

FUSION



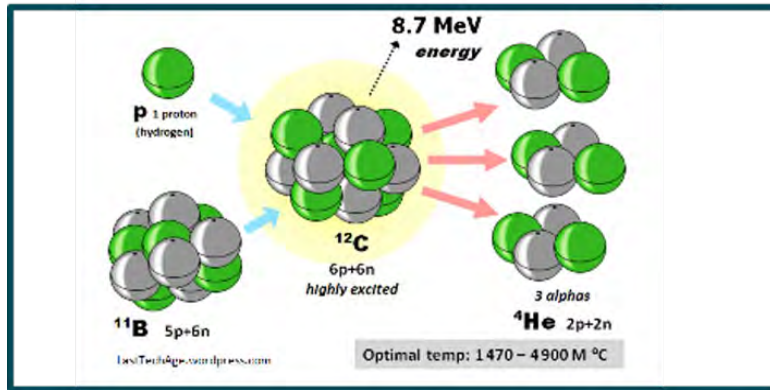
FUSion Studies of prOton boron Neutronless reaction in laser-generated plasma

Durata dell'esperimento: 2023-2025

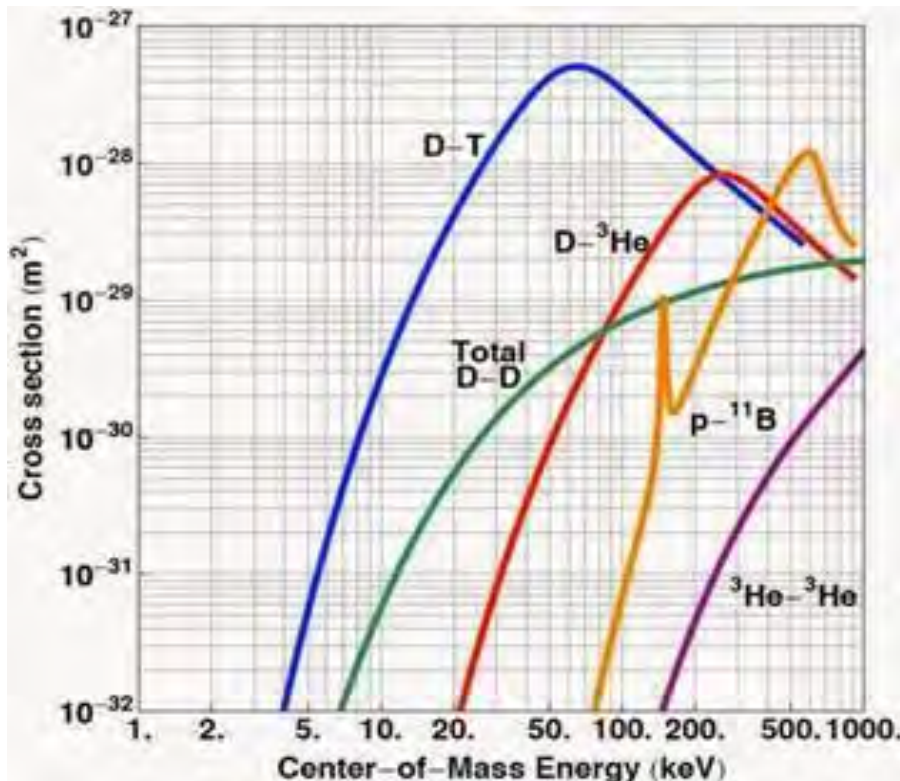
Partecipanti: **INFN-LNS**, **ENEA**, LNGS, MI, RM2, TO, FI, Bologna (F.Odorici 0.2, L. Malferrari 0.2)

PREMESSA: lo studio della reazione di fusione p-11B che produce 3 particelle alfa energetiche è molto interessante poichè coinvolge isotopi stabili ed abbondanti (i reagenti) e non vi sono neutroni nei prodotti della reazione

Fusione a Confinamento Inerziale: perchè la p-11B è di interesse?



