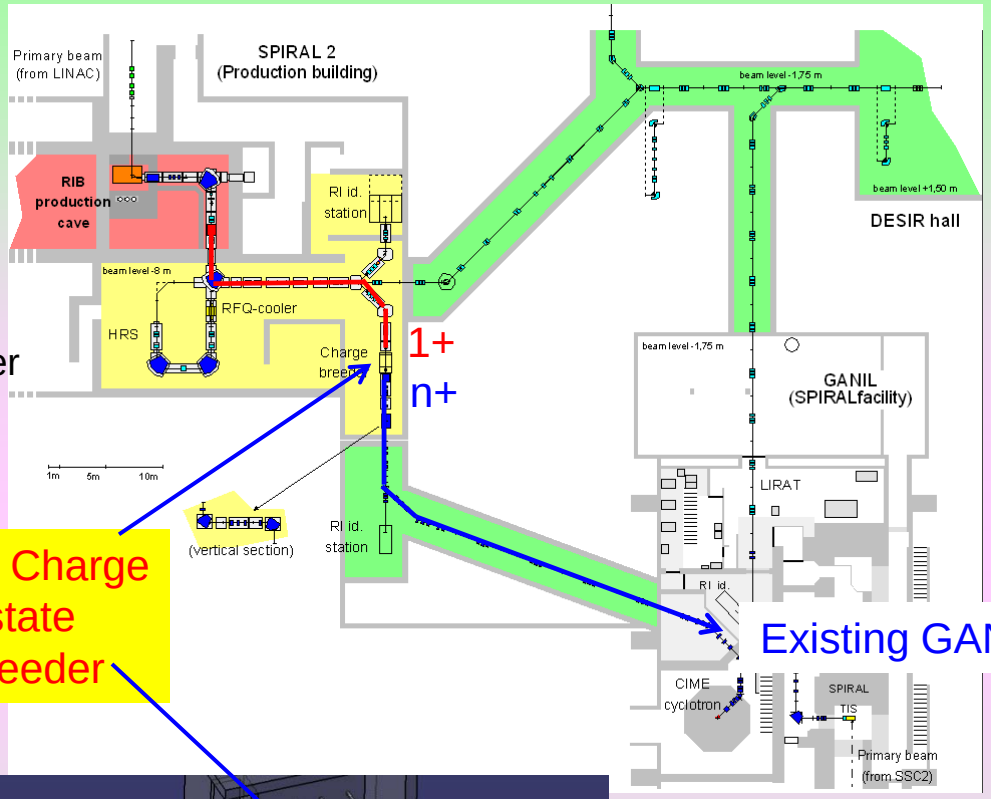
SPIRAL2 and SPES
LPSC Charge Breeder Developments
and
LNL/LPSC Collaboration

T. Lamy, *LPSC Grenoble*
with
A.Galatà (LNL)
and
J. Angot (LPSC)

SPIRAL2 Layout and ECR charge breeding

Production cave

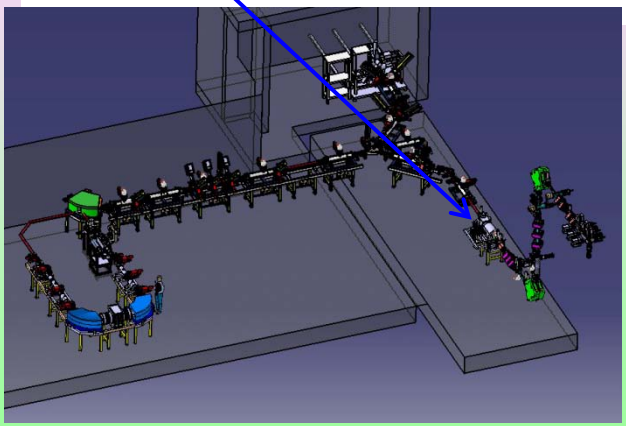
HRS
and
RFQ cooler



DESIR Hall

ECR Charge state Breeder

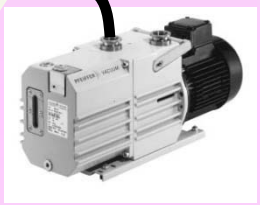
Existing GANIL



Example: 2.45 GHz ECR Ion Source

Microwave oven: 2.45 GHz, 1 kW

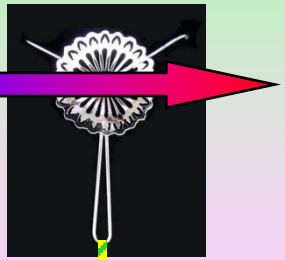
magnet



Vacuum pump

plasma

Extraction



Ion beam

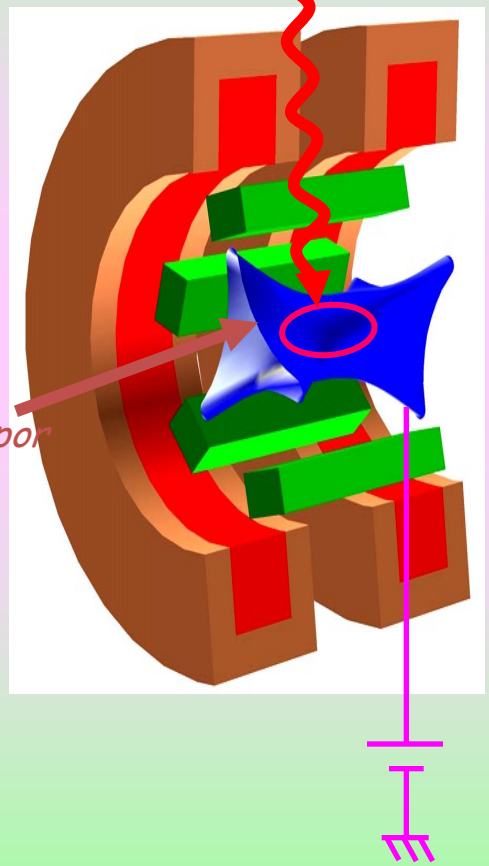
High voltage

Earth

- Electrons (e, m_e) in a magnetic field B ω_{ce} (rad/s) = e*B/m_e
- Electromagnetic wave of the same frequency $\omega_{HF} = \omega_{ce}$
  Electron Cyclotron Resonance
- Electrons in phase with the electric field
- Increase their energy and then ionize atoms allowing plasma creation (step by step ionization)

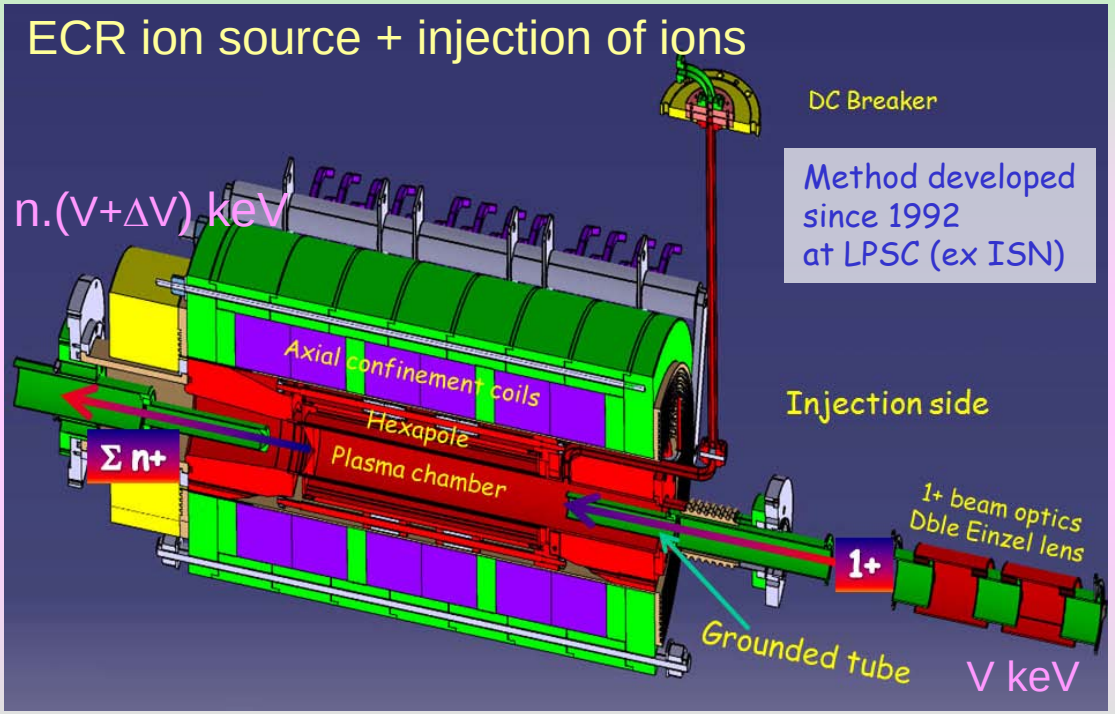
Basic principle of the ECR charge breeder

Microwaves (2.45 GHz to 28 GHz…60 GHz)



