LNL - GANIL - LPSC COLLABORATION ON THE CONTAMINANTS REDUCTION IN ECR CHARGE BREEDERS

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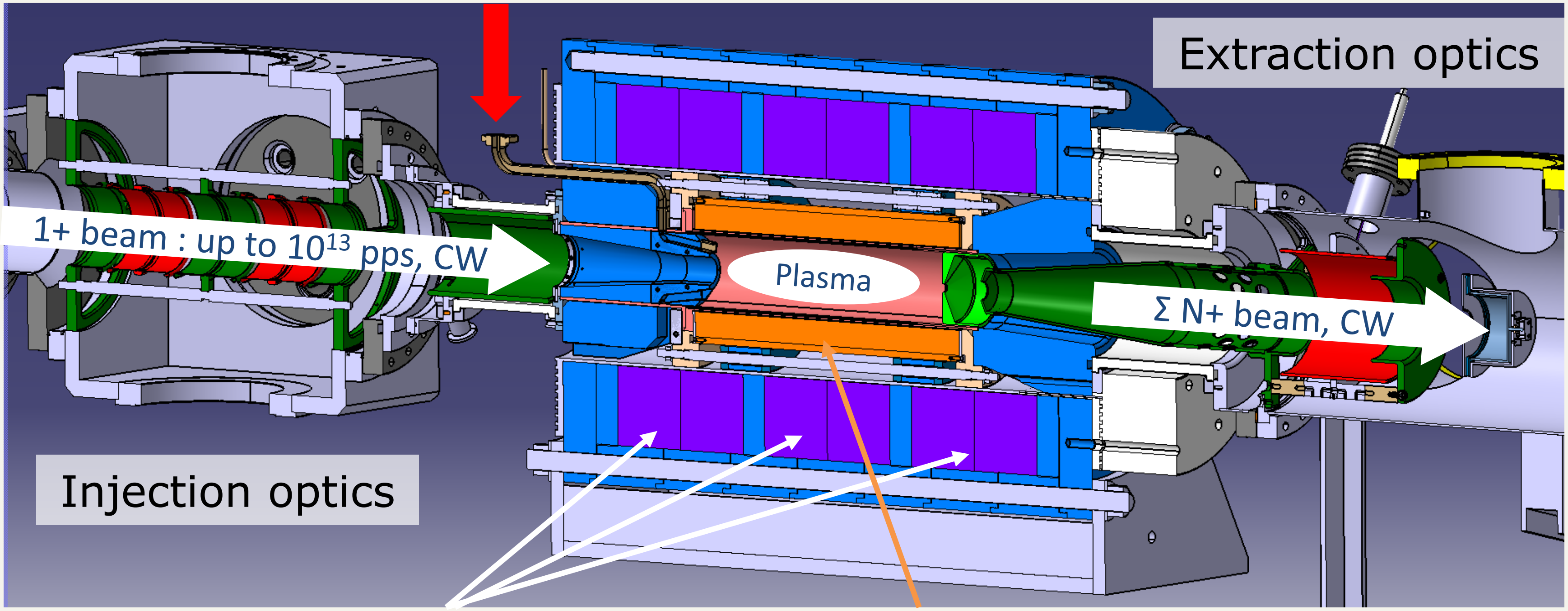
Outline

- Introduction to ECR Charge Breeding
- Contaminants limitations
- Plans for reduction – LNL GANIL LPSC collaboration
- Preliminary experiments
- Conclusion

CB : principle and features

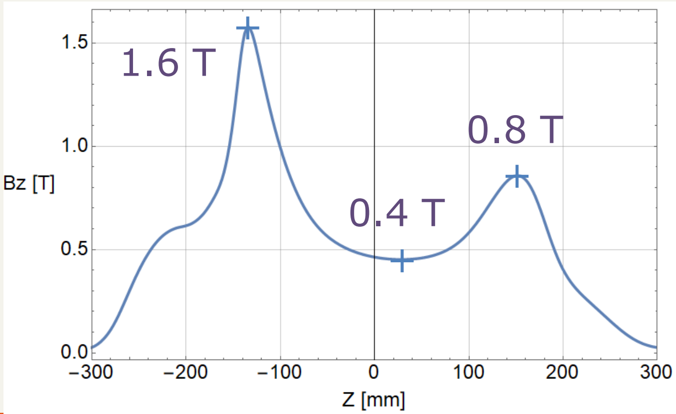
14.5 GHz 600W

PHOENIX Charge breeder



Hexapole : Br 0.8T at plasma chamber wall

Axial field



Total efficiency (low charge states excluded):	50 – 60%
Efficiency / one charge state:	5 - 20%
CB time :	5 – 20 ms/q
Optimum charge state :	A/q~3 up to A=50
	A/q~5 up to A=150

… contamination yield

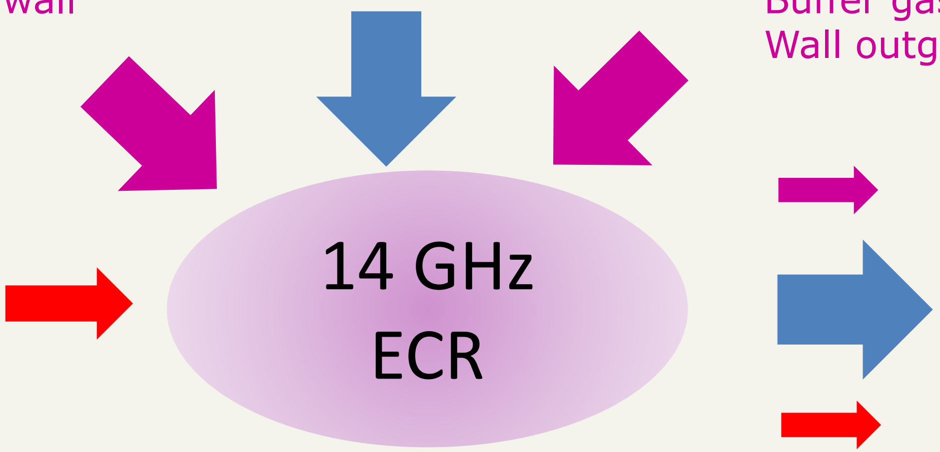
CB : principle and caracteristics

Wall sputtering
$\sim 10^{9} - 10^{10}$ *pps*
Plasma intercepts the wall

Buffer gas
$\sim 10^{16}$ *pps*

Gases contaminants
$\sim 10^{9} - 10^{13}$ *pps*
Leaks, O-rings permeation,
Buffer gas contaminants
Wall outgassing

