

# Fine frequency tuning of the PHOENIX charge breeder used as a probe for ECRIS plasmas

Lamy Thierry<sup>(1)</sup>, Angot Julien<sup>(1)</sup>, Galata Alessio<sup>(2)</sup>  
Koivisto Hannu<sup>(3)</sup>, Marie-Jeanne Melanie<sup>(1)</sup>, Medard Jerome<sup>(1)</sup>, Sortais Pascal<sup>(1)</sup>,  
Tervainen Olli<sup>(3)</sup>, Thuillier Thomas<sup>(1)</sup>, Toivanen Ville<sup>(3)</sup>

(1) Laboratoire de Physique Subatomique et de Cosmologie, Grenoble France

(2) INFN-Legnaro National Laboratories, Legnaro, Italy

(3) University of Jyväskylä, Department of Physics, Jyväskylä, Finland

- ❖ Fine frequency tuning of an ECR Charge State Breeder
  - The oxygen  $n^+$  ghosts or 'is there mysticism in an ECR CSB ??'  
'charge exchange, emittance, plasma characteristics'
  - The experiments
    - I was not subjected to headache before...
    - or
    - I feel like a kind of frustration...
  - Validity of the ECR Geller theory '3 knobs for ECRIS'  
Is there a fourth one ?
- ❖ We are not paid to play, we are paid to build SPIRAL2 !!!
- Radioactivity and contamination is a nightmare
  - Lets keep it in the right place ...

It seems, it is a serious and respectable topic...

In the SERCE Source

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

L. Celona, S. Gammino, G. Ciavola, F. Consoli, and A. Galatà, AIP Conf. Proc. **749**, 99 2004

During this Workshop:

*Operation of KeiGM for the carbon ion therapy facility at Gunma University*  
Muramatsu Masay NIRS, Chiba, Japan MOPOT01

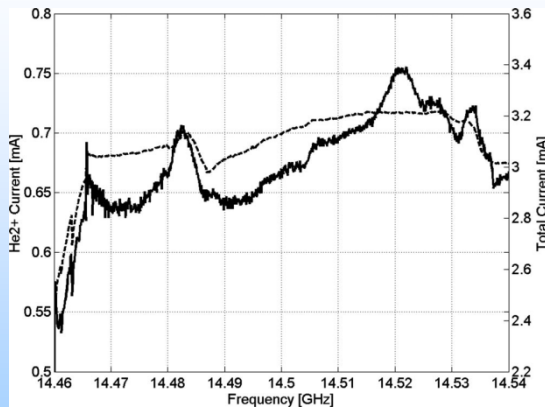
*Performance of the LBNL AECR-U with a TWTA*  
Benitez Janilee LBNL, Berkeley, USA TUPOT08

*Microwave frequency dependence of the properties of the ion beam extracted from a CAPRICE type ECRIS*  
Maimone Fabio, GSI Darmstadt Germany, Università degli Studi di Catania Italy TUPOT12

*Effects of microwave frequency fine tuning on the performance of JYFL 14 GHz ECRIS*  
Toivanen Ville JYFL, University of Jyväskylä Finland TUPOT10

*Characterization of the microwave coupling to the plasma chamber of the LBL ECR ion source*  
Lyneis Claude LBNL, Berkeley, USA WECOAK01

*Some considerations about frequency tuning effect in ECRIS plasmas*  
Mascali David INFN-LNS, Catania, Italy WECOAK02



From L. Celona et al.

**Observations of the frequency tuning effect in the 14 GHz CAPRICE ion source**

Rev. Sci. Instrum. **79**, 023305 (2008);

Total current extracted from the source dashed line and He2+ beam current full line evolutions with the frequency.

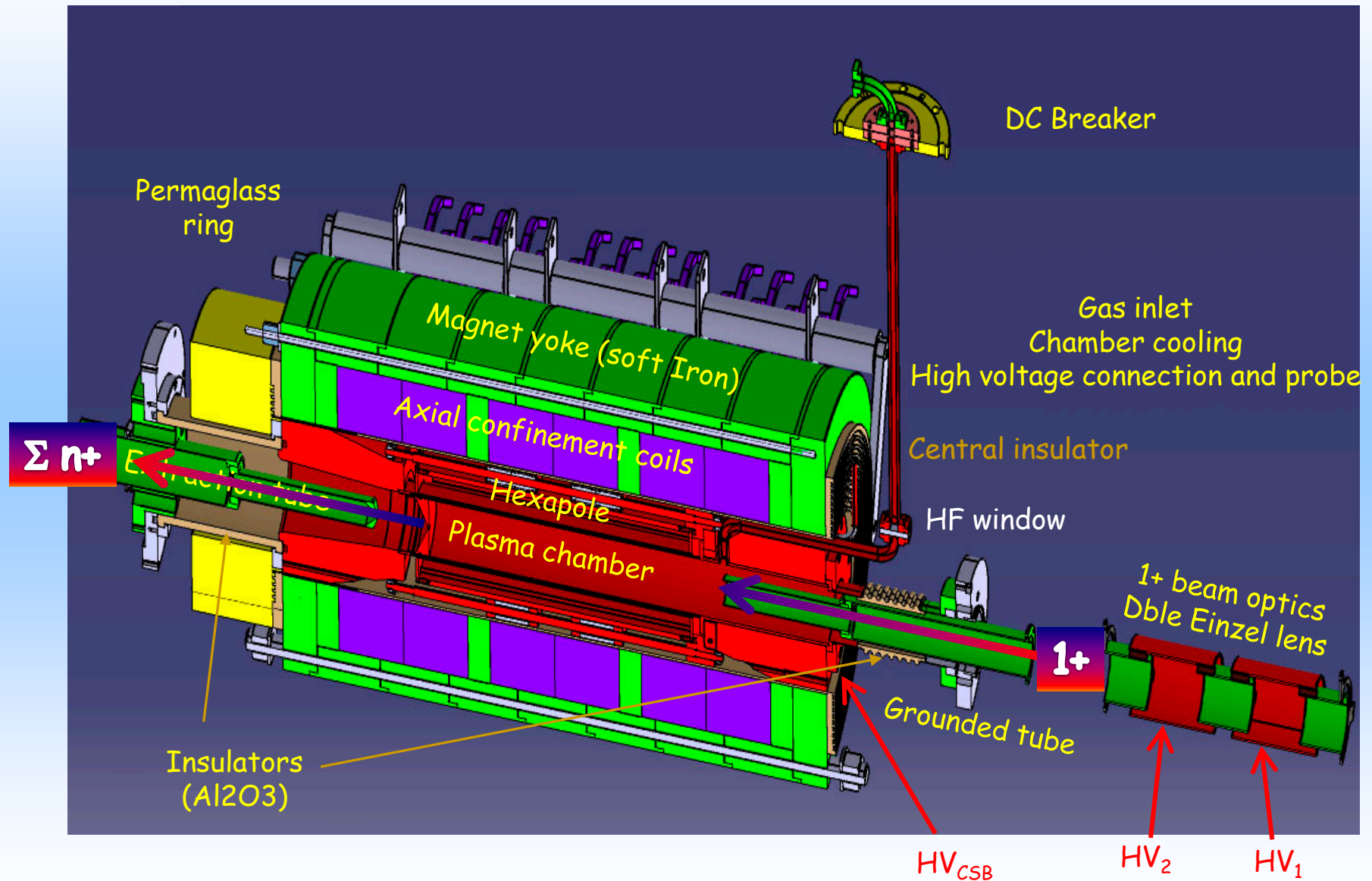
## ▪ Why to test with a charge breeder ?