Gas or vapor

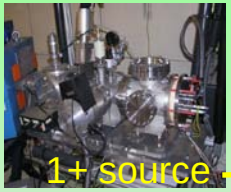
Phoenix 14-18 GHz charge breeder

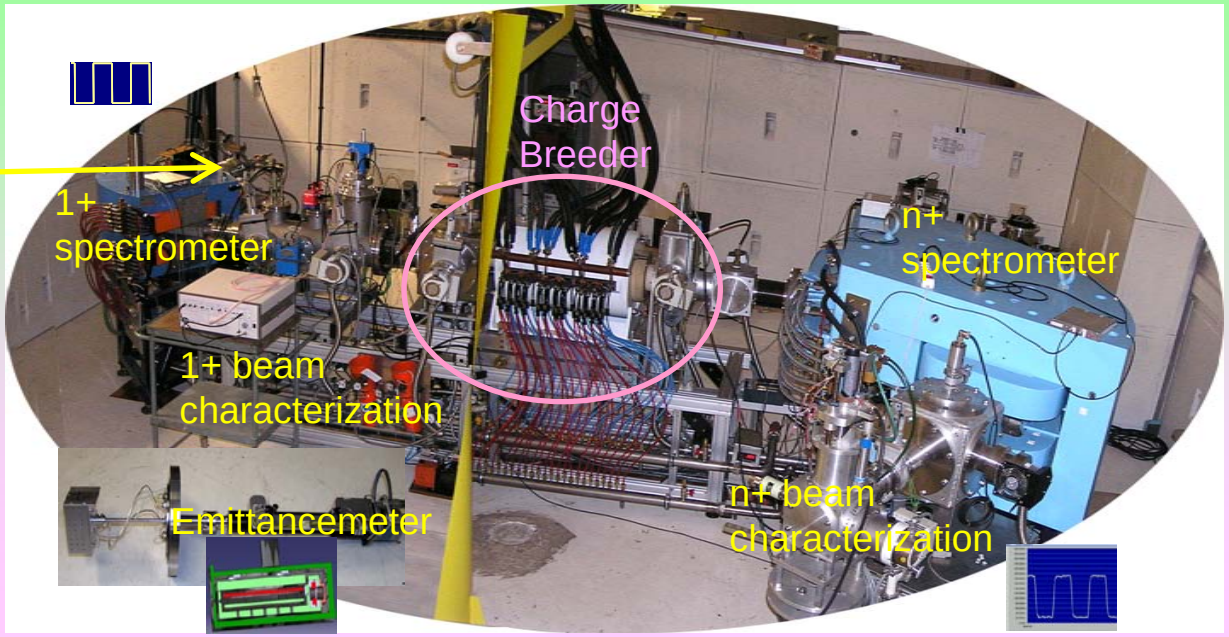


Capture condition

Final 1+ ions energy = plasma ion energy (a few eV)

The LPSC test bench, a RIB facility 'simulator'



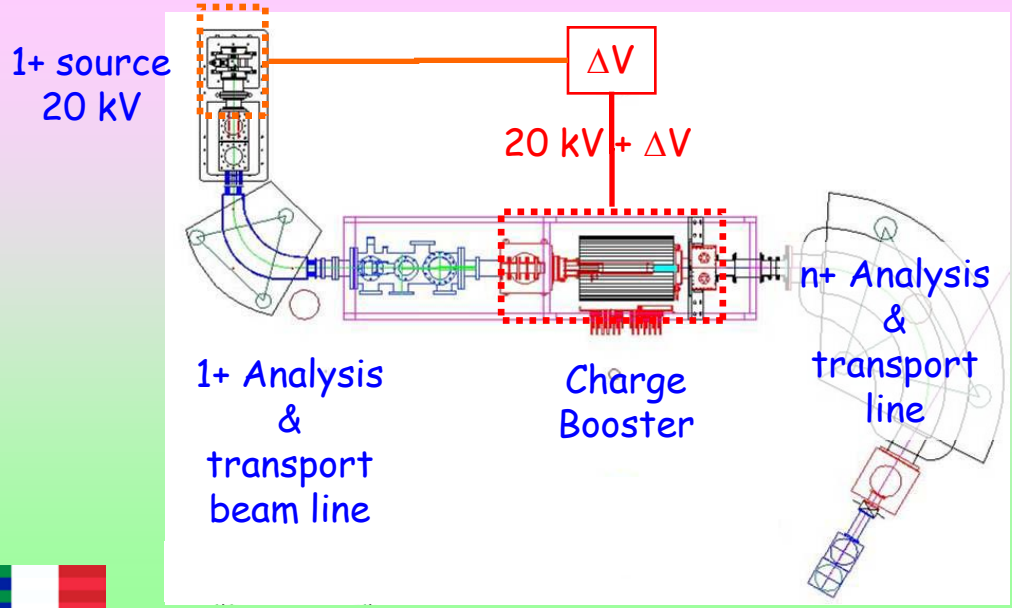


Efficiency

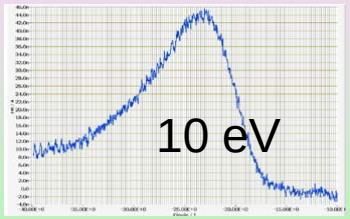
$$\eta_q = \frac{I(q+)}{q \times I(1+)}$$

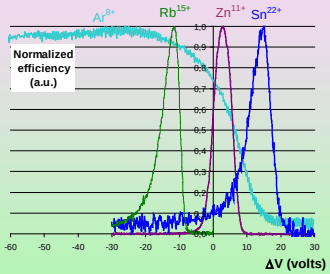
one Q/A

Rise time



To satisfy the capture condition
ΔV between 1+ and n+ sources





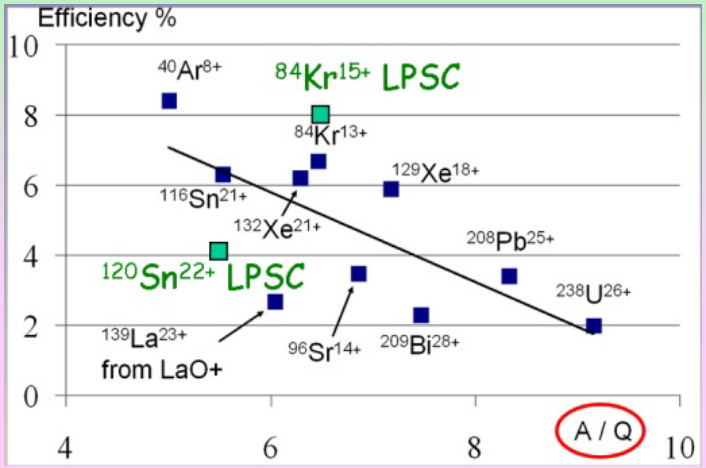
Tuning much easier for gases

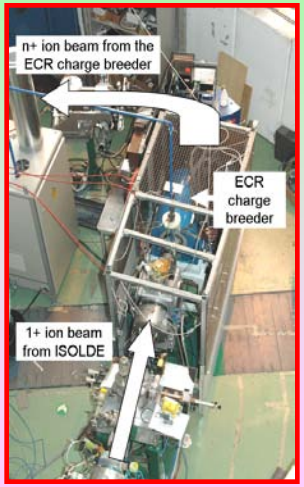
LPSC charge breeder "children"

Presently 2 exist based on the LPSC one (so 3 in total)

TRIUMF
(Friedhelm AMES)
Set up in line

Daresbury **ISOLDE** **GANIL/SPIRAL1**
Experiments with 1+ radioactive ions





Measurements with ions from standard ISAC ion sources

$^{40}Ar^{8+}$	5.5 %	102 ms (12.8 ms/q)
$^{84}Kr^{12+}$	6.3 %	401 ms (33.4 ms/q)
$^{129}Xe^{17+}$	4.8 %	432 ms (25.4ms/q)
$^{39}K^{9+}$	2.1 %	
$^{85}Rb^{13+}$	3 %	230 ms (17.7ms/q)
$^{133}Cs^{20+}$	3.5%	300 ms (15ms/q)

KEK - TRIAC

Elt.	T1/2	Eff.
$^{92}Kr^{12+}$	1.8 s	8.20%
$^{123}In^{16+}$	1.5 s	1.60%
$^{142}Ba^{21+}$	10.6m	1.50%
$^{143}Ba^{21+}$	14s	1.30%

For SPIRAL2
The LPSC charge breeder characteristics are
'for the moment'
considered as sufficient

For SPES
High energy requires
Higher efficiencies on higher charge states
→ **upgraded charge breeder**

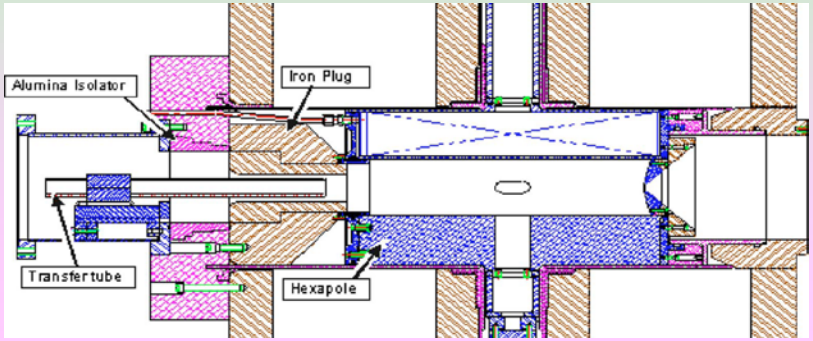
The present charge breeding experiments on the LPSC test bench are driven by LPSC and its collaboration with SPES-LNL

The Argonne National Laboratory mystery (Richard VONDRASEK)

ANL

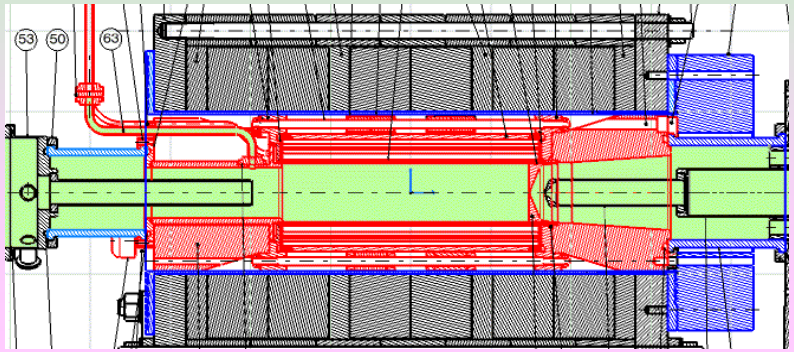
$^{85}Rb^{19+}$	**11.9%**	200 ms	(10.5 ms/q)
$^{84}Kr^{17+}$	15.6%	?	