- E' una reazione di fusione **che non genera neutroni**
- Due risonanze a circa **100 keV** and **600 keV** nel centro di massa
- E' considerata un **potenziale candidato** per schemi futuri di FCI, sia in modalità ibrida con DT che per potenziali reattori a p-¹¹B con schemi avanzati
- I reagenti **sono tra i più abbondanti in natura** rispetto ad altri reagenti adottati in analoghe reazioni (e anche più facilmente maneggiabili, rispetto al trizio, per esempio) e **non sono radioattivi**;
- E' una reazione di interesse nei processi **astrofisici**;
- E' di interesse per la realizzazione di **sorgenti α**



OVVIAMENTE QUESTA REAZIONE DEVE ESSERE STUDIATA IN UN PLASMA GENERATO DA UN LASER

S Atzeni, J Meyer-Ter-Vehn, <<Inertial Fusion>>, Oxford Science Publications (2004)

Obiettivi del progetto FUSION

FUSION **non vuole** realizzare un prototipo di reattore a fusione inerziale né produrre o misurare energia

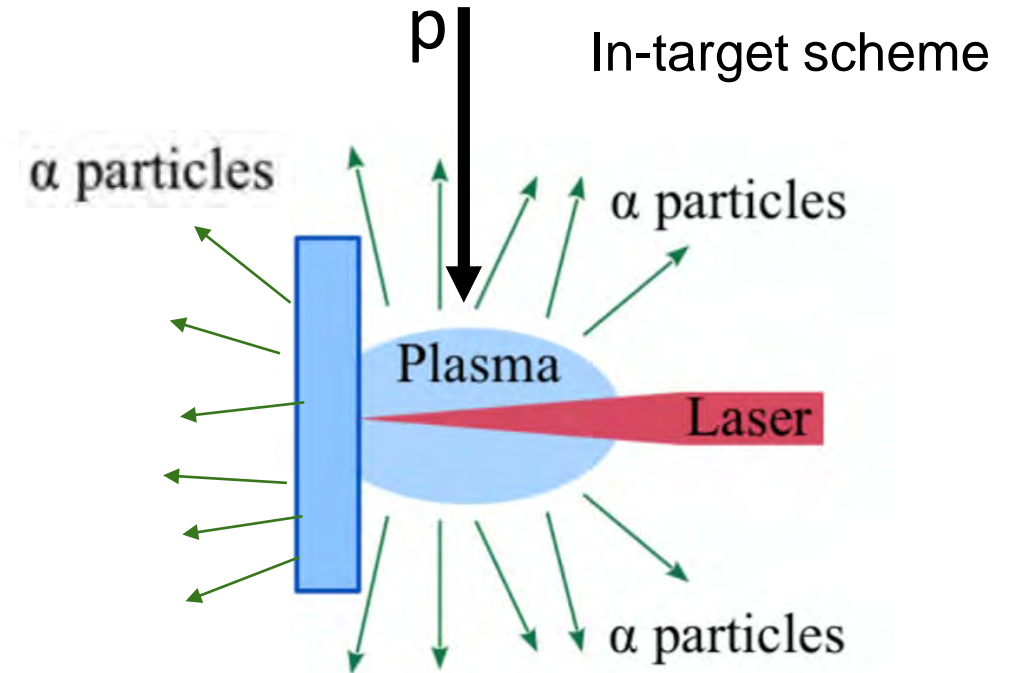
FUSION vuole

- **comprendere al meglio la reazione $p-^{11}B$** in un plasma generato da laser tipico di Fusione a Confinamento Inerziale (**ion stopping power,...**)
- **ottimizzarne le condizioni al fine di avere la massima efficienza**
 - percorso:
 - nuovi targets
 - nuovi approcci sperimentali
 - diagnostiche più performanti