We are looking for the highest efficiency for specific charge states  
 May be this fine frequency tuning may help to get this result

## ▪ The charge breeder is a kind of simple model

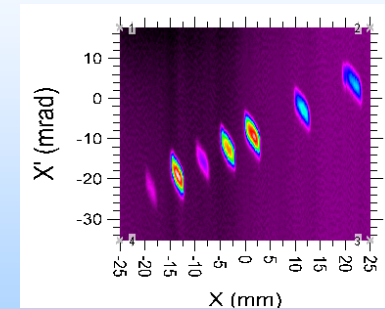
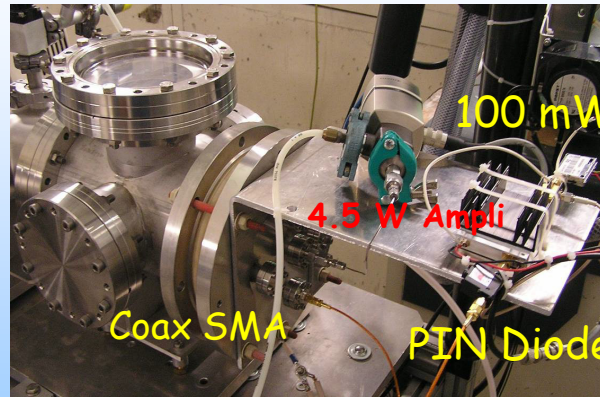
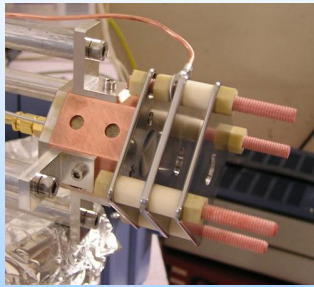
background plasma, characterized 1+ beam injected  
 analysis of the n+ ion beams extracted may give information on the plasma

# Present charge breeder configuration



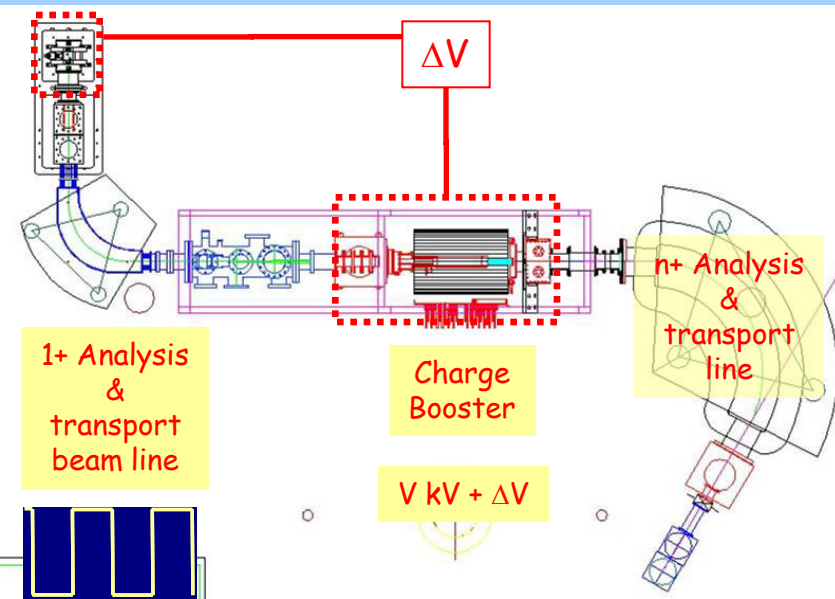
# Validity of the probe - n+ beams image of the plasma ?

1+ beam delivered by COMIC source: Xenon



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

1+ source  
V/kV



About 100 to 500 nA 1+ injected in a plasma from where 1 mA is extracted (negligible injected intensity ?)

Capture around 50 %  $\rightarrow$  250 nA 1+

Typical tuning

Average charge state extracted 17+

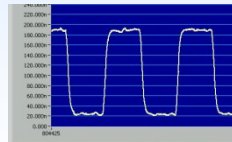
So about 8.5  $\mu$ A Xe extracted over 1 mA : less than 1 %

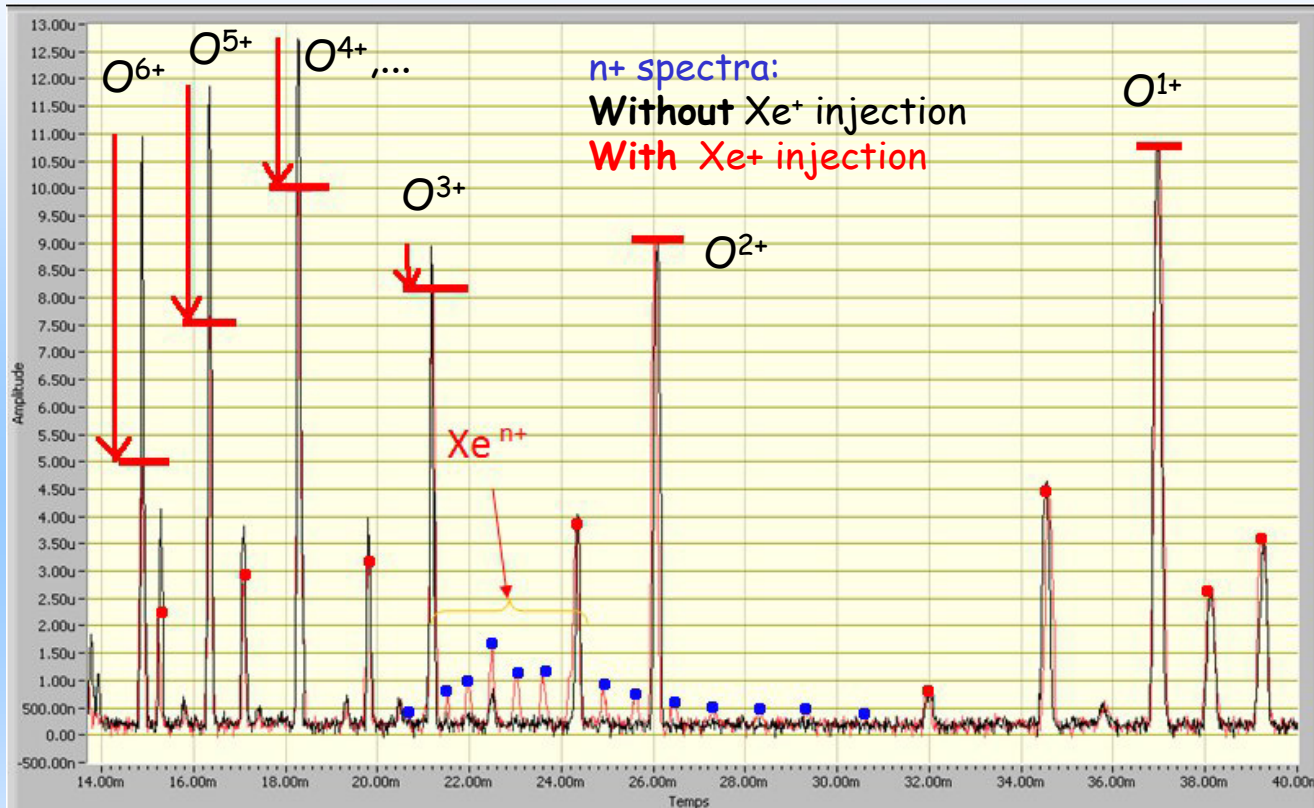
A 'normal' person may consider the injection as 'non perturbative' and consider the transformation of the 1+ beam in n+ as a good way to get plasma information

But...

1+

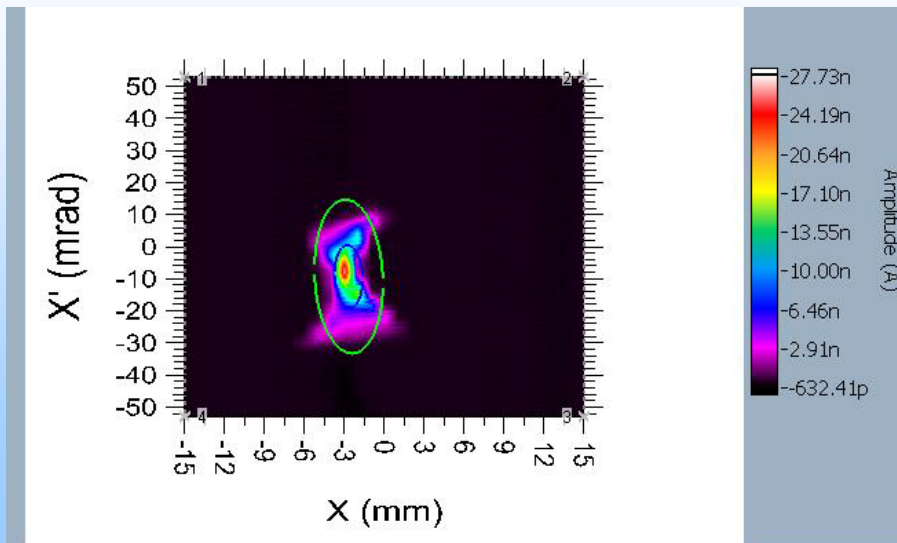
n+



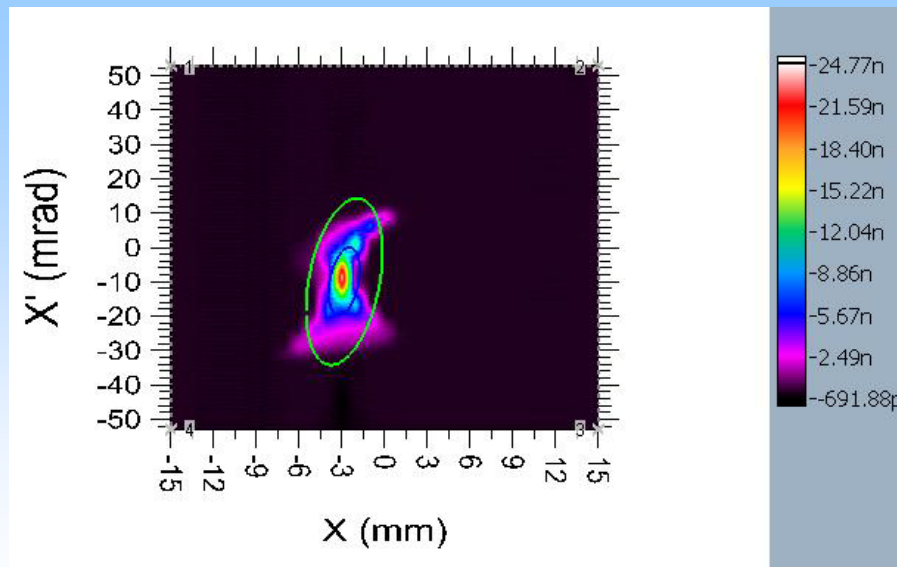


Where are they ...?