3 times more efficient ?



LPSC

$^{85}Rb^{15+}$	**3.6 %**	70 ms	(4.7 ms/q)
	or 5 %	225 ms	(15 ms/q)



Same principles, almost same geometry

Two HF frequencies (10.44 + 11.90 GHz)

14 GHz (possible 14 + 18 GHz)

High vacuum (cryopumps)

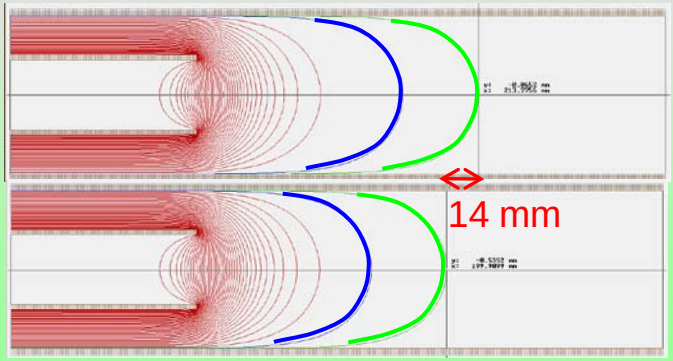
'Poor' vacuum (perbunan Orings, old vacuum chambers)

Charge breeder operated at 50 kV

Charge breeder operated at 20 kV

50 kV

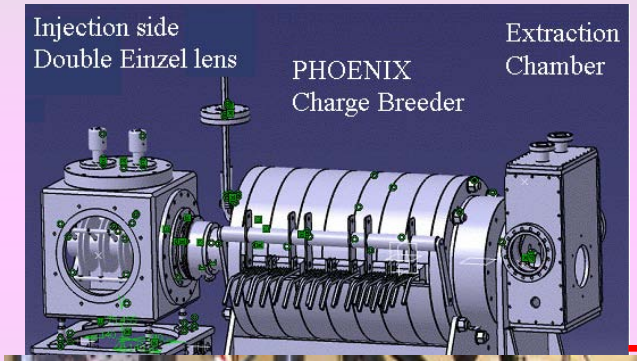
20 kV

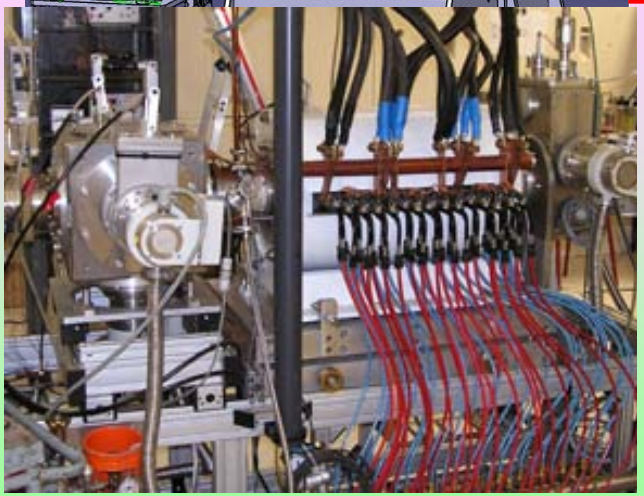


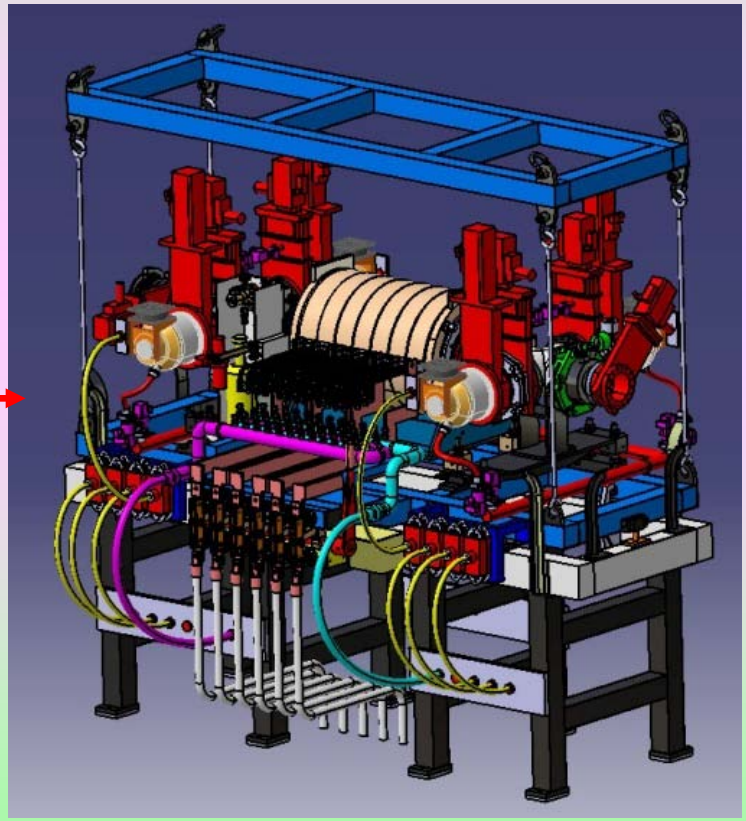
The 1+ energy of operation (potential)
Changes the slowing down configuration
(capture)

Due to potential high radioactivity: ‘nuclearization’ of the charge breeder

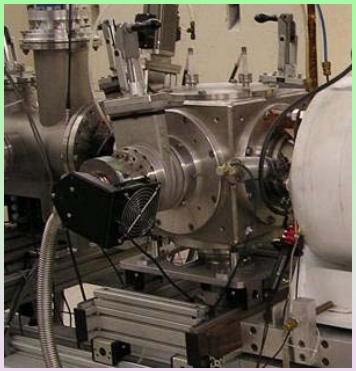
Justify the technological choices
Increase reliability of critical components, strengthen weak parts
Decrease the time necessary for maintenance operations
(The workers irradiation has to be as low as possible in the yellow zone)