1+ signal
up to 10^{13} *pps*

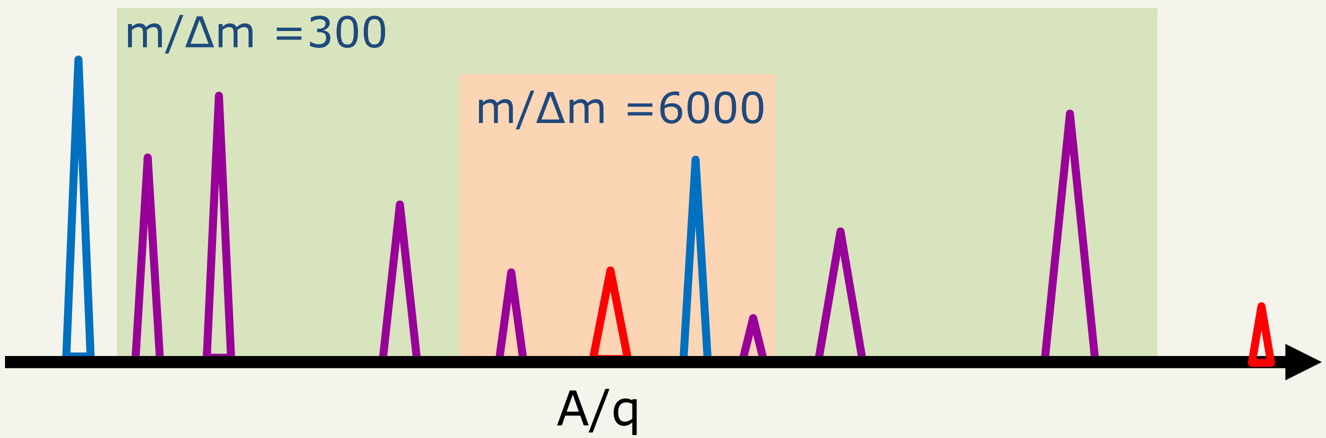


contaminants

Itotal~1 mA
($\sim 10^{15} - 10^{16}$ pps)

N+ signal

Resolving power of downstream separator :



- **Signal** to **noise** ratio is a key parameter for ECRIS CB at low RIB intensity

LNL LPSC GANIL Collaboration

- LNL GANIL and LPSC use PHOENIX charge breeders with close configuration
- Contaminants reduction is a key point for SPES and SPIRAL1 regarding :
  - Production yields (10^2 to 10^{10})
  - Resolving power of downstream separators
  - For the facility tuning (blind tuning)

- LNL LPSC and GANIL decided to collaborate on the contaminants reduction
  - Starting point in 2018 : research collaboration agreement signed between LNL and LPSC

- Work on the reduction of all the contaminants sources

  Taking advantage of the pionneering work done at ANL

  - Vacuum
  - Plasma chamber wall sputtering
  - Gas contaminants

LPSC Charge breeder development plan

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09/2018

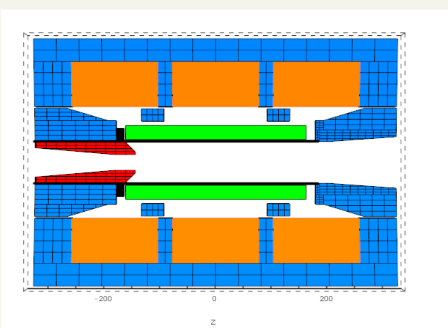
- ✓ Charge Breeder 6 coil config
- ✓ 1+n+ Performances check
- ✓ 1+N+ beam line upgrade
- ✓ Validation experiments
- ✓ Contaminants preliminary experiments

10/2020

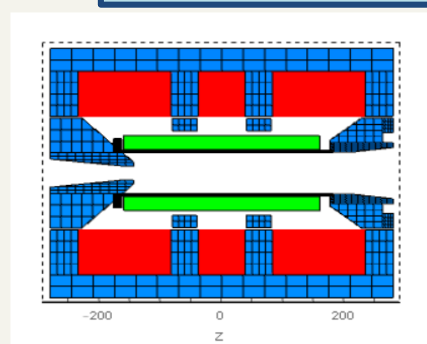
- Charge Breeder 5 coil config
- 1+n+ Performances check
- Contaminants reduction experiments : liners

10/2022

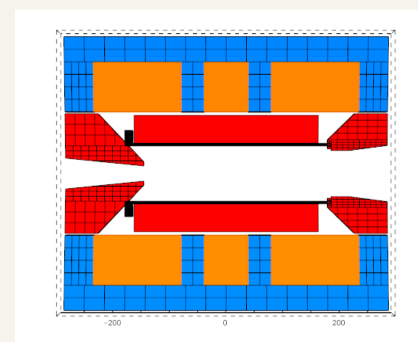
- Charge Breeder Enlarged plasma chamber config
- 1+n+ Performances check
- Contaminants reduction experiments



✓ Configuration developped until now



- Improve axial field profile
- Decrease coils cross talk
- Improve beam injection and extraction



- Improve high charge state production
- Reduce the contaminants proportion

LPSC Charge breeder development plan

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09/2018 — 10/2020 — 10/2022

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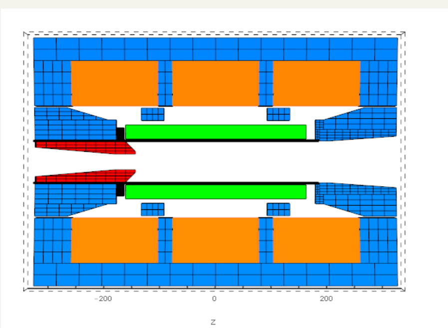

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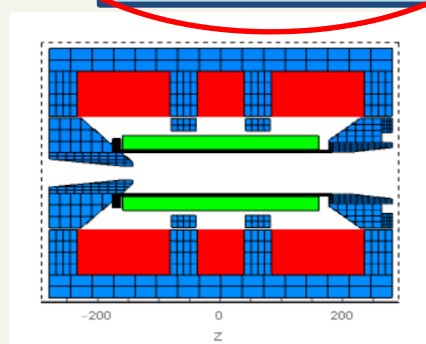

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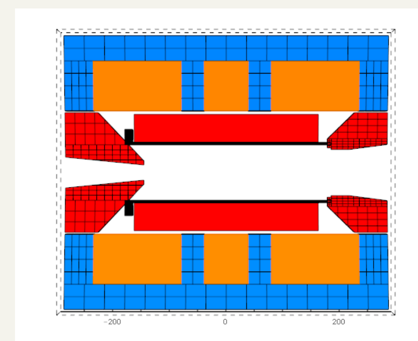