No charge exchange, low charge states don't increase when higher ones are destroyed...



O<sup>6+</sup> emittance without Xe injection  
10.1  $\pi$ .mm.mrad



O<sup>6+</sup> emittance without Xe injection  
10.2  $\pi$ .mm.mrad ...

They should still arrive  
in the faraday cup...

# The oxygen N+ ghosts, the 1+ beam : a plasma killer ?

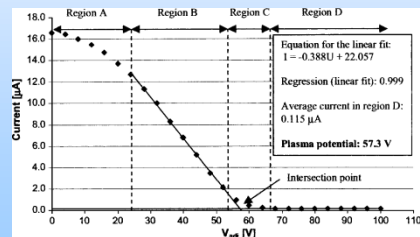
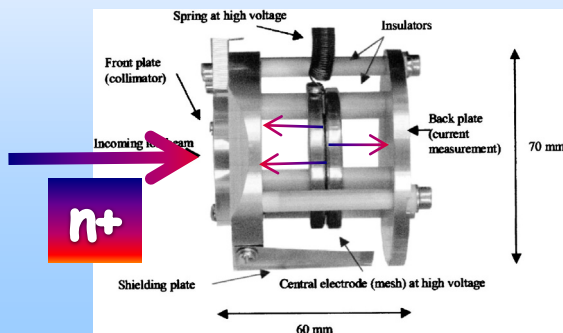
## Plasma potential measurement (JYFL instrument)



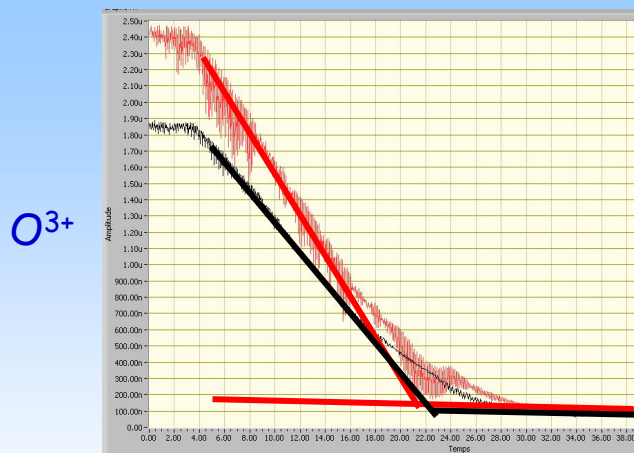
O. Tarvainen, P. Suominen, and H. Koivisto

A new plasma potential measurement instrument for plasma ion sources

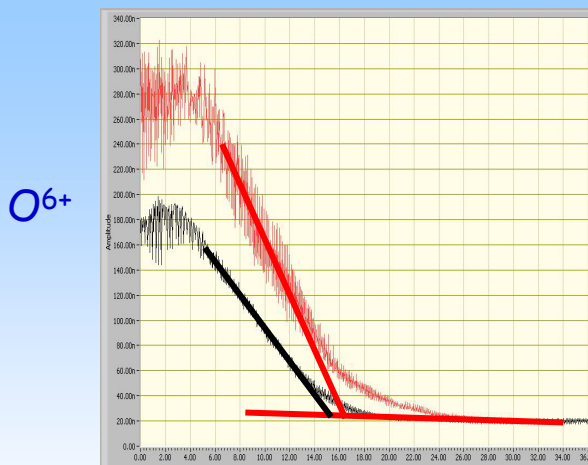
Rev. Sci. Instrum. 75, 3138 (2004)



## Two examples in different experiments

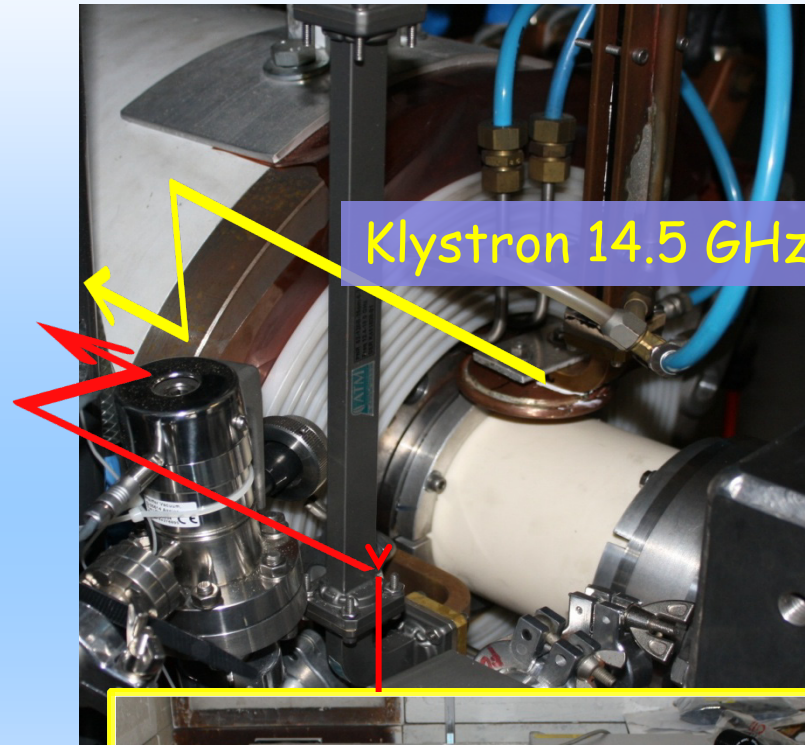
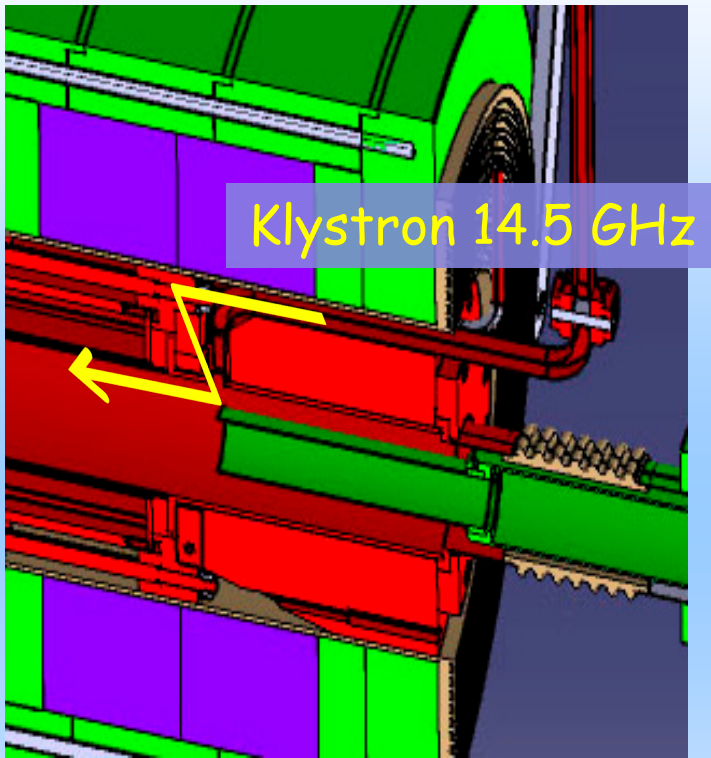


Without 1+ injection: 22.5 eV  
With 1+ injection: 21.5 eV



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

A reward is promised to the people who will help to understand the crime...