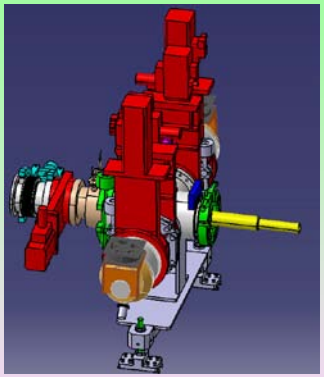


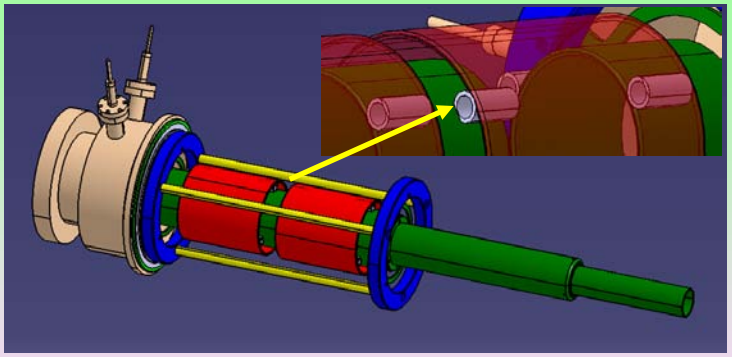


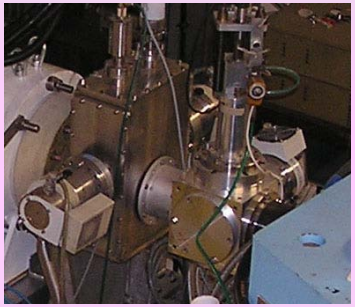


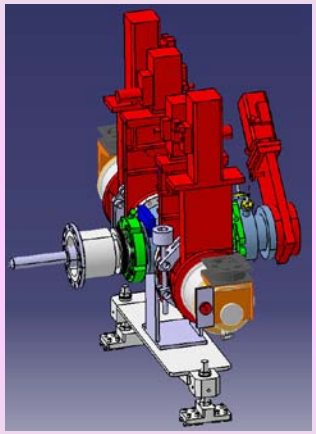
SPIRAL2 activities a few examples

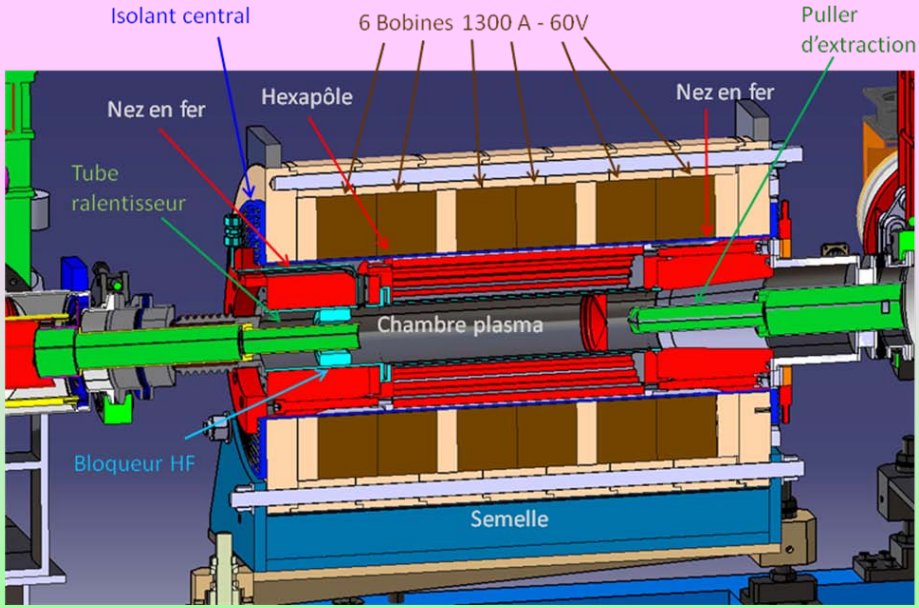


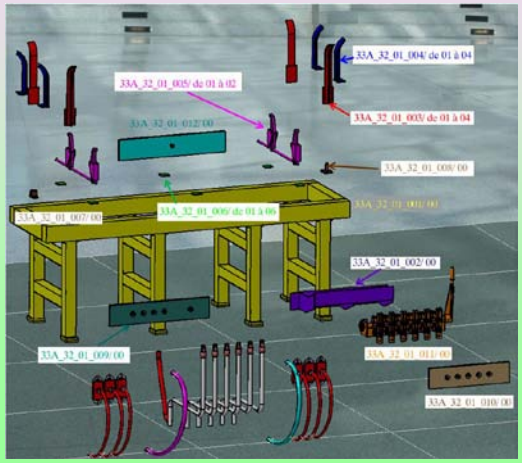






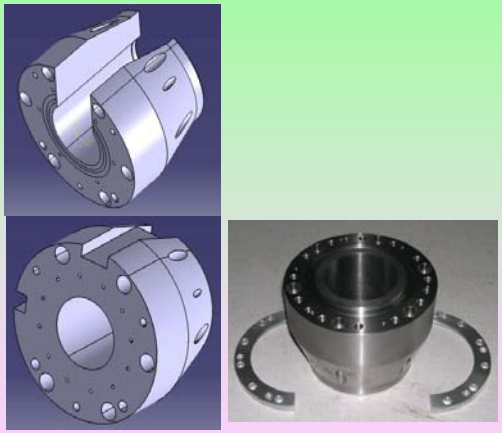


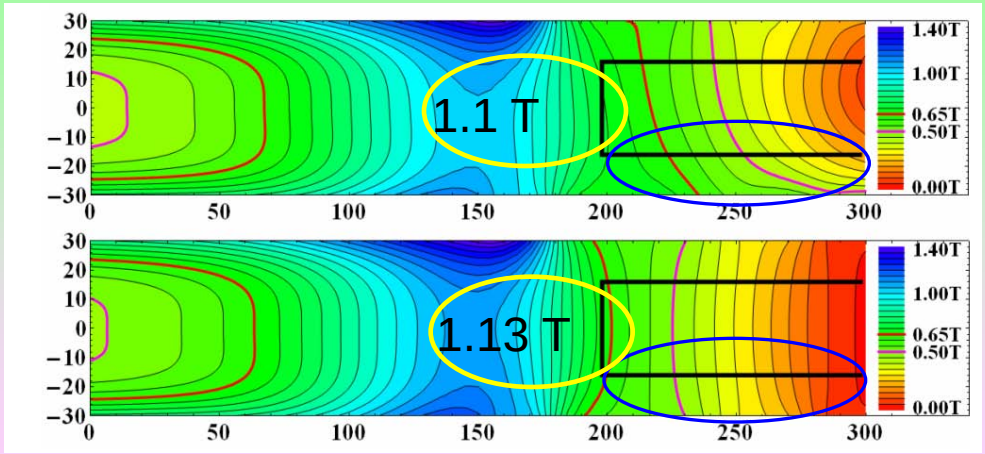




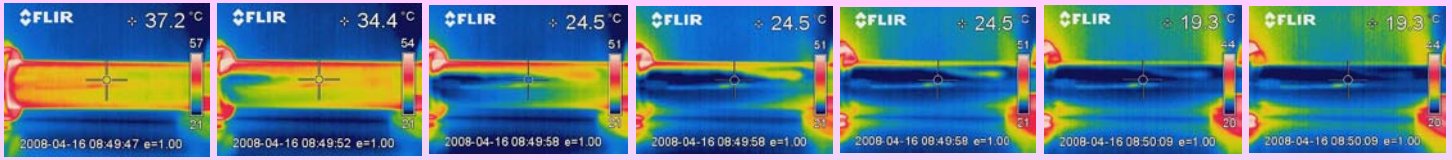
SPIRAL2 activities a few examples

Magnetic field (RADIA 3D - MATHEMATICA)



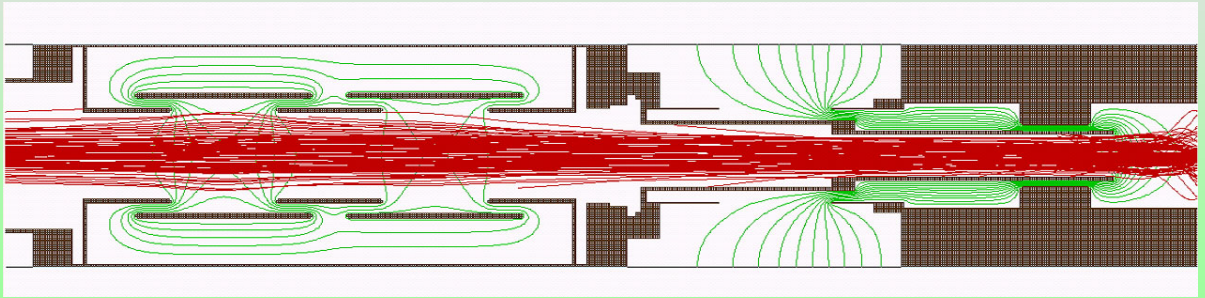


Plasma chamber cooling measurement : 25 ms



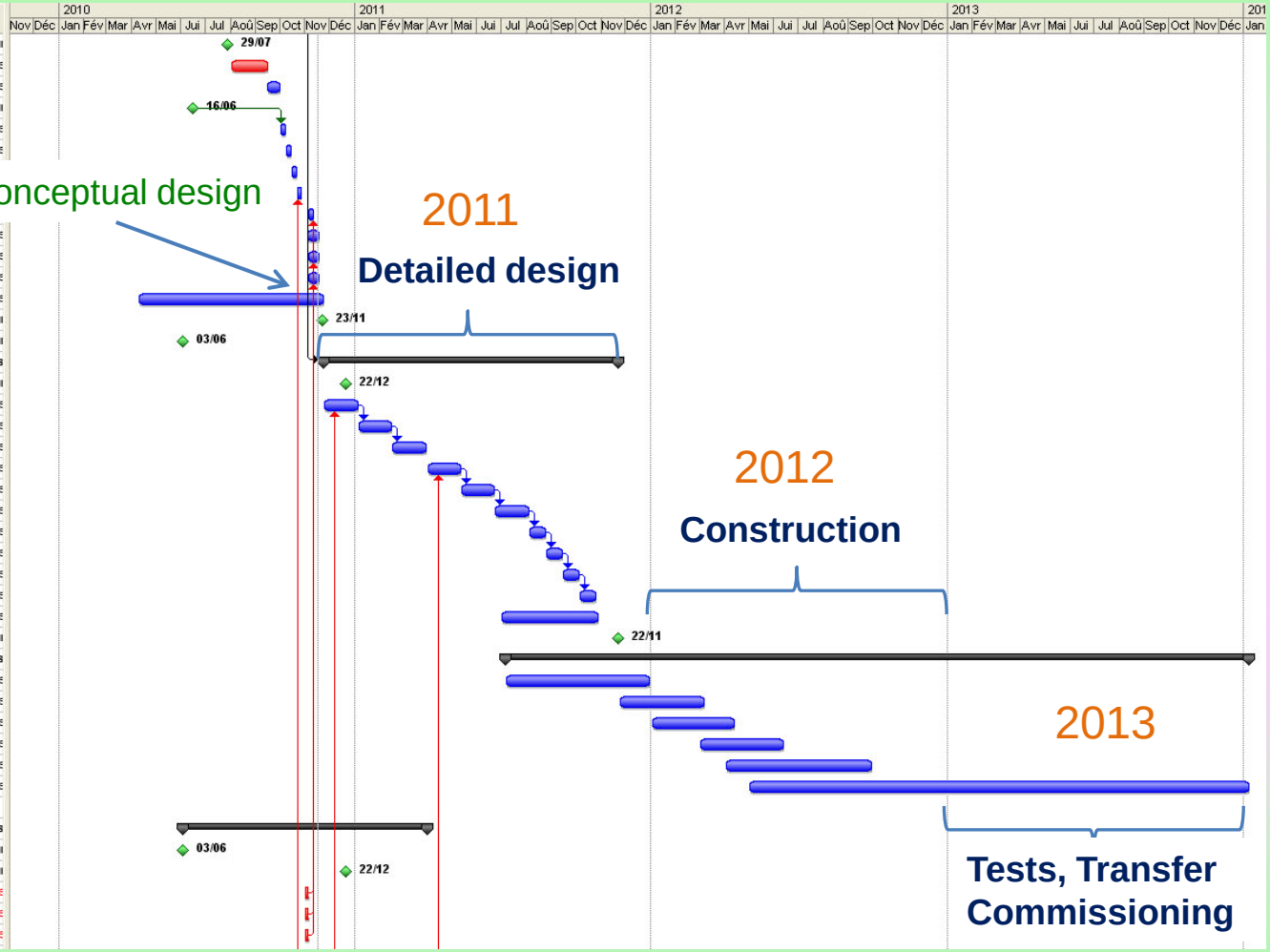
Double Einzel lens transmission to low energy ion beam (97% of 80 π.mm.mrad)