- Improve high charge state production
- Reduce the contaminants proportion

1+N+ Beam line upgrade

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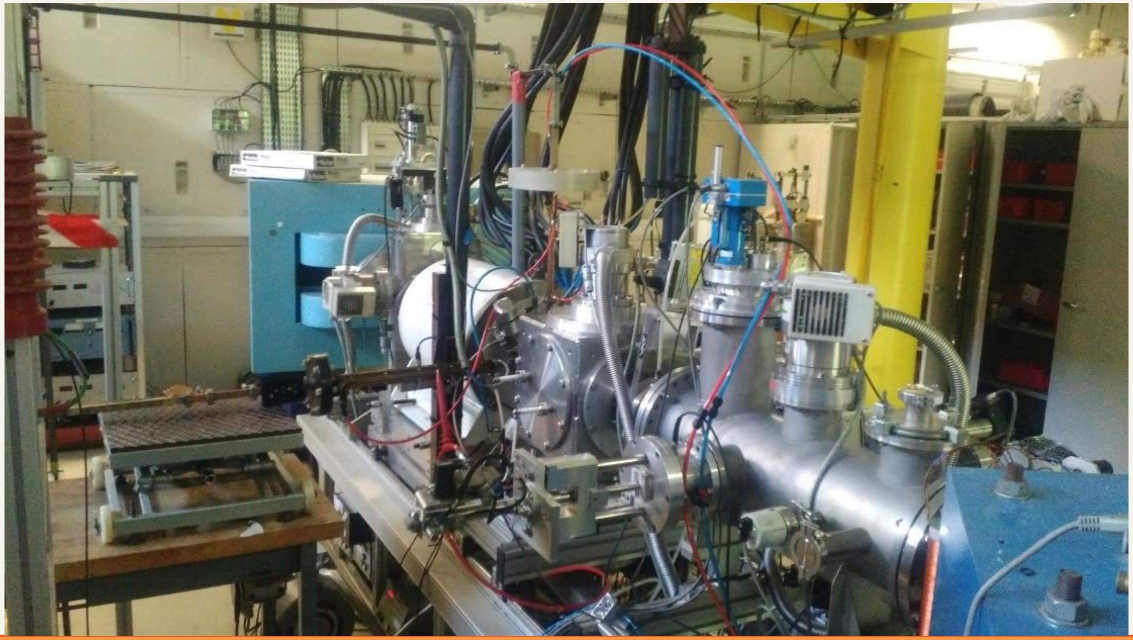
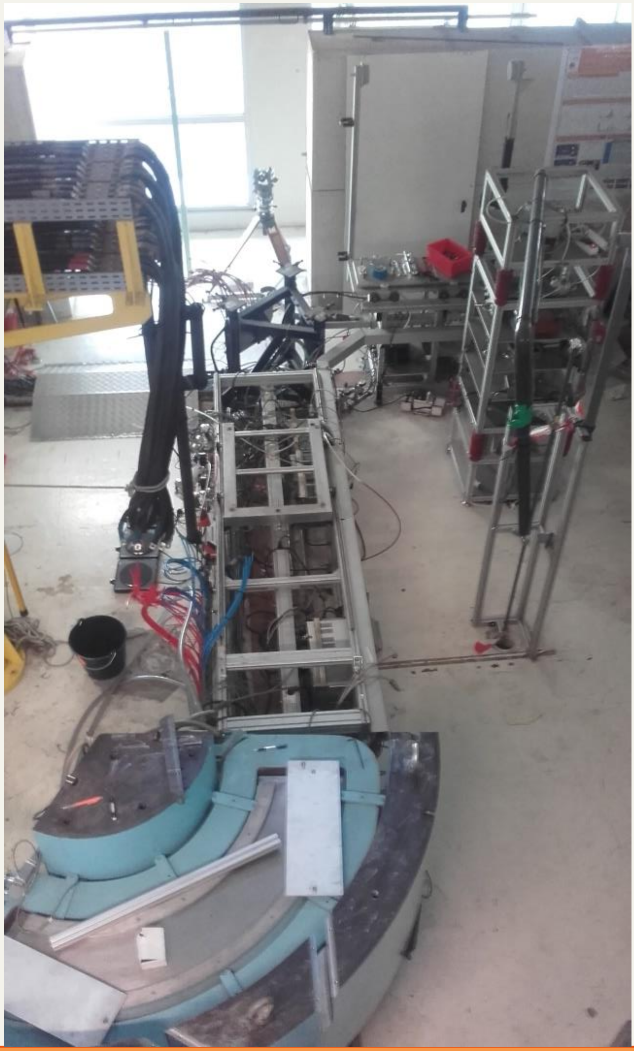
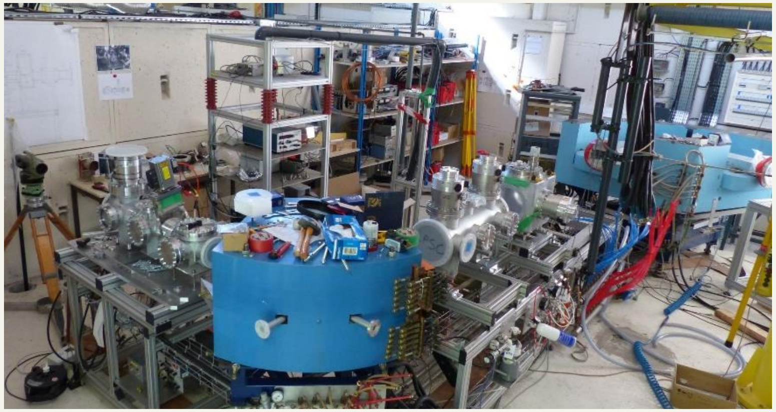
- Goal : improve the vacuum and the devices alignment
- Starting situation : the 1+N+ beam line was assembled in 2002.
  - Pollution with pumping oil vapors
  - Aged pumping system (50 years turbo pumps)
  - Most of sealing by O-rings
  - Alignment was very difficult
- The whole beam line was dismounted

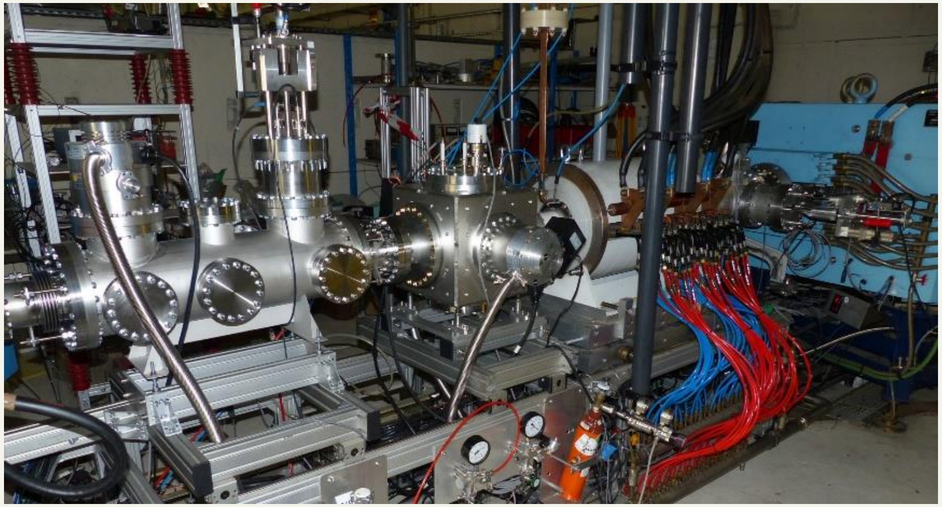




1+N+ Beam line upgrade

- All the vacuum chambers were modified or replaced to be UHV compatible
- Injection and extraction lenses replaced
- Diagnostics were replaced to be UHV
- 1+ and N+ spectrometers modified to grant alignment
- Cleaning
- Assembly
- Alignment