**TWTA 13.75-14.5 GHz**

Input -17 dB (20 $\mu$ W)

Max Power 400 W

Max reflected power 10 %

Then fault mode trying to recover 10 times

Impossible to optimize the booster with the TWTA

- Either reduced power (200 W), either drive the booster with klystron + TWTA

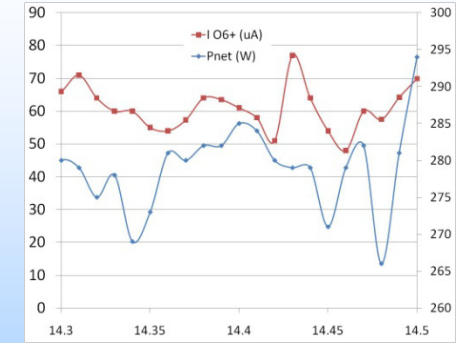
**TWTA**

**Very beginning** variations of the background gas intensity something happens !

The net power varies of less than 10 % (of  $\approx 300W$ )

The  $O^{6+}$  intensity variation reaches 40 %

Good...



**Then**

Injection of  $930 \mu A$  of  $Ar^{1+}$

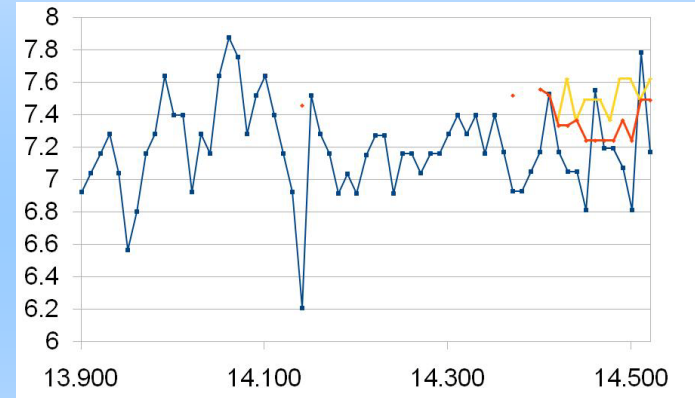
Variation of the breeding efficiency for  $Ar^{9+}$

**Blue curve (30 June 16:00)**

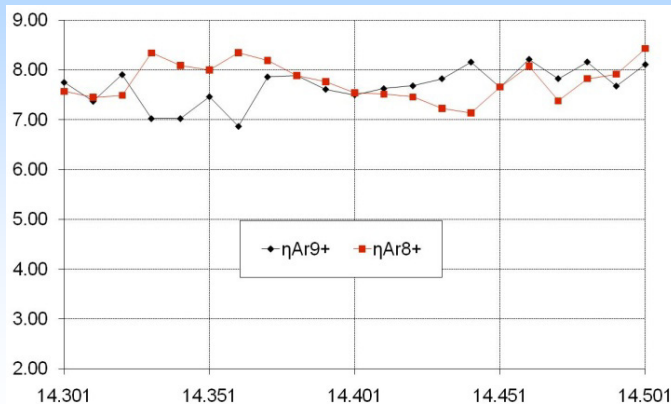
it varies ... Great !

30 June 18:50, not the same evolution...

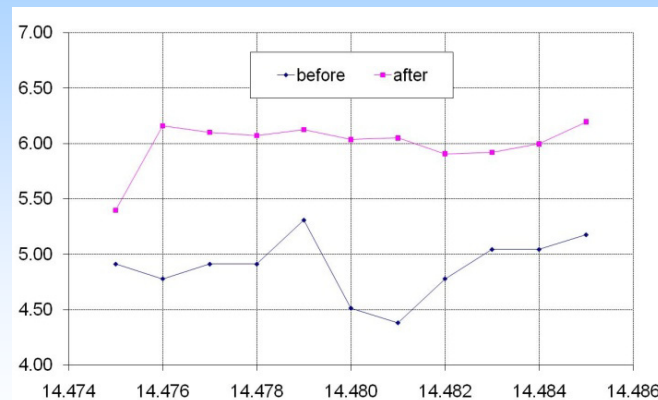
1<sup>st</sup> July another one... the team gets nervous...



**Studies in a specific range**



**But**

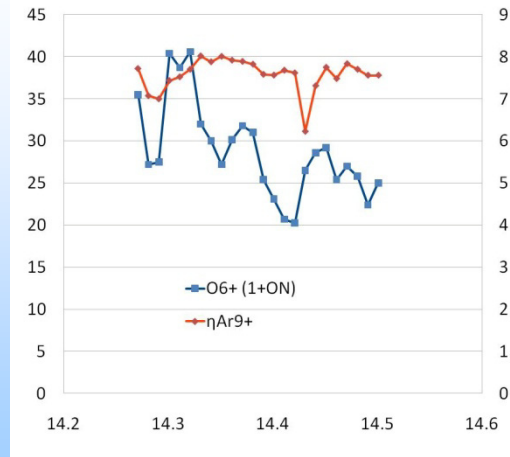


**Big reproducibility problem...and no exiting results frustration arises**

## Fine freq. tuning

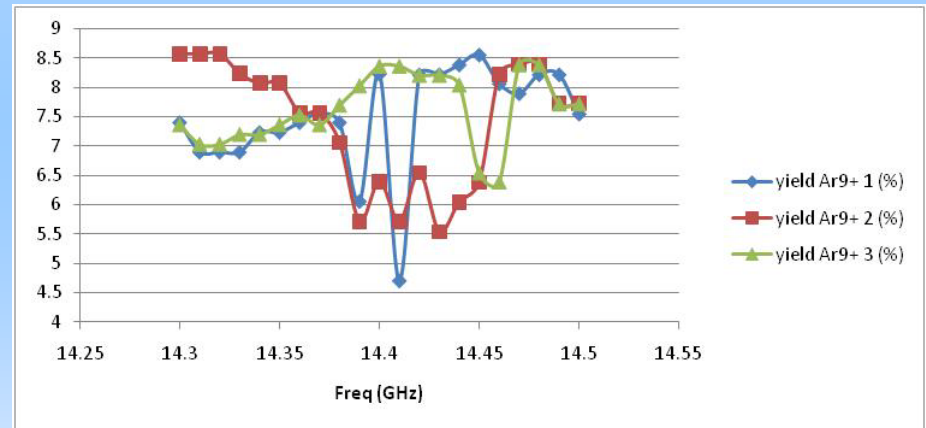
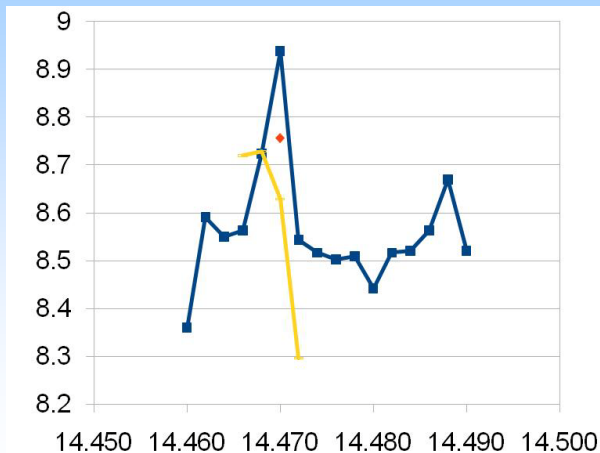
Effect on background gas compared to effect on 9+ charged bred Ar  
the O6+ can double, the Ar<sup>9+</sup> varies...

$\mu\text{A}$

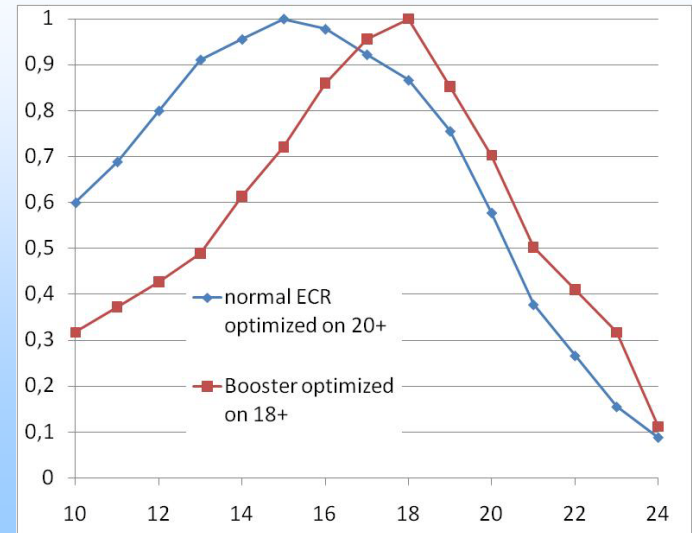
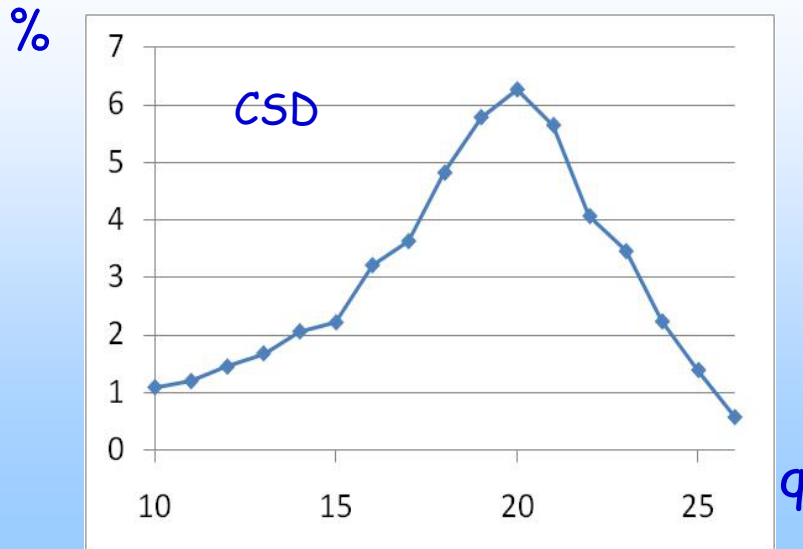


%

Three experiments with the 'same' conditions...