(SIMION + B field map)



SPIRAL2 Charge breeder
Planning

Nom de la tâche	Durée
Revue de suivi de la maintenance du Booster Spiral2 nucléaris	0 jour
Maladie projeteur	33 jours
Suite étude mécanique connexion servitudes	12 jours
Réunion Alignement Booster de charges n°1	0 jour
Etude mécanique préliminaire, intégration principes d'alignemen	5 jours
Fin étude mécanique préliminaire caissons injection extraction	5 jours
Fin étude mécanique préliminaire noyau central Booster	
Fin étude cinématique des opérations de maintenance	
Fin étude mécanique préliminaire connexion des servitudes	
Rédaction d'un dossier d'estimation des coûts de réalisation	11 jours
Fourniture des spécifications de vide	11 jours
Fourniture des spécifications d'automatisme et de contrôle com	11 jours
Rédaction dossier de définition du Booster de charge	164 jours
Revue de définition préliminaire Booster	0 jour
J1 Définition des interfaces procédés/bâtiments (niveau APS)	0 jour
Etude de définition détaillée	**261 jours**
J3 Définition des interfaces précises procédés/batiments (nive	0 jour
Etude détaillée Booster (plans consultation)	30 jours
Etude détaillée caissons injection et extraction (plans de consu	30 jours
Etude détaillée support ensemble Booster (plans de consultatic	30 jours
Etude détaillée connexion des servitudes (plans de consultatio	30 jours
Etude cinématique des opérations de maintenance	30 jours
Définition des équipements du local de maintenance associé au	30 jours
Vérification des dossiers de plans pour consultation	15 jours
Edition du cahier des charges pour fabrication	15 jours
Réalisation des plans pour fabrication	15 jours
Vérification des dossiers de plans pour fabrication	15 jours
Mise à jour du dossier de définition (4 mois)	87 jours
Revue de définition détaillée (15 jours après la rédaction du do	0 jour
Réalisation usine	**659 jours**
Préparation des avis d'appel public à concurrence	129 jours
Consultations	75 jours
Analyse des offres	75 jours
Signature des contrats / lancement fabrication	75 jours
Fabrication / suivi	129 jours
Montage / test / Qualification	443 jours
Définitions (en interface avec système)	**217 jours**
J2 Définition des interfaces servitudes procédés(niveau APS)	0 jour
J4 Définition des interfaces précises servitudes / procédés (ni	0 jour
Définition Spiral2 des standards de connexion servitudes (sign	3 jours
Définition Spiral2 des documents vide à fournir (calcul vide ?)	3 jours
Définition Spiral2/LPSC du contour du contrôle commande	3 jours



24 Nov. 2010 Preliminary design study review

LEA COLLIGA

Attachment to the Memorandum of Understanding GANIL-INFN

INFN-LNL **neutron convertor** to GANIL-SPIRAL2 ↔ IN2P3-LPSC **charge breeder** to SPES-LNL

Activities during collaboration of INFN-LNL and IN2P3-LPSC

Phase 1
Scientific collaboration – 1 or 2 developments by INFN for SPIRAL2
Conceptual design of the SPES charge breeder

Phase 2
Design and construction by LPSC – joint tests and commissioning

Performed in 2010
Scientific collaboration (Alessio Galatà – LNL at LPSC)

Operation of the LPSC charge breeder - Fine frequency tuning effect - Suppression of the grounded tube

Many Technical problems encountered on the LPSC test bench

Old (40 years) supplies for the coils of the source, the 1+ and n+ spectrometers

Oscillation of the n+ spectrometer magnetic field

Different supplies from the lab tested

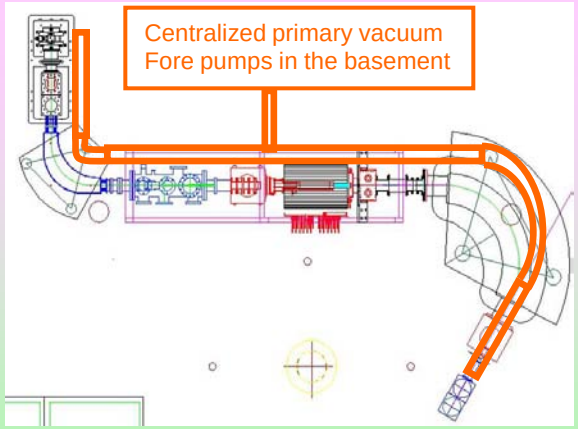
New supply bought and installed

Old 14 GHz HF transmitter problem

Klystron changed

Vacuum problem (Booster injection vacuum level degradation when operating the 1+ source)

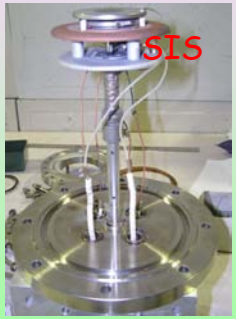
Lower pressure at the injection side gives better capture and multi ionization efficiency

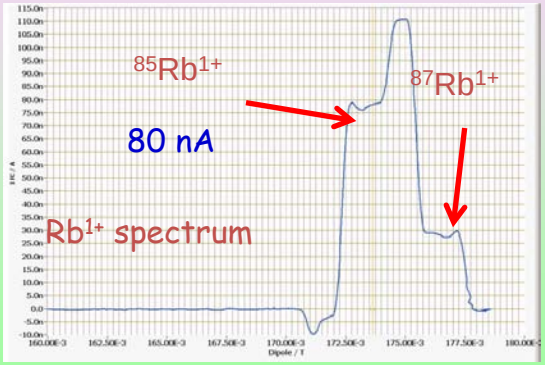


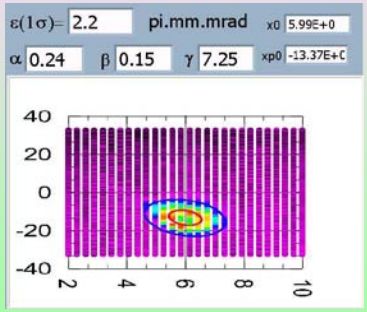
Additional fore and turbo pumps installed

Booster vacuum isolated from 1+ line

Breakdown problems on the Rb Source







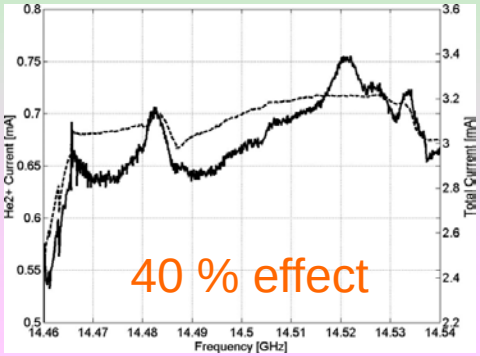
Under rebuilding

Phase 1: LNL-LPSC Scientific collaboration

Fine frequency tuning in ECR ion sources

Permits to accurately optimize and improve ECR ion sources operation

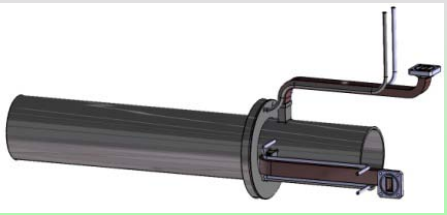
S. Gammino, G. Ciavola, and L. Celona, Nucl. Instrum. Methods Phys. Res. A 491, 342 2002



L. Celona et al.
Observations of the frequency tuning effect in the 14 GHz CAPRICE ion source
Rev. Sci. Instrum. 79, 023305 (2008)

It may permit to optimize charge states and efficiency of charge breeding

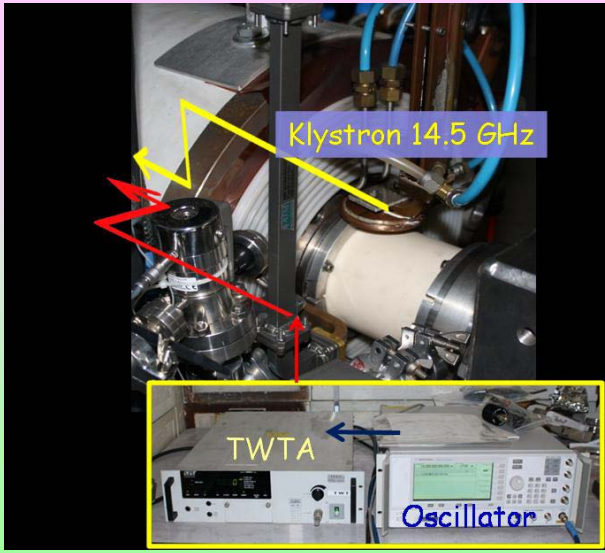
Oscillator rented by LPSC
Traveling Wave Tube Amplifier lent by LNL