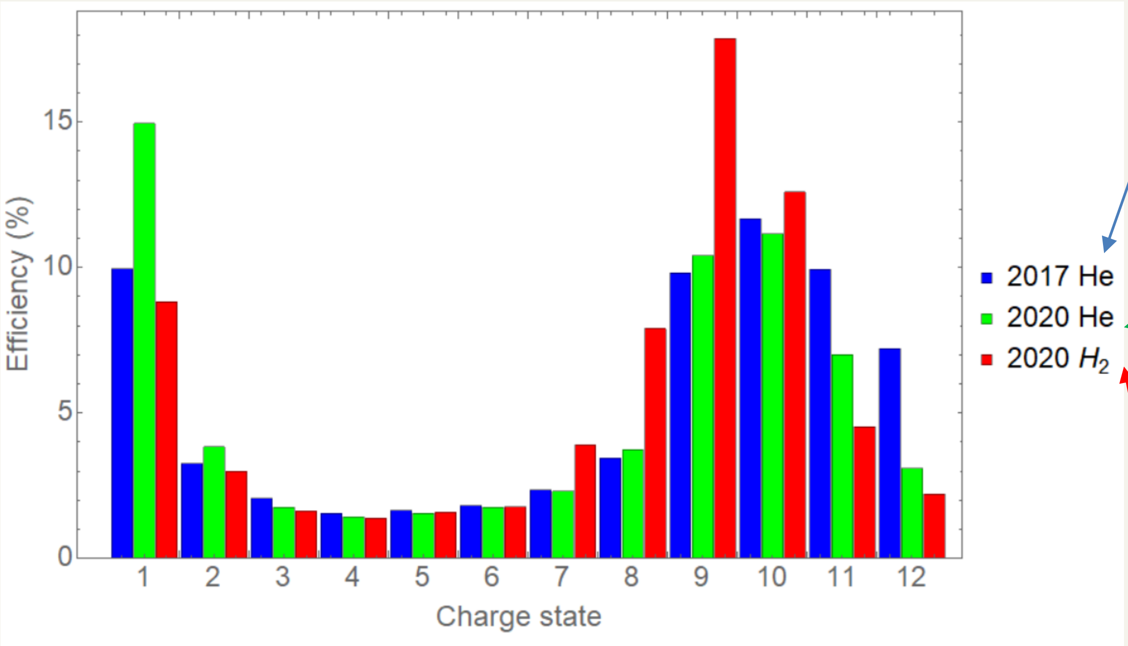


- Set under vacuum :

~5 10^{-7} mbar ➔ ~ 4 10^{-8} mbar dividing by 2 the number of turbo pumps

Validation experiments after upgrade

- Check of the performances with K charge breeding



Bz 1.57/0.44/0.83T Br 0.8T
400W Pinj 4.4 10^{-7} mbar
O^+ 4.8 µA N^+ 1.65µA C^+ 1.52 µA

Bz 1.57/0.45/0.85T Br 0.8T
500W Pinj 9.3 10^{-8} mbar
O^+ 5.1 µA N^+ 2.9µA C^+ 1.15 µA

Bz 1.58/0.45/0.84T Br 0.8T
600W Pinj 1.4 10^{-7} mbar
N^+ 0.3µA C^+ 0.7 µA

- Comparable distribution using He as support gas

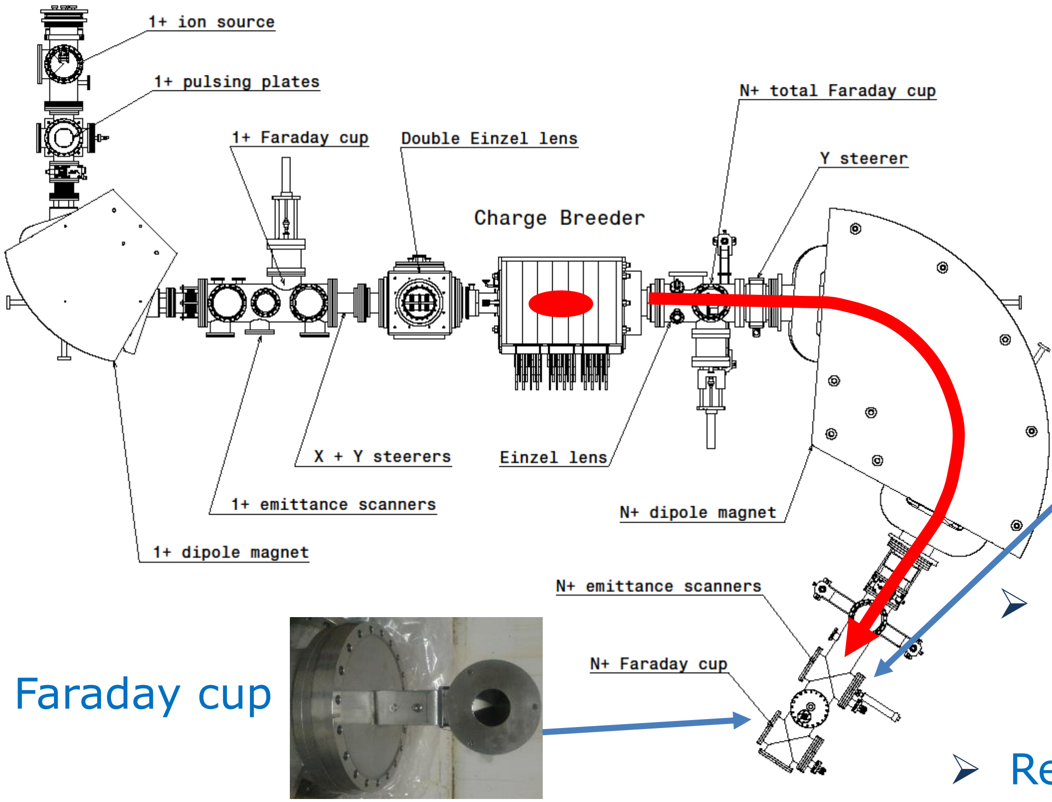
  lower capture and distribution slightly shifted on lower CS now

  ➔ incomplete conditioning ?