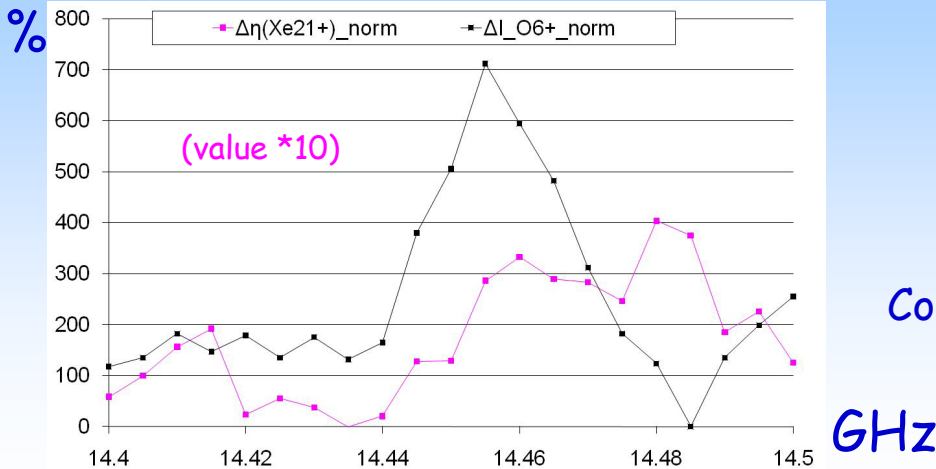
Another 'experiment' Ar<sup>9+</sup>  
Tension increases in the team...  
Lets try Xenon...



14,5 GHz  
(Pi 150W / Pref 17W) + 425 W klystron

CSD comparison  
Caprice source - PHOENIX Booster

Caprice source 14.5 GHz tuned on Xe20+ at GSI  
K. Tinschert, R. Iannucci, J. Bossler, and R. Lang  
Rev. Sci. Instrum., Vol. 75, No. 5, May 2004

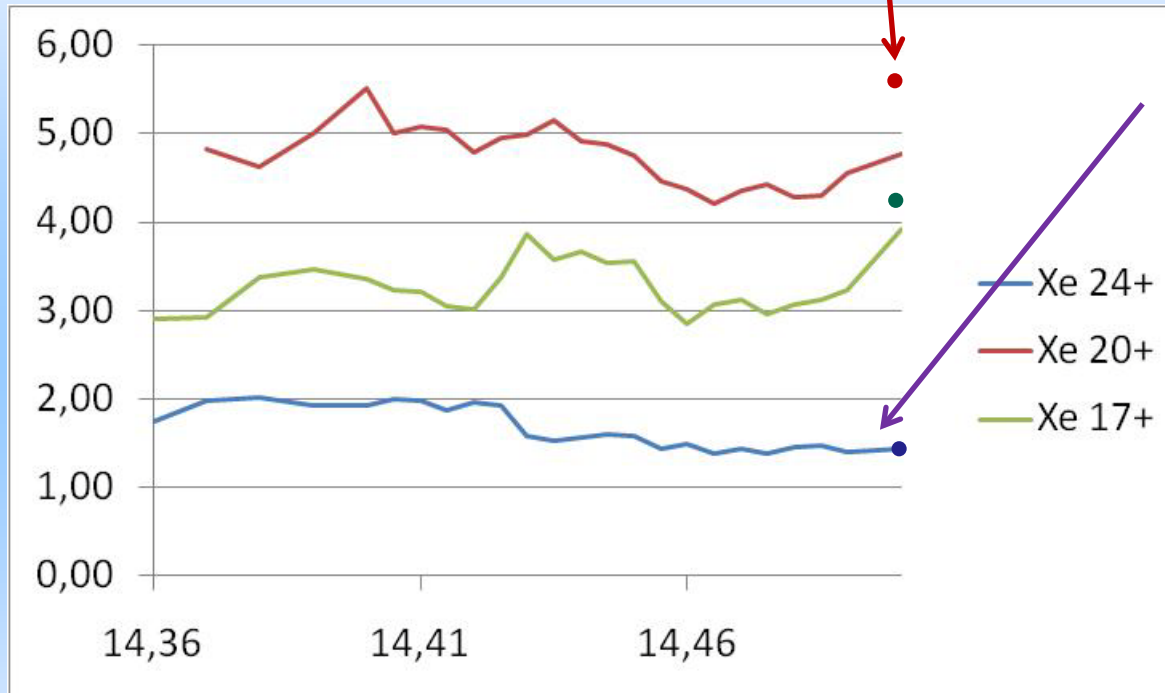


Charge bred Xe<sup>21+</sup> efficiency  
Background gas O<sup>6+</sup> destruction (OF-ON)

Comparison of the gain relative to the minimum values  
No real correlation...

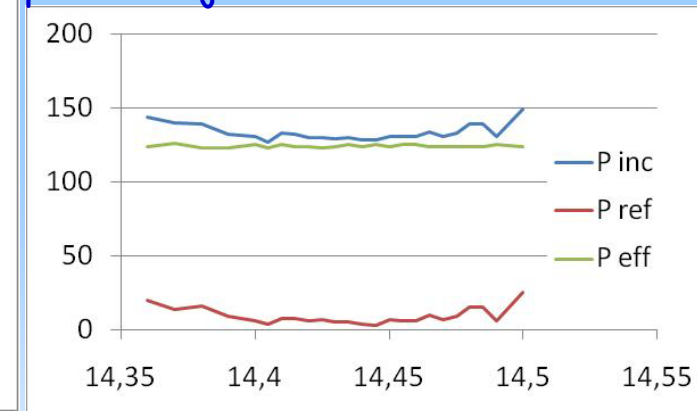
During TWTA power increase, too much reflected power  
So plasma first performed and tuned on Xe<sup>20+</sup> with klystron (376 W)

Initial klystron tuning



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

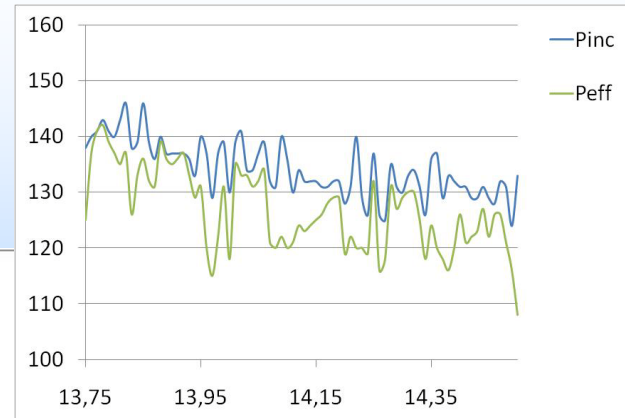
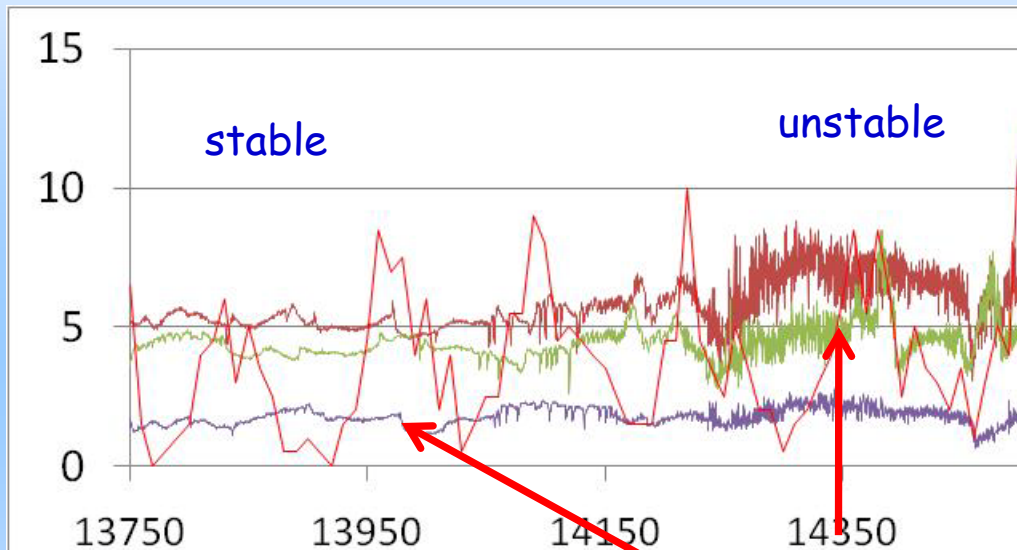
Then frequency decrease, power adjusted



At 14.71 MHz, plasma regime changed, no possibility to recover the tuning  
Even for this partial study not easy to establish a 'scientific' interpretation !  
So let's try sweep mode...!

