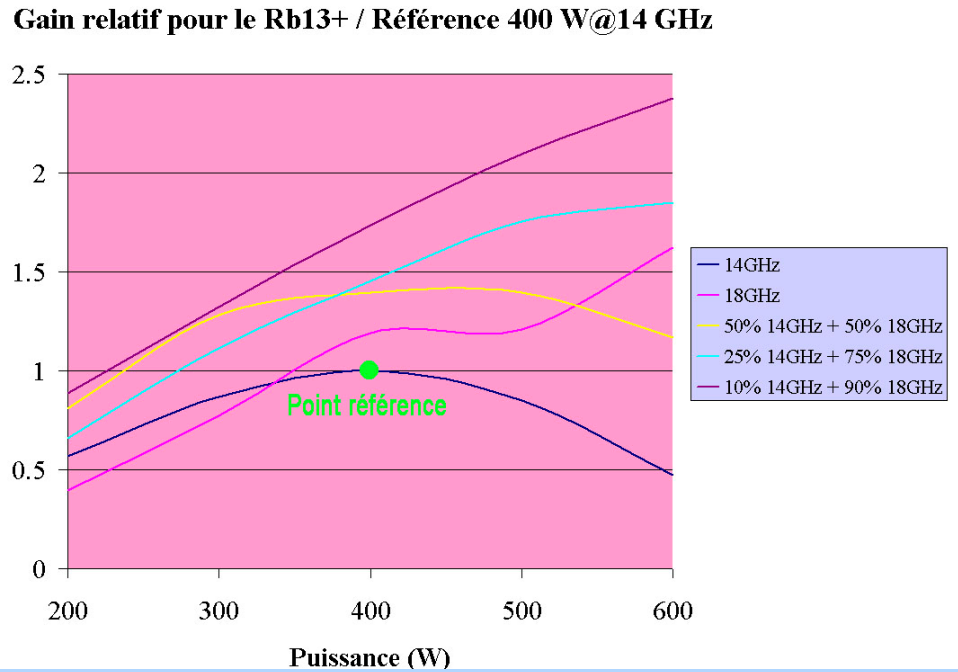


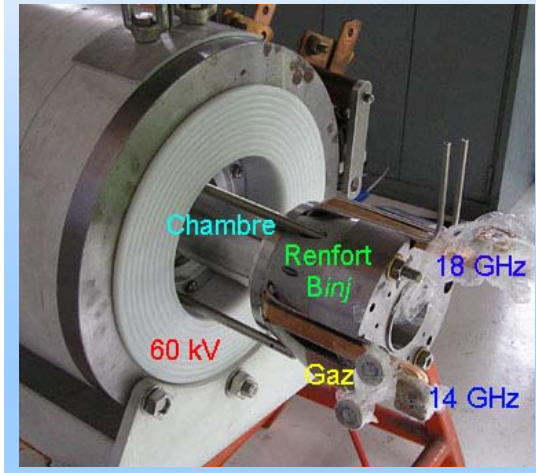
Details, be a bit more patient…:
Pascal Sortais talk at next ICIS

CERN/ISOLDE – LPSC collaboration
Efficiency measurements for C^{1+*}

Thanks for your attention !

Effet des fréquences ECR dans le Booster (14 et 18 GHz)



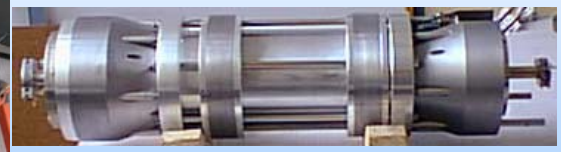


Effet testé et comparé à référence 14 GHz (400W)
Premiers résultats encourageants
Meilleure efficacité pour 18 GHz
Efficacité maxi. obtenue par l'injection d'une faible proportion de 14 GHz (10%).

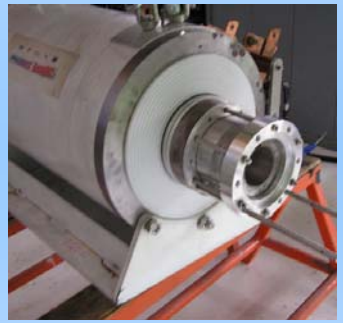
Prochaine étape: renforcement du champ radial (Hexapôle Phoenix V1)
Augmentation de 0.8 à 1.2 T (en cours)

Nucléarisation, analyse maintenance

Lors d'un upgrade récent du Booster



Noyau central du booster



Les upgrades permettent d'analyser les opérations de maintenance
Ne doivent pas compliquer les interventions – si possible les simplifier