13.75-14.5 GHz, input -17 dB (20µW)

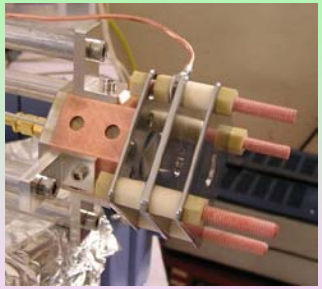
Max Power 400 W
(about the power required by the breeder)

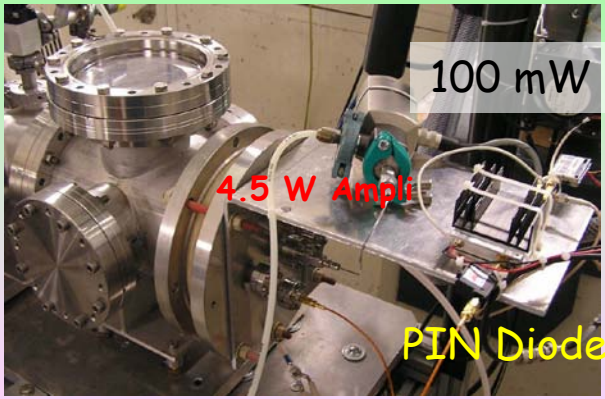
Max reflected power 10 %

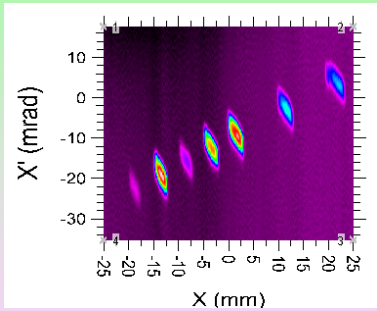


Fine frequency tuning of LPSC charge breeder

1+ beam delivered by COMIC source





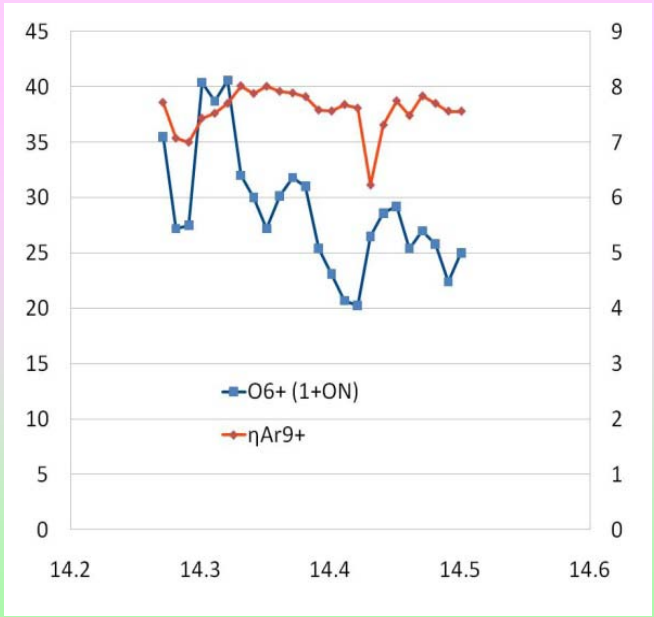


1 to 5 π.mm.mrad

Example:
Xe 550 nAe
3 W
ext. 3/10 mm
15 KV

Frequency tuning of the charge breeder

μA



%

Injection of oxygen gas and Ar^{+} ion beam

50 MHz steps with constant power

Clear effect on background gas (oxygen)

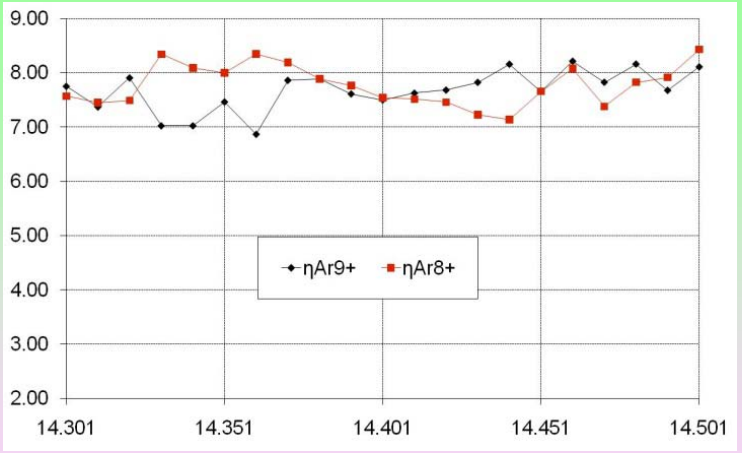
Effect on charge breeding of Argon (Ar^{9+}) but no gain

Fine frequency tuning of LPSC charge breeder

Other Ar experiment

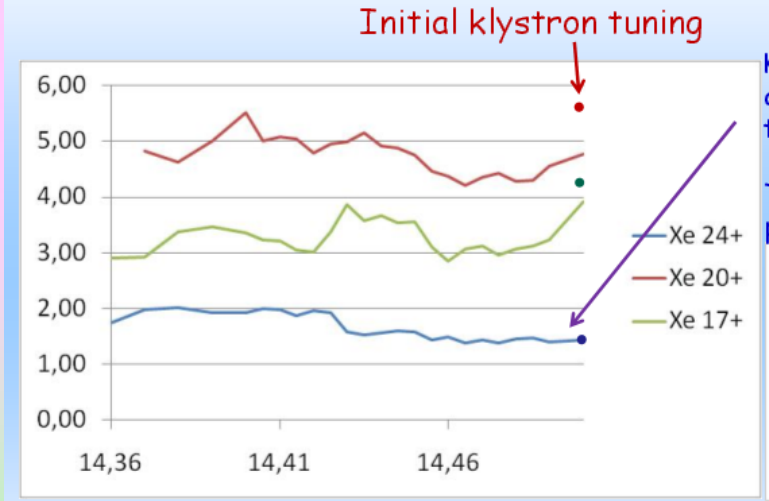
Lower effect
Weak correlation between different charges

Problems of reproducibility



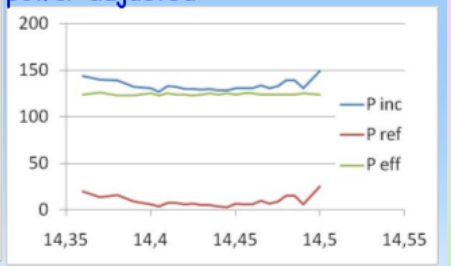
Xe experiment

During TWTA power increase, too much reflected power
So plasma first performed and tuned on Xe^{20+} with klystron (376 W)



Klystron power decrease
and TWTA power increase (124 W)
to get the same efficiency for 24+

Then frequency decrease,
power adjusted



- ► Fine frequency tuning has an influence on the buffer gas ion intensity
  - ► In the same time no strong effect seen on the charge bred ions (Efficiency and CSD)
- ► For specific tunings better plasma stability observed

1+/n+ a plasma probe ?

Injection of a known 1+ beam in the plasma and extraction of the N+ ones created inside could give some information on the plasma characteristics
Is the method a plasma probe ?

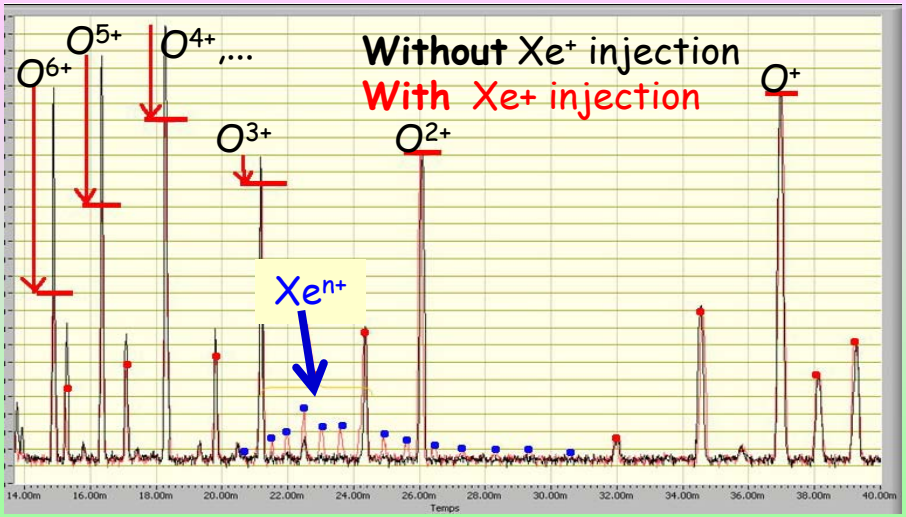
Xenon example

About 100 to 500 nA 1+ injected
We extract about 1 mA from the plasma (negligible injected intensity)