- High efficiency (17.9% K^{9+}) obtained with H_2

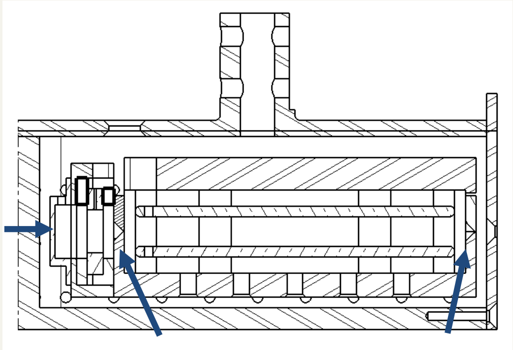
Contaminants preliminary experiments

- Technique to measure the contaminants spectrum



Faraday cup

Allison type emittance scanner

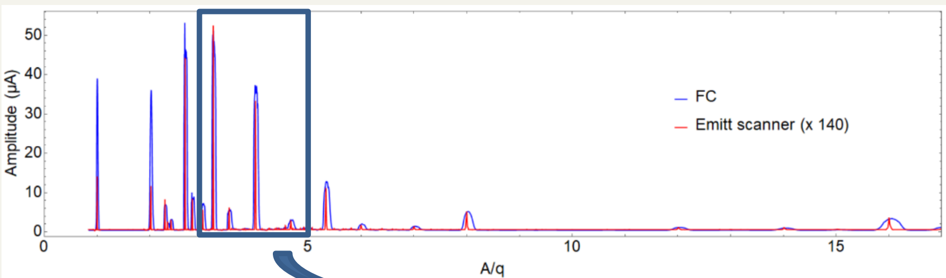


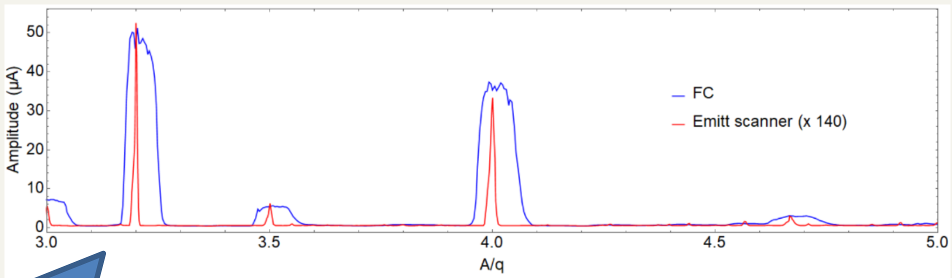
Selection with 0.2 mm slits

- Provides higher resolution spectrum

  … cutting the beams

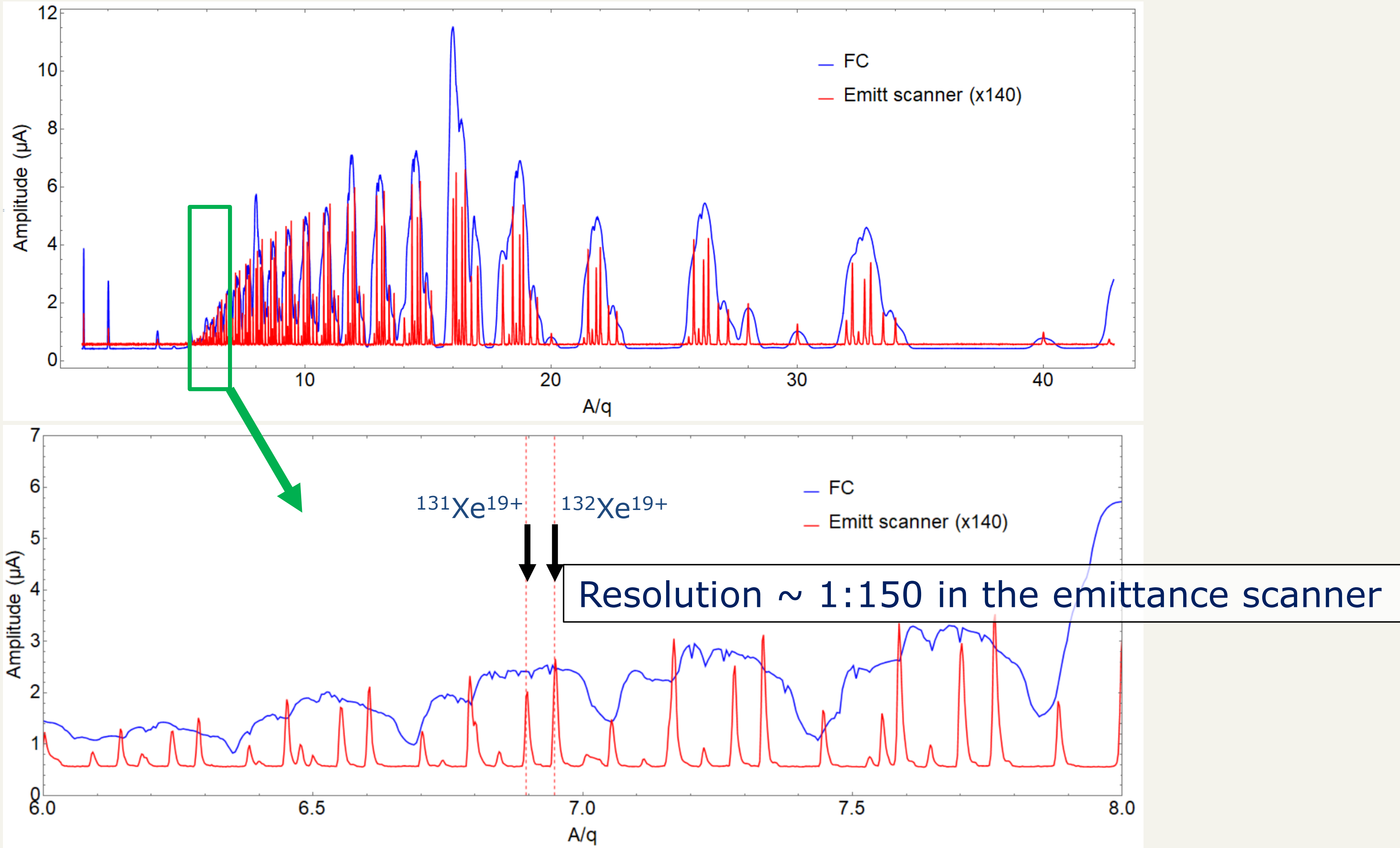
- Relative measurements comparison





Contaminants preliminary experiments

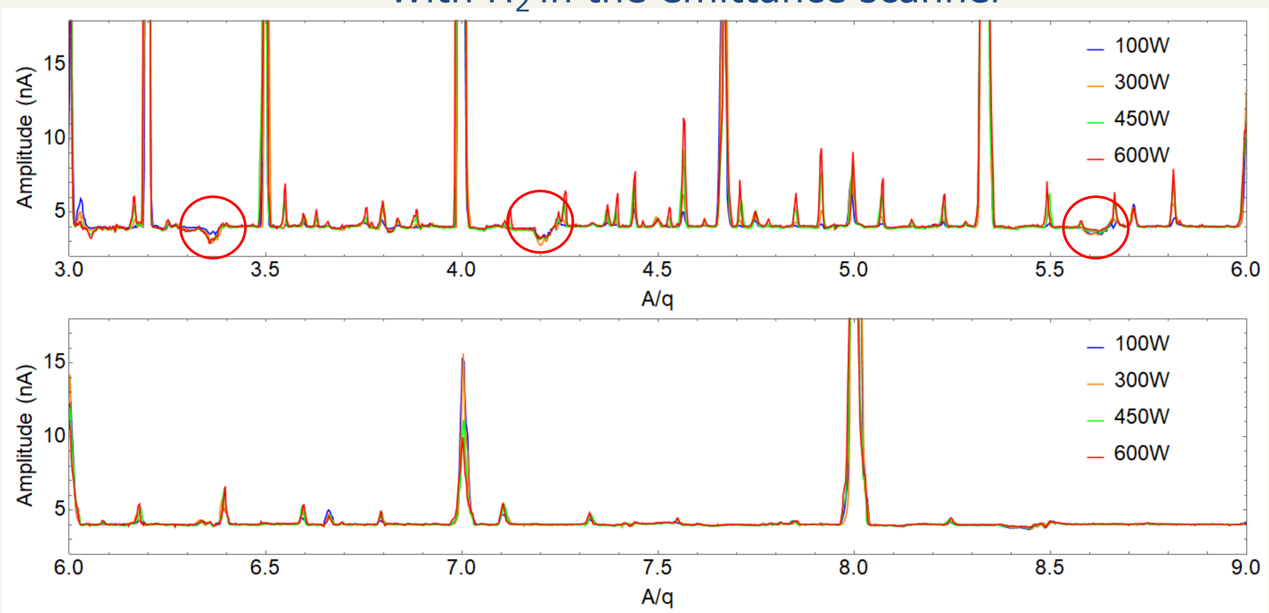
- Resolution estimate in the emittance scanner with Xe plasma