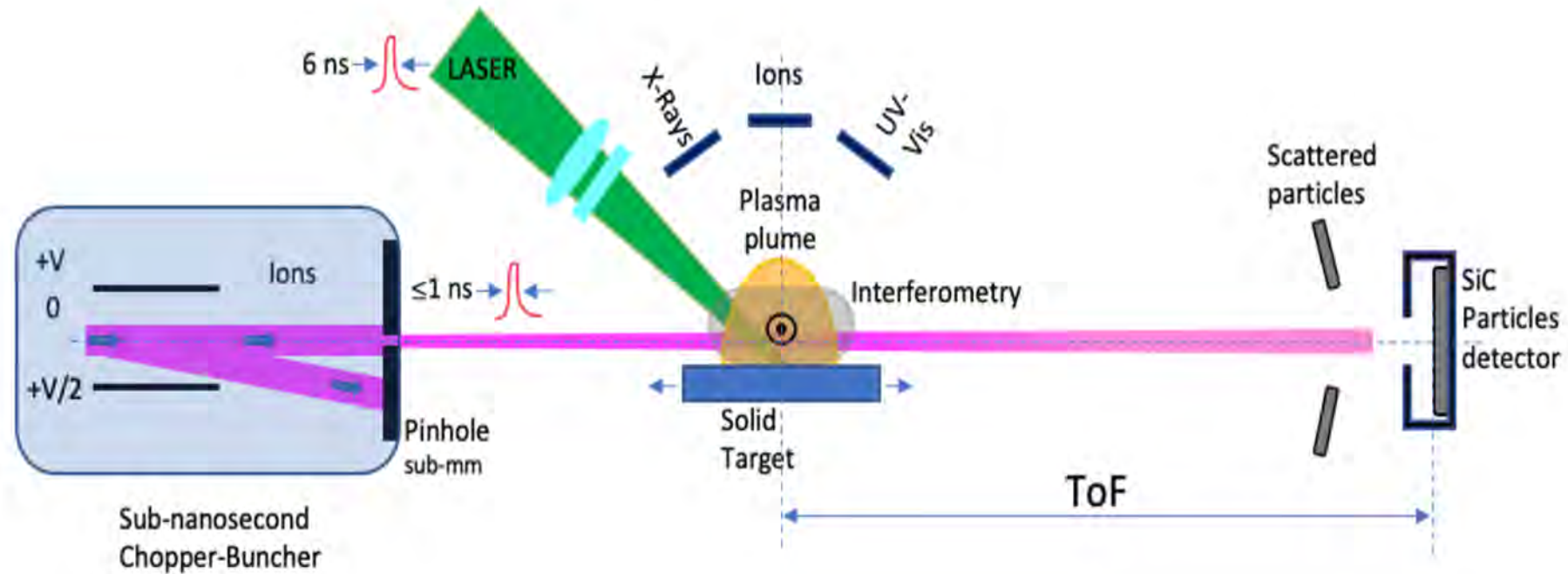
Ricadute e impatto di FUSION

- possibile futuro impiego in un reattore a fusione $p-^{11}B$ o in cui $p-^{11}B$ è parte del bersaglio insieme a DT
- avanzamento conoscenze di astrofisica
- sorgenti alpha localizzate ad alta brillantezza

Schema di una reazione $p-^{11}B$ attivata in un plasma generato da laser



Bologna è coinvolta nel **WorkPackage 2**: misura di perdita di energia di protoni e alfa in plasma; impegno nello sviluppo del setup e analisi dati



1. Si producono e caratterizzano dei targets contenenti Boro che poi vengono colpiti da un laser (2J, 6ns, 1064 nm) cosicché da produrre un plasma
2. Bunch di protoni (<1MeV) e alfa verranno sincronizzati con il plasma generato
3. Le diagnostiche permetteranno, ad ogni sparo laser, di caratterizzare il plasma
4. **Verrà misurata la perdita di energia degli ioni nel plasma vs densità e temperatura del plasma stesso**

Status dell'esperimento

- Acquistate gran parte delle attrezzature per il setup sperimentale
- **Bologna:**
 - studio della movimentazione del target;
 - gestione del distanzimetro per il controllo della focalizzazione del fascio laser.
- Allestimento del setup sperimentale (presso DIFA-UniCT e LNS) nel corso del 2024 e presa dati nel corso del 2025

Esperimento IONS

Studio di una camera al plasma «attiva» per sorgenti ioniche/apparati di tipo ECR:

- realizzazione di un prototipo per «AlSHa» – sorgente di ioni ECR @ LNS
- prossima applicazione (scaling x3) su esp. PANDORA – apparato a confinamento di plasma ECR @ LNS