Capture around 50 % → 250 nA 1+

Typical tuning: Average charge state extracted 17+
So about 8.5 µA Xe extracted over 1 mA : about 1 %

The injection could be considered as 'non perturbative' (good probe)

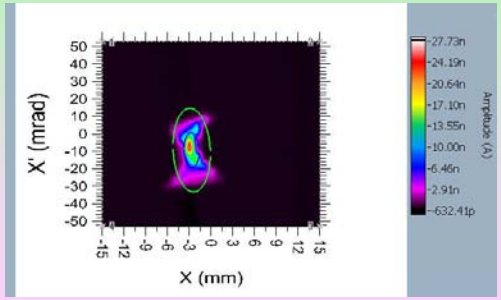


The non perturbative injection destroys the plasma characteristics

No charge exchange

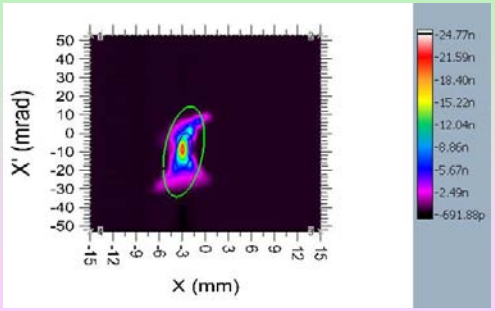
Destruction of the plasma characteristics

O^{6+} Emittance measurement

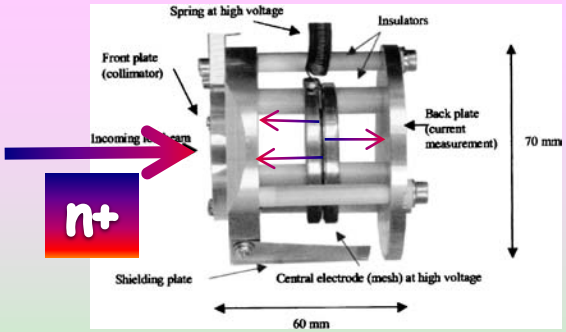


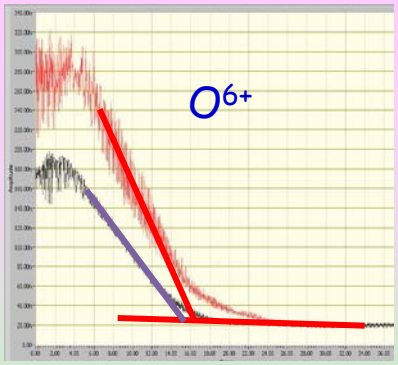
O^{6+} emittance without Xe injection
$10.1\ \pi$.mm.mrad

O^{6+} emittance with Xe injection
$10.2\ \pi$.mm.mrad ...



Plasma potential measurement (JYFL instrument)



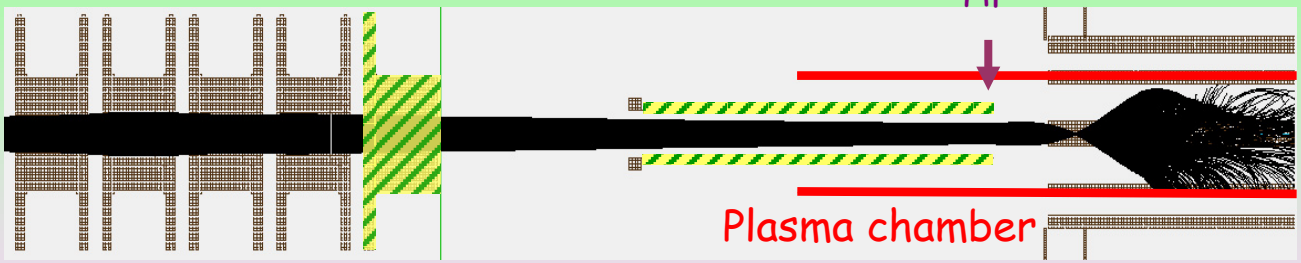


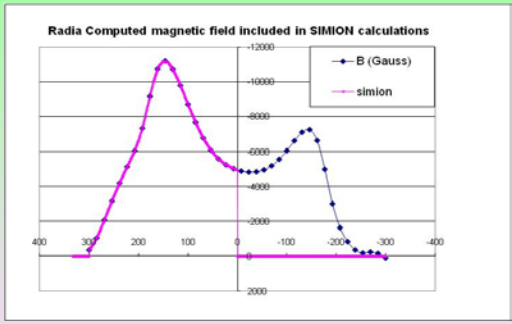
Without 1+ injection: 15.5 eV
With 1+ injection: 16.5 eV

So electron distribution function evolution ? Plasma dynamics ?...still a mistery
May help to the understanding of ECR ion source physics…