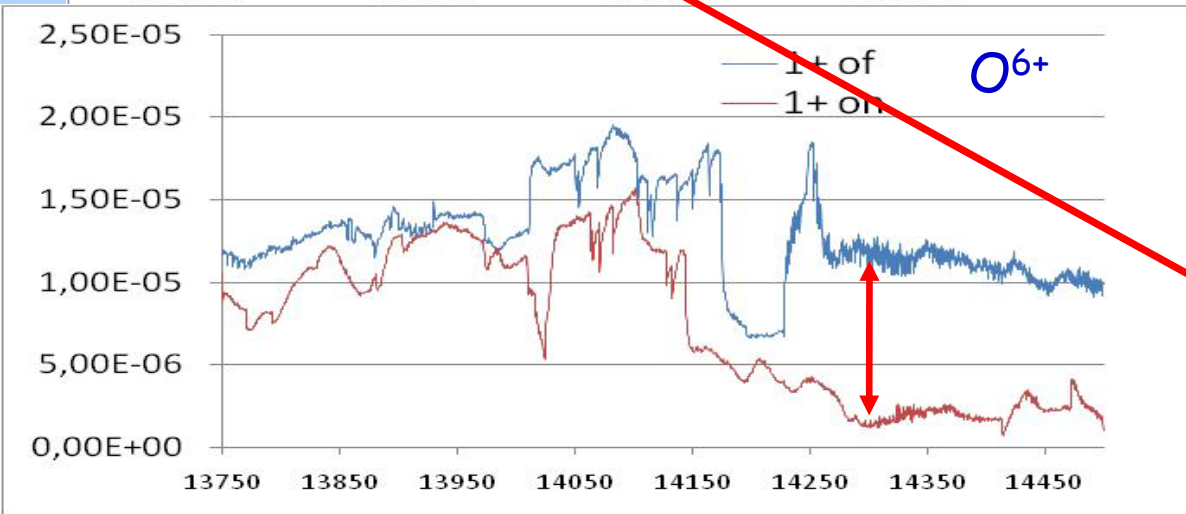
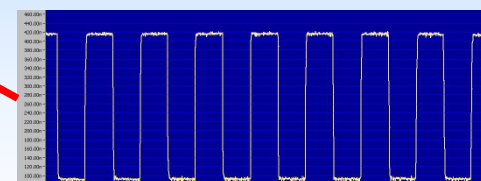
Automatic frequency variation  
From 13.75 up to 14.5 GHz, 2 MHz steps, 20 ms/step

Power variation during the sweep



- efficiency 20+
- efficiency 17+
- efficiency 24+
- Pref

Roughly highest O6+ destruction,  
Highest efficiency  
But instable operation...



# Partial conclusion of the booster fine frequency tuning

Very complex experimental studies

No magic effect on efficiencies... (is it interesting to spend time on it ?)

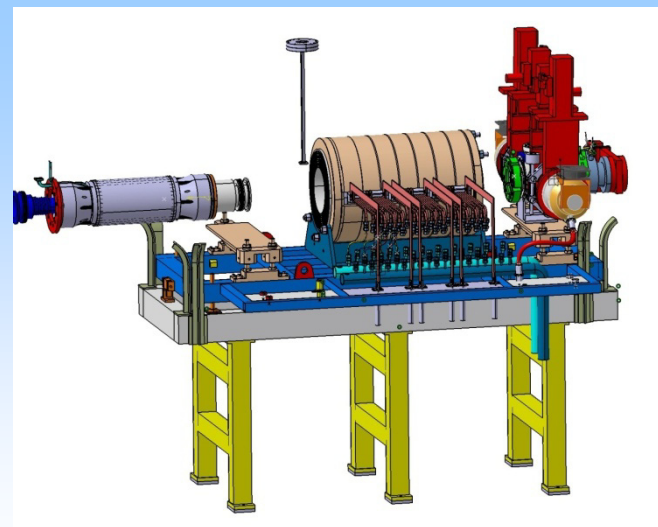
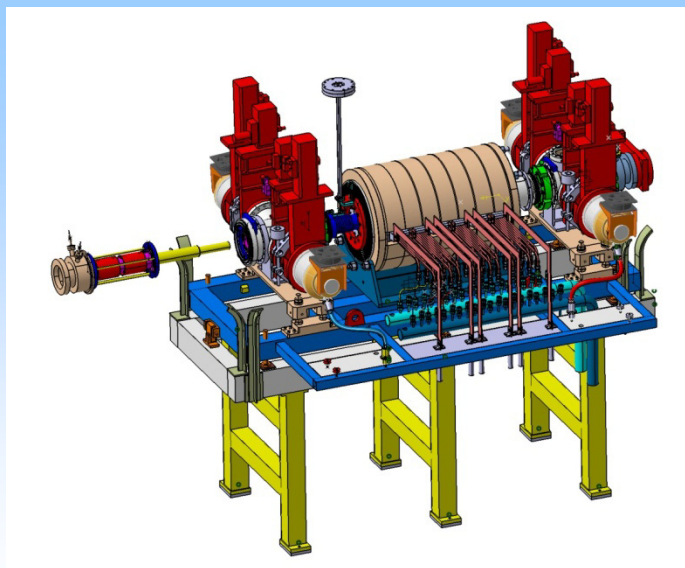
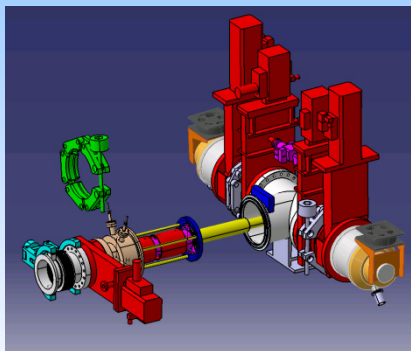
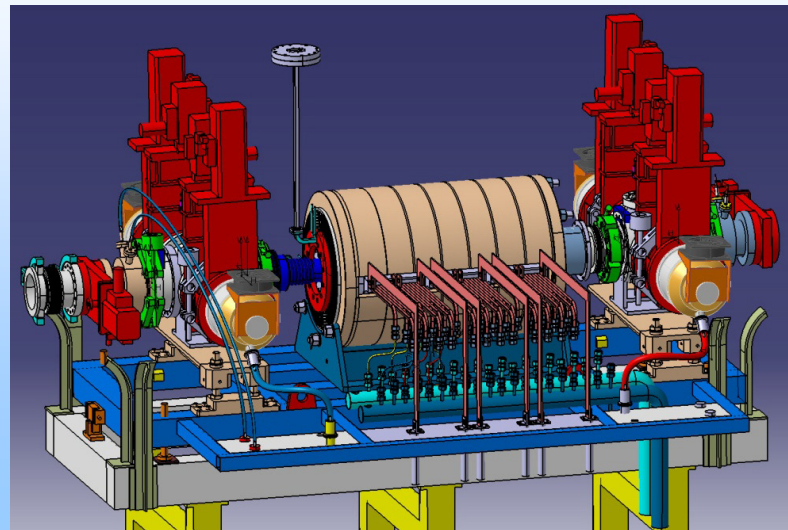
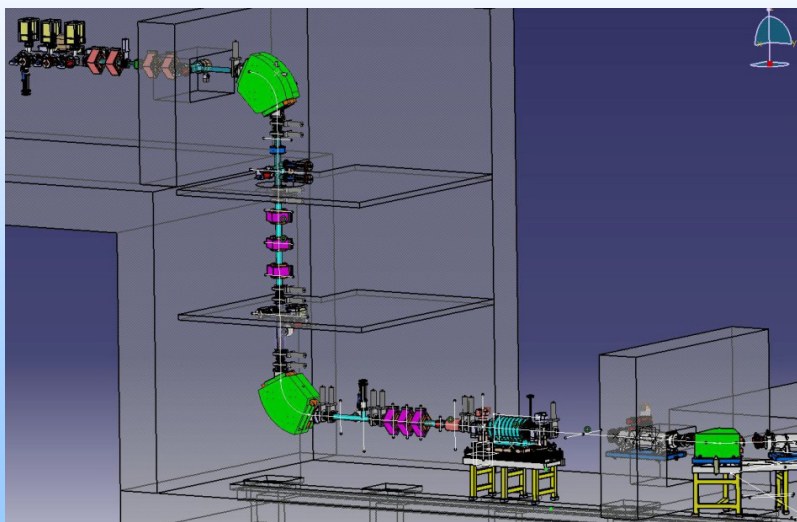
Much less effect on  $1+/n+$  than on normal beams from ECRIS