Contaminants preliminary experiments

- This technique was used to make comparative measurements :
  - With several support gas (effect of the support gas mass) : H_2 He N_2 O_2
  - At several CB microwave power 100, 300, 450, 600W
- The CB was tuned (Axial B field and support gas dosing) to maximize the 1+N+ K10+ efficiency, at 600W, with each support gas
- Record of the spectrums in the FC and in the emittance scanner at each microwave power

With H_2 in the emittance scanner



- Able to measure peaks down to 100 pA
- Dips in the spectrum
- A/q list of all the contaminant peaks

Contaminants preliminary experiments

- Present configuration of the plasma chamber

Injection plug: Fe with Ni and Ag plating

Extraction electrode : 2017A (Al, Cu, Mg…)

Waveguide : Brass (Cu, Zn, Pb, Sn …)

Plasma chamber : 304L SS (Fe, Cr, Ni, Mn, Si, N, P…)

- Gas contaminants (CANgas® MESSER)

  - H_2 99.999% (H_2O<5ppm, O_2<1ppm, N_2<5ppm, Hydrocarbon <0.1ppm, CO +CO_2<0.1ppm)
  - He 99.999% (H_2O<20ppm, O_2< 1 ppm, N_2 < 4 ppm, Hydrocarbon < 0.2 p
  - N_2 99.999% (H_2O<3ppm, O_2<2ppm, Hydrocarbon <0.1ppm)
  - O_2 99.999% (H_2O<2ppm, N_2<20ppm, Hydrocarbon <0.2ppm, CO+CO_2<0.4ppm)

- list of all the contaminants including isotopes
- Comparison with the spectrum peaks list

Contaminants preliminary experiments

contaminants A/q peak value

List of most probable isotopes

contaminants A/q peak value	List of most probable isotopes
3.	$^{15}N^{5}$ $^{18}O^{6}$ $^{24}Mg^{8}$ $^{30}Si^{10}$ $^{33}S^{11}$ $^{36}Ar^{12}$ $^{39}K^{13}$ $^{51}V^{17}$ $^{54}Cr^{18}$ $^{54}Fe^{18}$ $^{57}Fe^{19}$ $^{60}Ni^{20}$ $^{63}Cu^{21}$ $^{66}Zn^{22}$ $^{78}Kr^{26}$ $^{84}Kr^{28}$ $^{96}Mo^{32}$
3.0277	$^{94}Mo^{31}$ $^{97}Mo^{32}$
3.1658	$^{19}F^{6}$ $^{57}Fe^{18}$ $^{95}Mo^{30}$ $^{98}Mo^{31}$
3.2531	$^{39}K^{12}$ $^{65}Cu^{20}$ $^{78}Kr^{24}$ $^{114}Sn^{35}$
3.4012	$^{34}S^{10}$ $^{51}V^{15}$ $^{68}Zn^{20}$ $^{85}Rb^{25}$ $^{119}Sn^{35}$
3.5502	$^{39}K^{11}$ $^{78}Kr^{22}$ $^{117}Sn^{33}$
3.5966	$^{18}O^{5}$ $^{36}Ar^{10}$ $^{54}Cr^{15}$ $^{54}Fe^{15}$ $^{97}Mo^{27}$ $^{115}Sn^{32}$ $^{126}Xe^{35}$
3.6302	$^{98}Mo^{27}$ $^{109}Ag^{30}$
3.6584	$^{95}Mo^{26}$ $^{117}Sn^{32}$ $^{128}Xe^{35}$
3.6947	$^{85}Rb^{23}$ $^{96}Mo^{26}$ $^{122}Sn^{33}$
3.7556	$^{94}Mo^{25}$ $^{109}Ag^{29}$ $^{124}Sn^{33}$
3.7711	$^{83}Kr^{22}$ $^{98}Mo^{26}$ $^{117}Sn^{31}$ $^{132}Xe^{35}$
3.7983	$^{19}F^{5}$ $^{57}Fe^{15}$ $^{95}Mo^{25}$ $^{114}Sn^{30}$ $^{129}Xe^{34}$ $^{133}Cs^{35}$
3.8374	$^{92}Mo^{24}$ $^{96}Mo^{25}$ $^{115}Sn^{30}$ $^{119}Sn^{31}$
3.8828	$^{66}Zn^{17}$ $^{97}Mo^{25}$ $^{128}Xe^{33}$ $^{132}Xe^{34}$
3.921	$^{51}V^{13}$ $^{94}Mo^{24}$ $^{98}Mo^{25}$
4.	$^{20}Ne^{5}$ $^{24}Mg^{6}$ $^{32}S^{8}$ $^{36}Ar^{9}$ $^{40}Ar^{10}$ $^{56}Fe^{14}$ $^{60}Ni^{15}$ $^{64}Ni^{16}$ $^{68}Zn^{17}$ $^{80}Kr^{20}$ $^{84}Kr^{21}$ $^{92}Mo^{23}$ $^{96}Mo^{24}$ $^{112}Sn^{28}$ $^{120}Sn^{30}$ $^{124}Sn^{31}$ $^{128}Xe^{32}$ $^{132}Xe^{33}$
4.1091	$^{37}Cl^{9}$ $^{78}Kr^{19}$ $^{115}Sn^{28}$
4.1227	$^{33}S^{8}$ $^{66}Zn^{16}$ $^{132}Xe^{32}$
4.2458	$^{34}S^{8}$ $^{51}V^{12}$ $^{68}Zn^{16}$ $^{85}Rb^{20}$ $^{119}Sn^{28}$
4.2622	$^{64}Ni^{15}$ $^{98}Mo^{23}$ $^{115}Sn^{27}$ $^{128}Xe^{30}$ $^{132}Xe^{31}$
4.3331	$^{39}K^{9}$ $^{65}Cu^{15}$ $^{78}Kr^{18}$ $^{117}Sn^{27}$ $^{130}Xe^{30}$
4.3712	$^{35}Cl^{8}$ $^{83}Kr^{19}$ $^{118}Sn^{27}$ $^{131}Xe^{30}$
4.3949	
4.4385	
4.4612	$^{107}Ag^{24}$
4.4966	^{18}O[illegible] $^{36}Ar^{8}$ $^{54}Cr^{12}$ $^{54}Fe^{12}$ $^{63}Cu^{14}$ $^{117}Sn^{26}$ $^{126}Xe^{28}$
4.528	$^{95}Mo^{21}$
4.5648	$^{114}Sn^{25}$
4.6184	$^{60}Ni^{13}$ $^{97}Mo^{21}$ $^{120}Sn^{26}$ $^{134}Xe^{29}$
4.6684	$^{56}Fe^{12}$ $^{84}Kr^{18}$ $^{98}Mo^{21}$ $^{112}Sn^{24}$ $^{126}Xe^{27}$
4.7102	$^{33}S^{7}$ $^{66}Zn^{14}$ $^{80}Kr^{17}$ $^{132}Xe^{28}$
4.7474	$^{19}F^{4}$ $^{57}Fe^{12}$ $^{95}Mo^{20}$ $^{114}Sn^{24}$ $^{133}Cs^{28}$
4.7802	$^{129}Xe^{27}$
4.851	$^{63}Cu^{13}$ $^{97}Mo^{20}$ $^{126}Xe^{26}$ $^{131}Xe^{27}$
4.9156	$^{118}Sn^{24}$