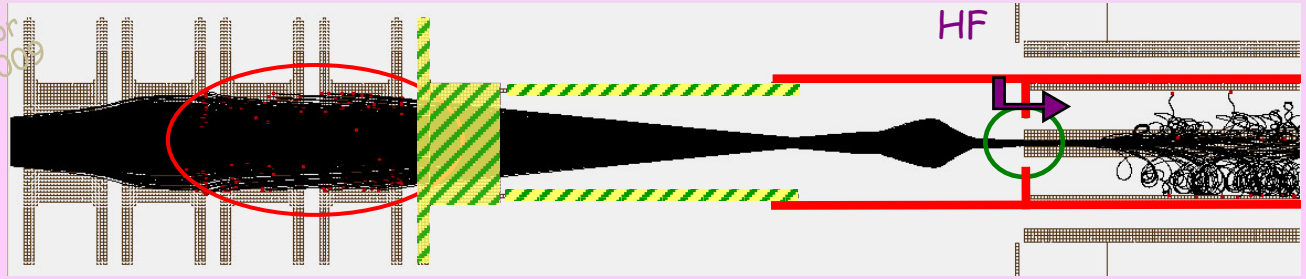
1+ injection simplification

Present configuration



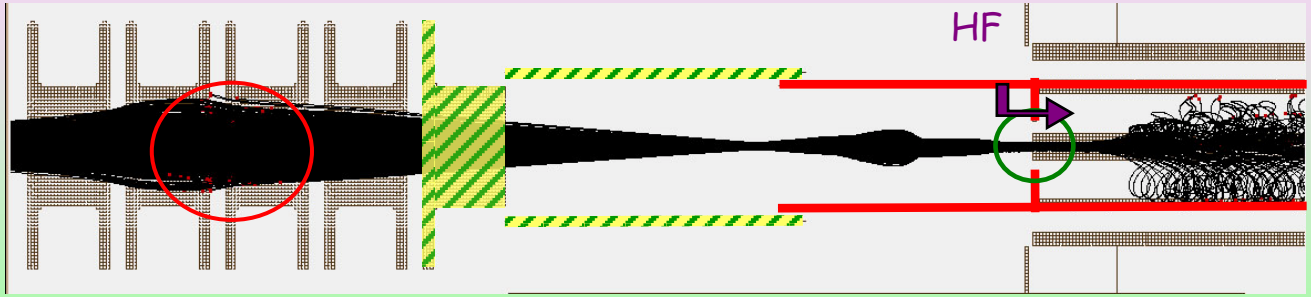


Large diameter grounded tube



Heavy Ion Accelerator Technology Venice, 2009

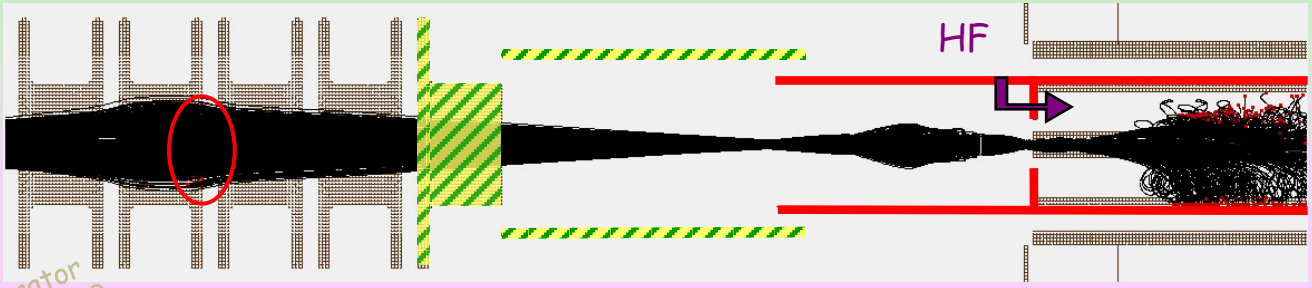
External grounded tube



1+ injection simplification

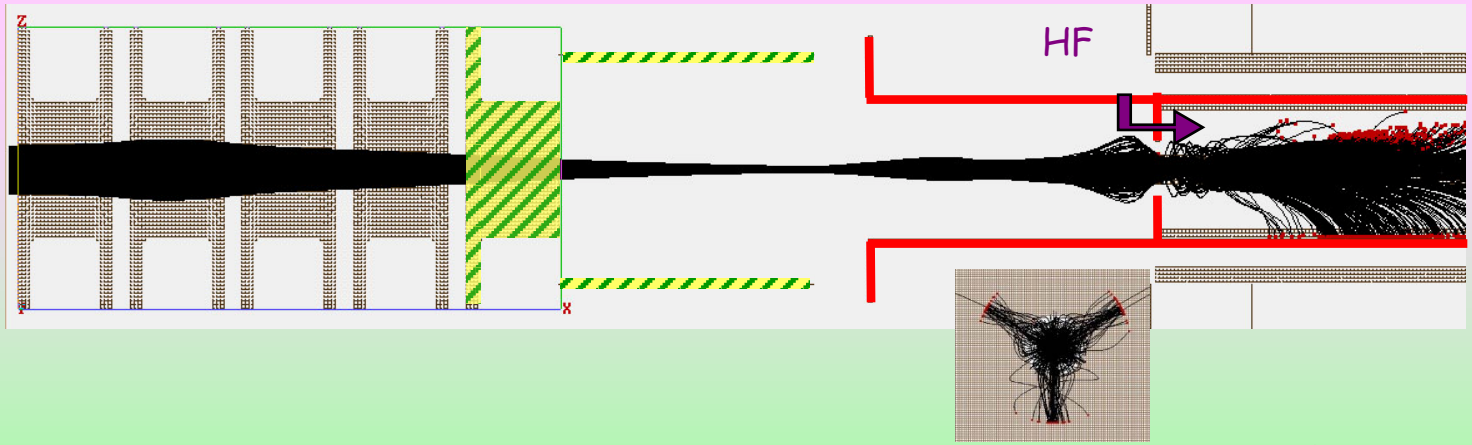
Large diameter external grounded tube

Not easy to implement mechanically



Heavy Ion Accelerator Technology Venice, 2009

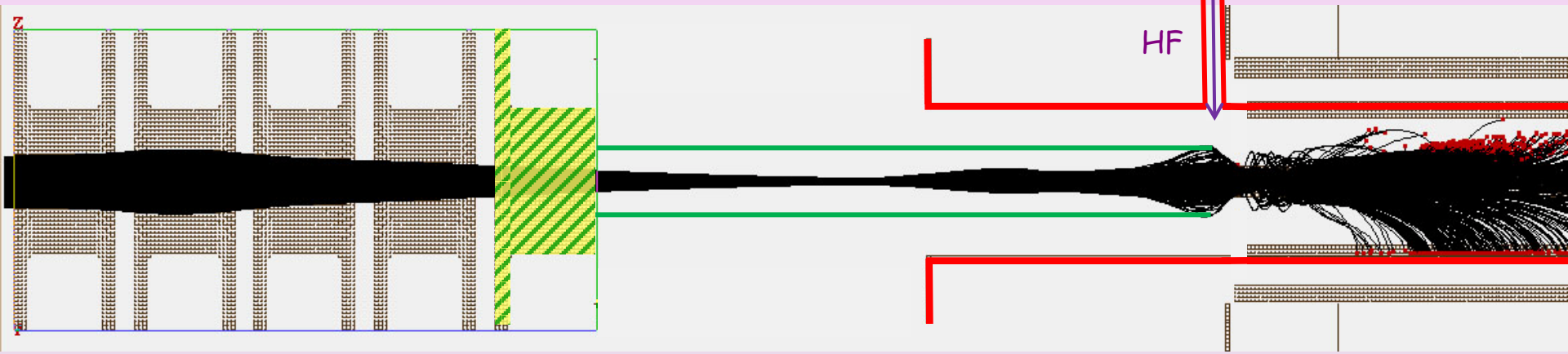
Large diameter and short tube

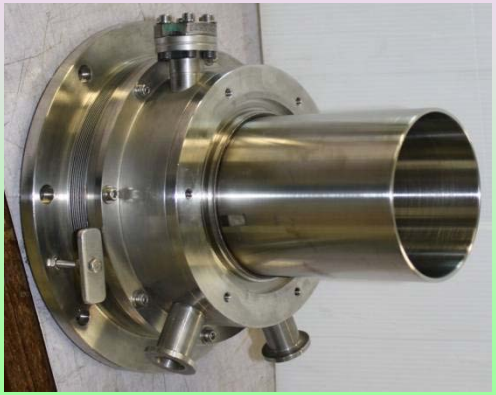


Almost like grounded tube removal

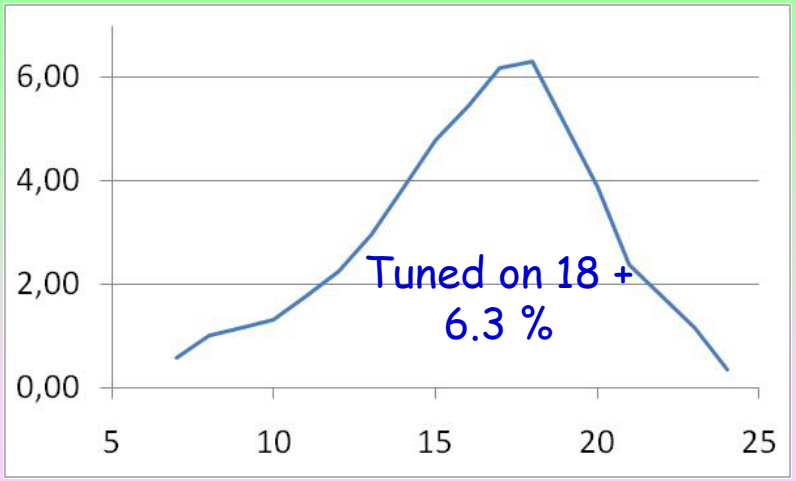
Has to be tried

1+ injection simplification

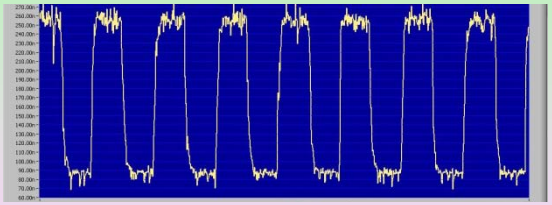




1+ injection simplification

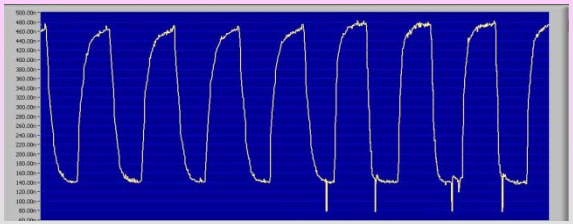


Booster open in the morning
Result get in the aternoon !



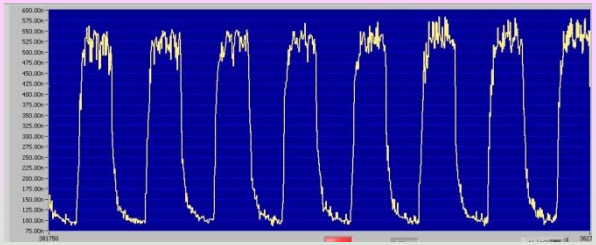
21 +
2.37 %
140 ms ~ 7 ms/q

85 watts ! Drain current 400 μA
Normally (with grounded tube) about 400 W…!
Easier tuning (looks like an ECRIS) much better stability !



21 + tuning
187 W more gas
4.65 % 330 ms ~ 16 ms/q

Mechanics
(maintenance)
more simple
Less
contaminated parts



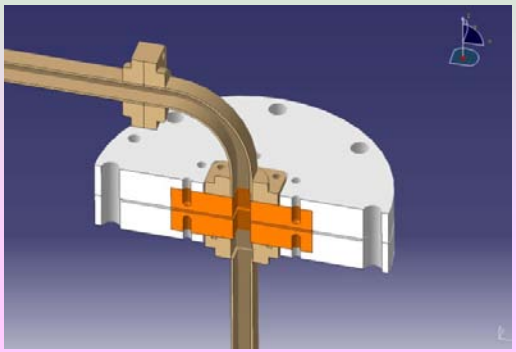
21 + more tuning
370 W less gas
5.01 % 260 ms ~ 13 ms/q

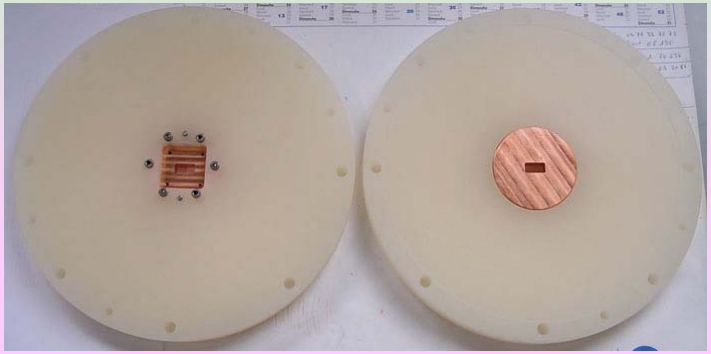
Has to be tested with metallic ion beams !

Our joint future

2011 Collaboration program foreseen

HF DC breaker development by INFN-LNL can be profitable to the whole ECRIS community





Increase of the radial magnetic field (hexapole change), capture, CSD

SPES charge breeder Conceptual Design (fall 2011 to be discussed)

Funding asked by LPSC

Improve the charge breeder beam line vacuum (ANL results ?)

Develop a new 2.45 GHz alkali and metallic ion source

Conclusions

Destruction of multicharged ions
by low intensity 1+ heavy ion beam **is a mystery**

Fine frequency tuning is disappointing

Grounded tube removal is really promising

May be fine frequency tuning study should be performed
in this new configuration…

Very fruitful collaboration with A. Galatà !
Profitable to at least LPSC and SPIRAL2
For SPES in the near future I hope…