To conclude something, use the sweep mode, control the TWTA power during the sweep

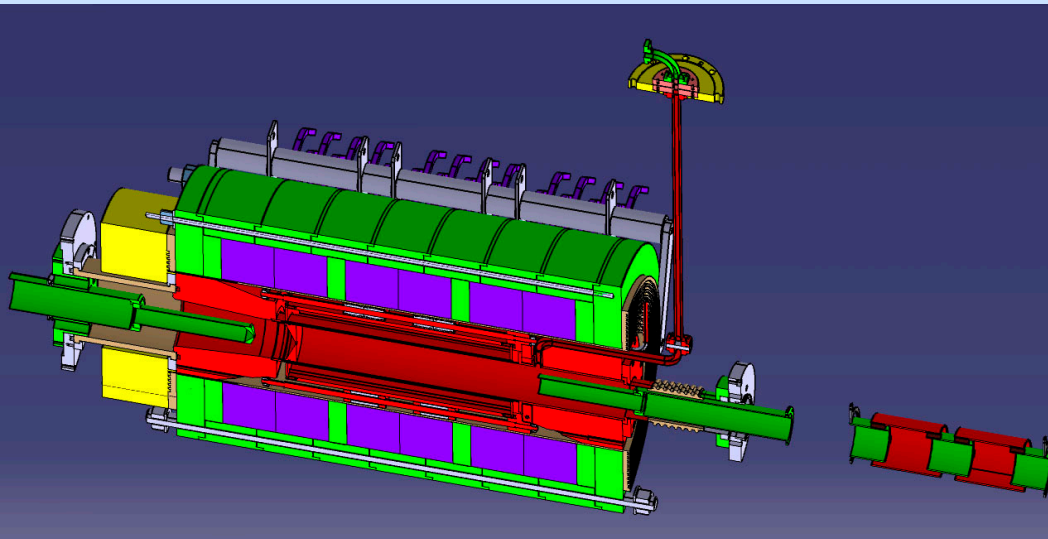
Could be a 'fourth knob' to get the stability but is it really interesting for radioactive charge breeding... ?

Is there the same effect in CAPRICE configurations than in sources with direct HF input ?

## SPIRAL2 Booster nuclearization



Mechanical design must facilitate as much as possible maintenance operations



The deceleration tube is used to bring The 1+ beam into the breeder due to HV configuration and optics.

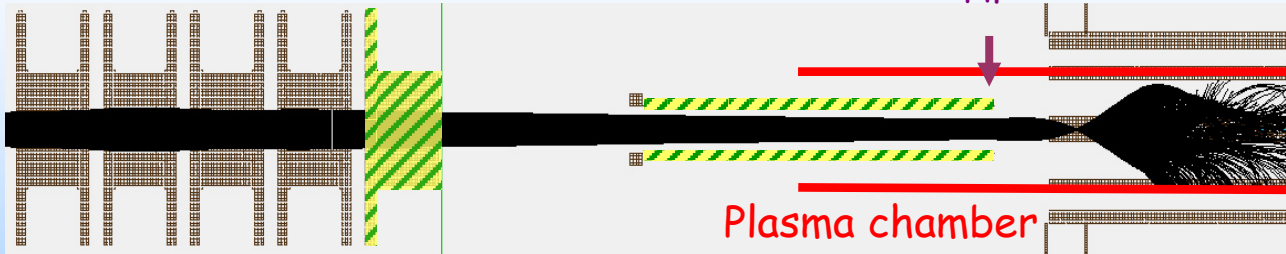
Injection and extraction tubes prevent from easily removing the central core of the CSB

Possible solution: motorized tubes, not easy at injection due to double einzel lens

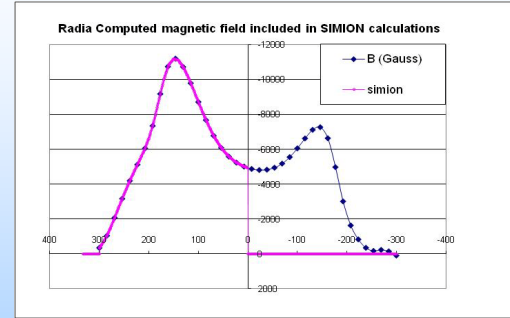
Other solutions ?