- Support Gas : H_2
- Metallic ions coming from the material sputtering (Mo, Sn, Fe, Cu, Mg, Ag)
- Gaseous elements (support gas contamination, vacuum, previous experiments)
- Some peaks corresponding to only one isotope
- The same was done with He, N_2 and O_2

Contaminants preliminary experiments

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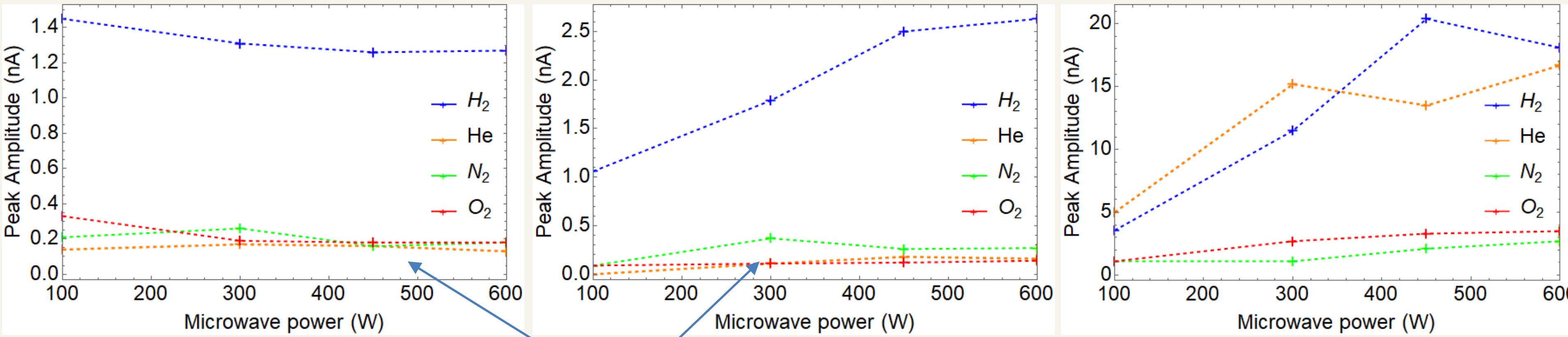
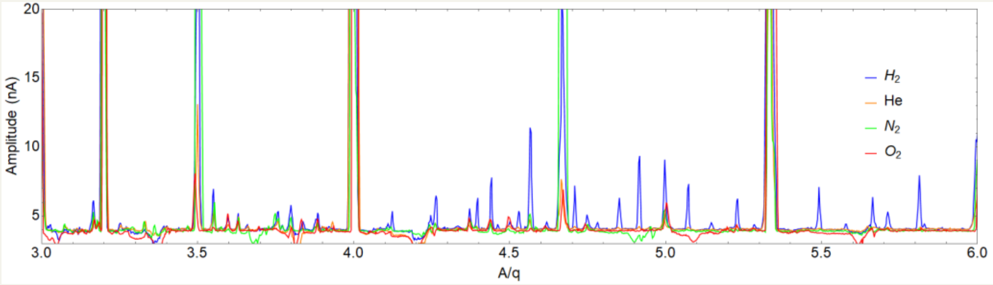
- Amplitude evolution of peaks

$^{40}Ar^{7+}$ $^{96}Mo^{15+}$ $^{12}C^{5+}$



Very low signal / noise

- H_2 gives higher contamination (it is the best support gas for low mass species charge breeding…)
- This is true for most of other peaks



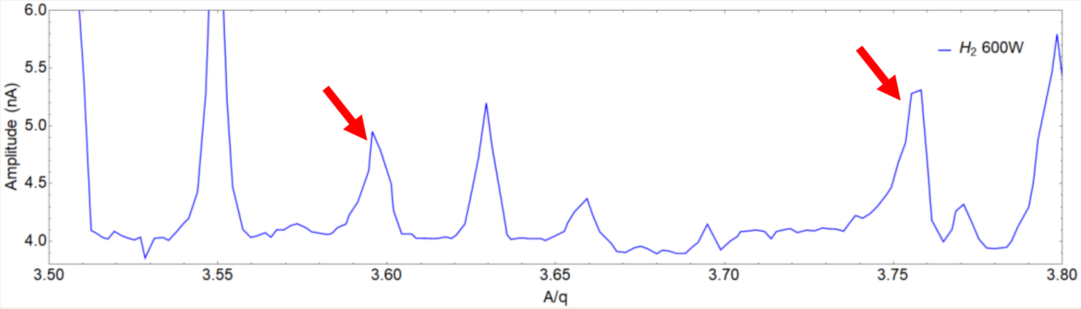
- Dependency with RF power : clear increase for $^{96}Mo^{15+}$ and $^{12}C^{5+}$, slight decrease for Ar^{7+} due to a shift to higher charge state ?