# 'Local' Booster R&D

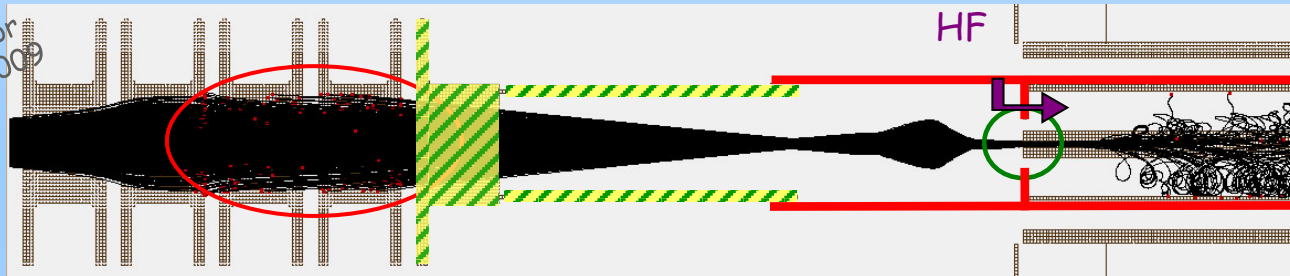
Present configuration



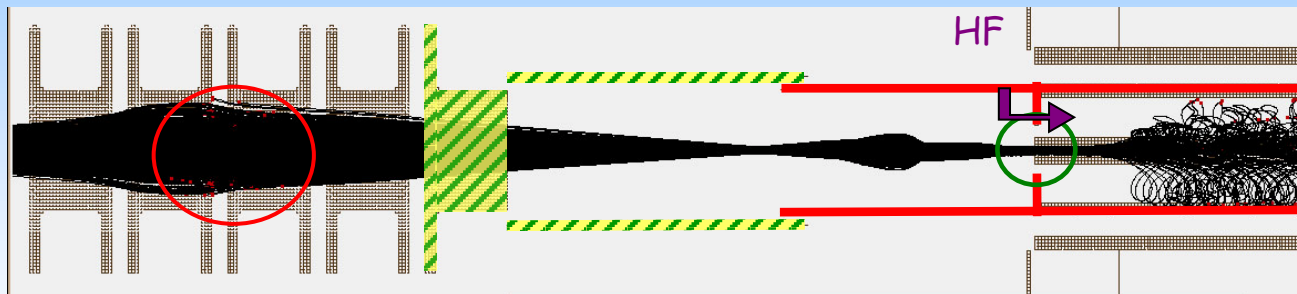
Large diameter grounded tube



Heavy Ion Accelerator  
Technology Venice, 2009



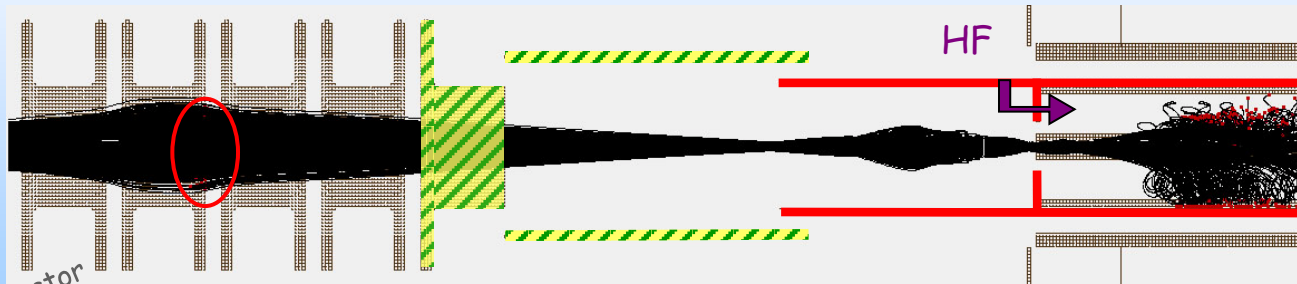
External grounded tube



# 'Local' Booster R&D

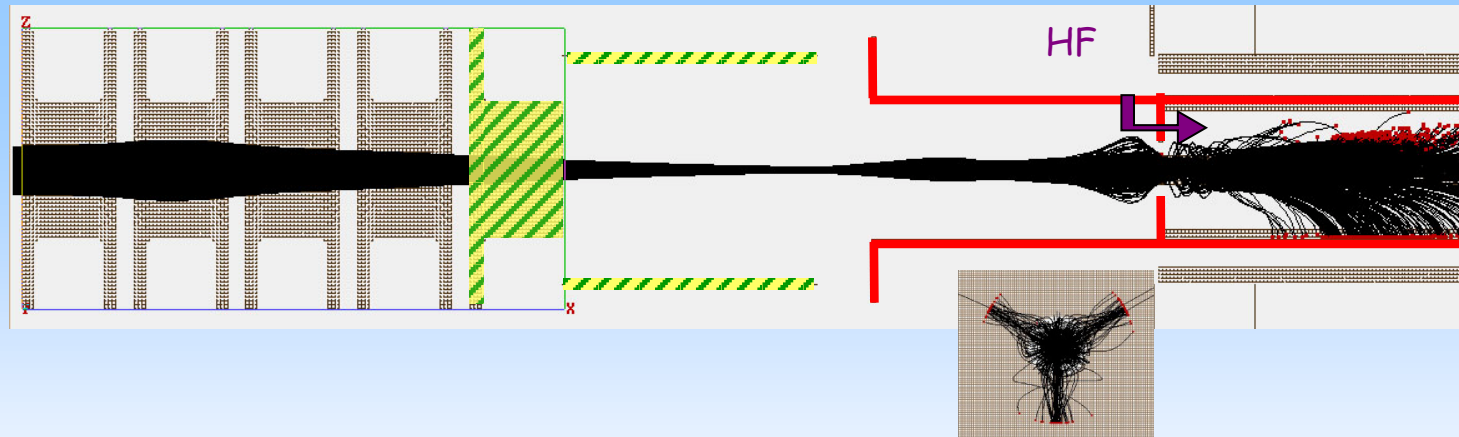
Large diameter external grounded tube

Not easy to implement mechanically



Heavy Ion Accelerator  
Technology Venice, 2009

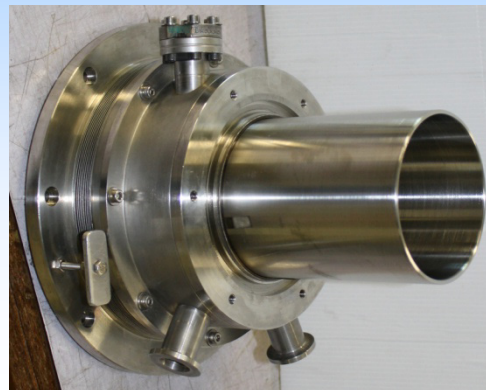
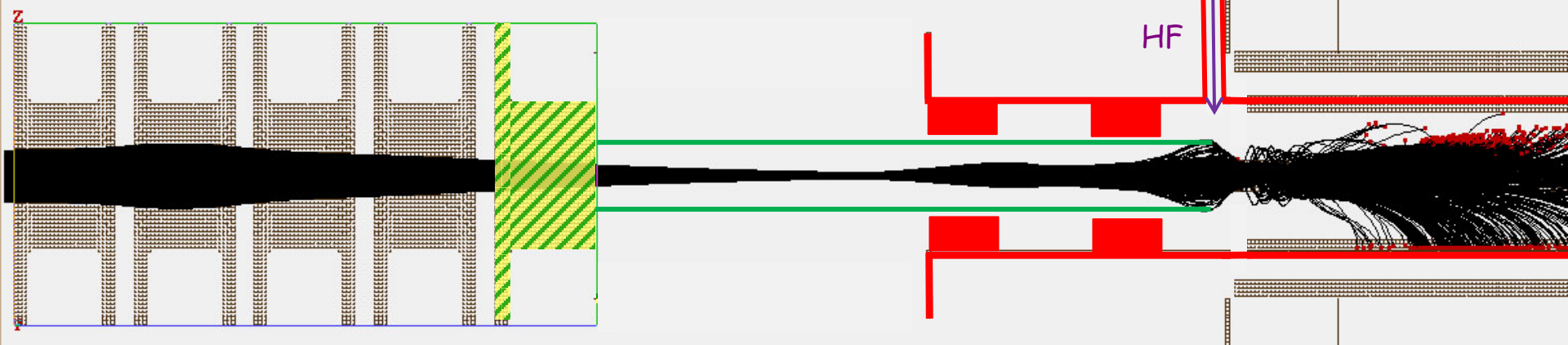
Large diameter and short tube



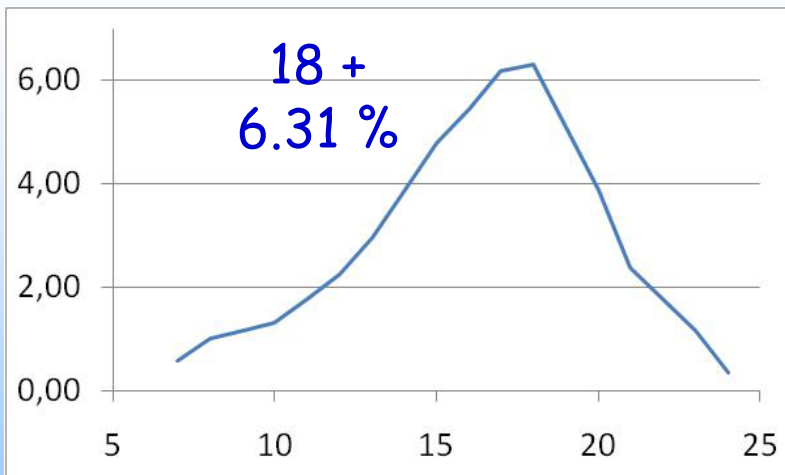
Almost like grounded tube removal

Has to be  
tried

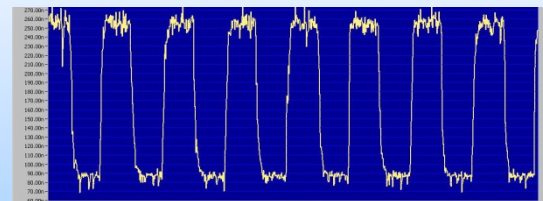
# Grounded tube removal



# A 'normal' open source is a charge breeder

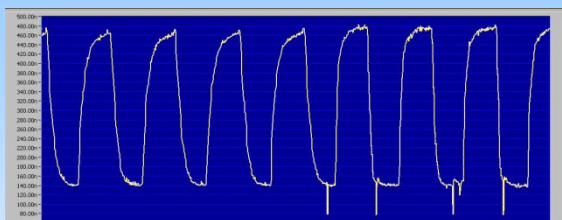


Booster open in the morning  
Result get in the afternoon !



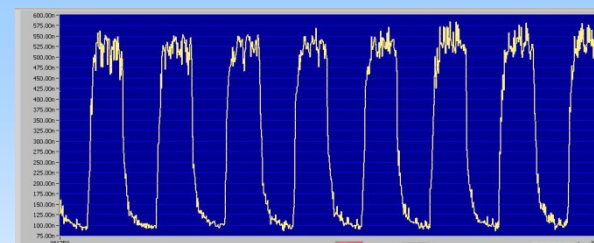
21 +  
2.37 %  
140 ms  
~ 7 ms/q

85 watts ! Drain current  $400 \mu\text{A}$   
Normally (with grounded tube) about 400 W...!  
Easier tuning (looks like an ECRIS)



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

**Mechanics  
(maintenance)  
more simple  
Less  
contaminated parts**



21 + game...  
370 W less gas  
5.01 % 260 ms  
~ 13 ms/q

# 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**  
Low HF power, stability, tuning range greatly increased  
Easier maintenance, less waste  
Has to be urgently checked for metallic ions

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

Thanks for your attention !

Have a nice train trip or hiking this afternoon !

Thank you so much, sincerely,  
for the pleasure you give me  
to have join us here in Grenoble !

We all know there is an extremely exciting  
future in our activities