Contaminants preliminary experiments

- Amplitude
  - The lower measurable amplitude is ~ 100pA with the emittance scanner, corresponding to ~2 10^{10} pps in the N+ FC.
  - As a comparison a 10^8 pps RIB flux at the CB entrance would give:

    10^8 x 10% (CB efficiency) ~ 10^7 pps
  - This technique doesn't allow to measure low intensity contaminant beams
  - Need of a different detector
  - A lot of contaminants are identified, with very high flux

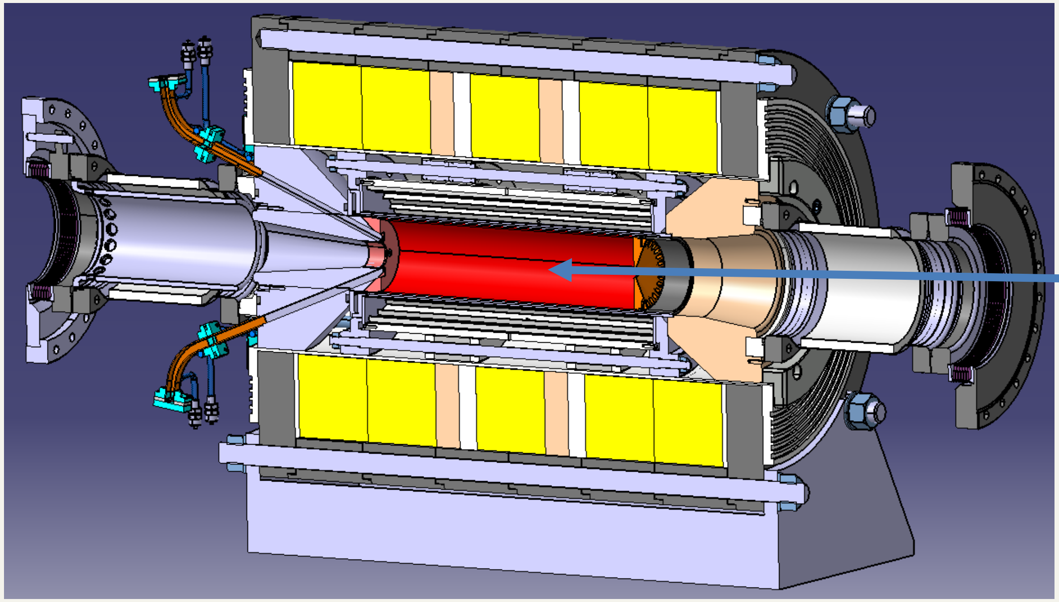
- A/q minimum step limitation :
  - Resolution limitation of the data acquisition output, to be improved

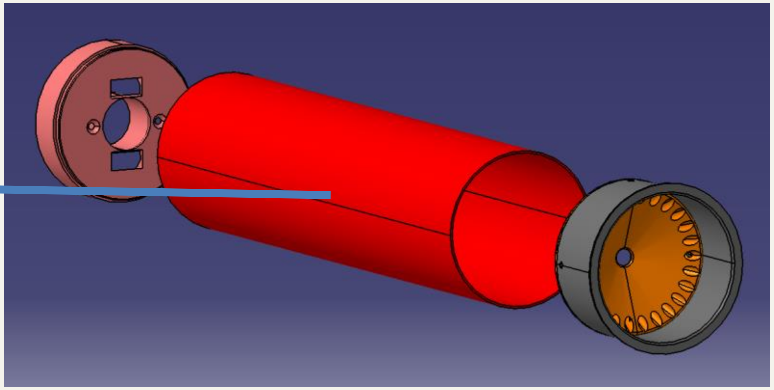


- Dips present in the spectrum
  - Due to secondary electrons emission
  - Shielding of the emittance scanner will be tested

Contaminants reduction : liners

- Design to cover all the surfaces in front of the plasma

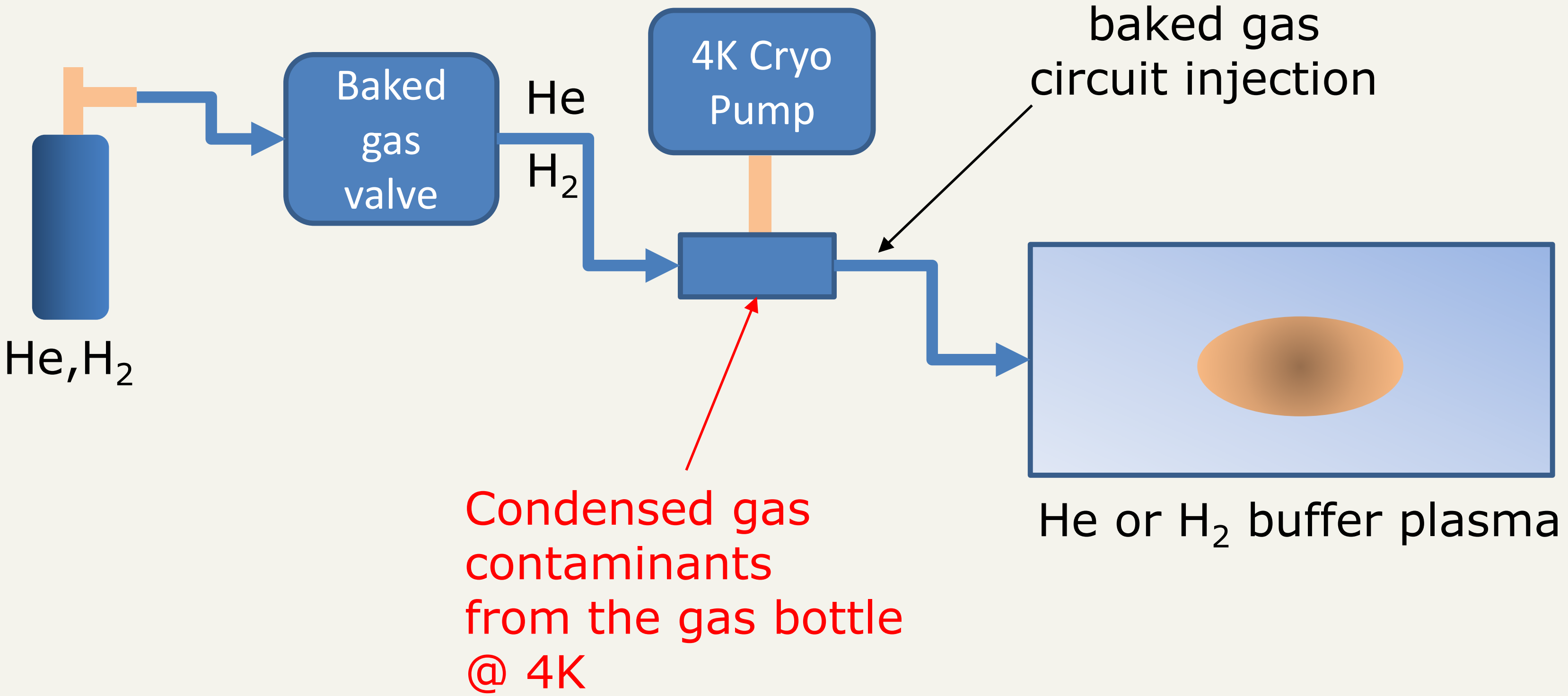




- Comparative experiments using several material :
  - Niobium
  - Tantalum
  - Al_2O_3 layer on pure Aluminum liner – collaboration with NIPNE

Contaminants reduction : gas

- Follow ANL steps to get rid of gas contamination
- Use He or H_2 as support gas



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Conclusion

- Upgrade of the 1+N+ beam line is finished, reduction of the residual pressure by a decade
- Preliminary contaminants reduction experiments showed limitations in the measurement technique, to be improved
- The R&D program on the charge breeder will go on to continue improving the performances…
- …with a great part dedicated to contaminants reduction

THANK YOU FOR YOUR ATTENTION

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LNL
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

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