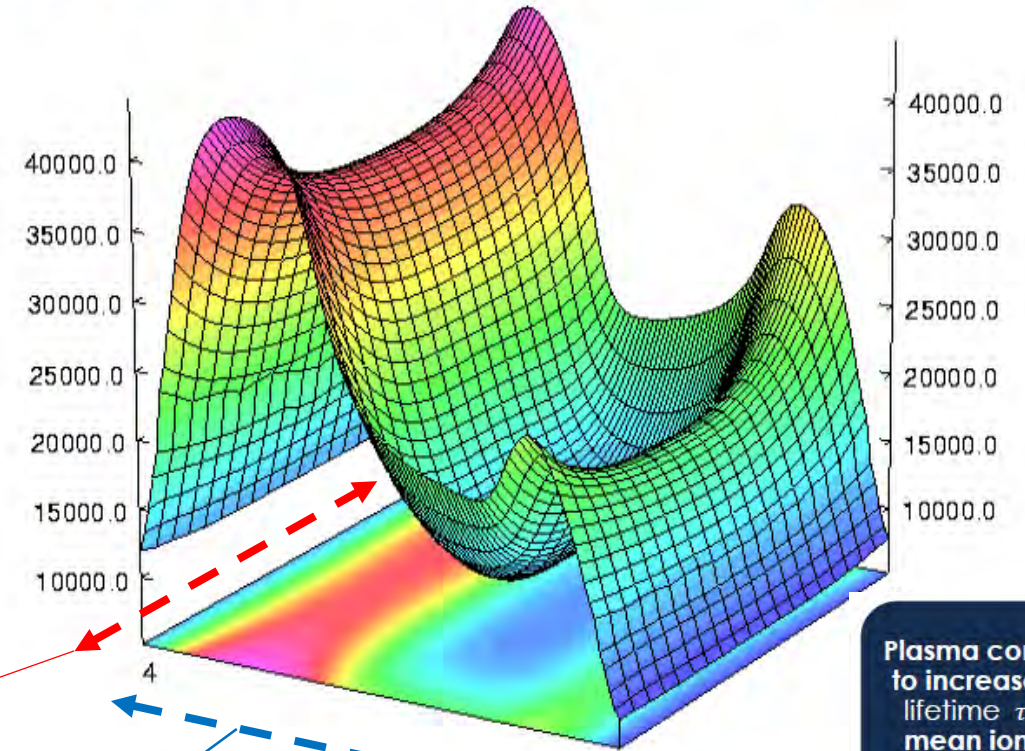
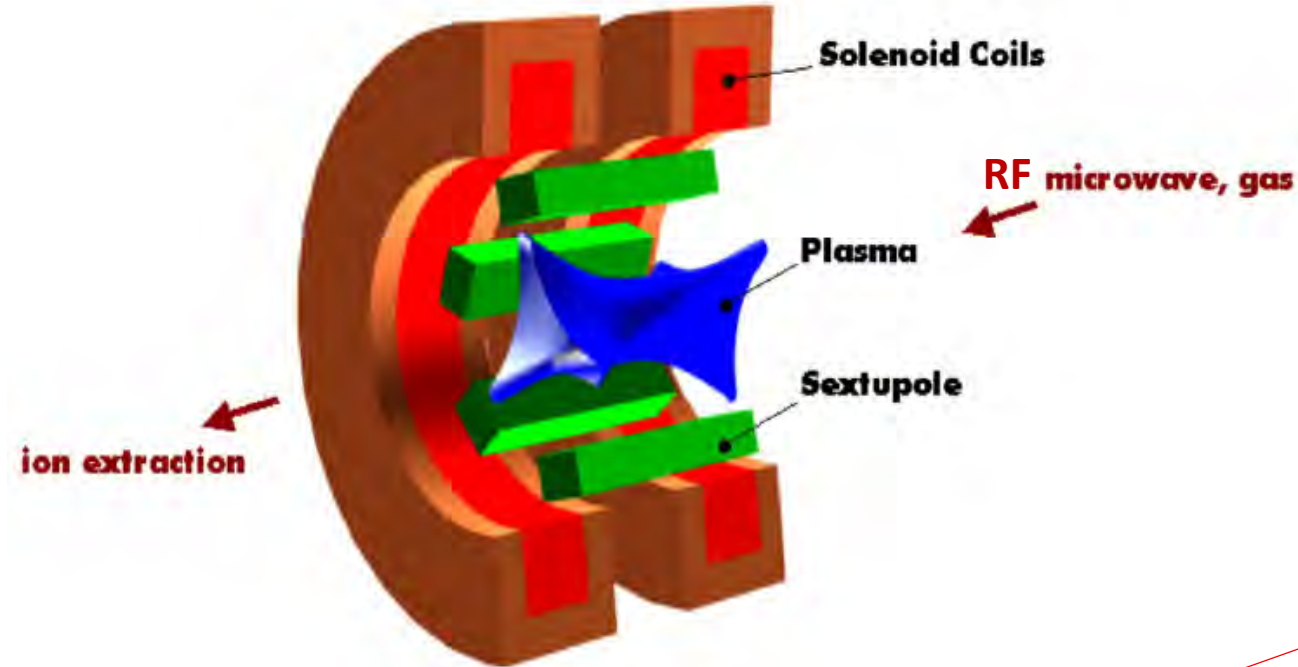
Collaborazione:

Bologna: F. Odorici (0.2 FTE), L. Malferrari (0.2 FTE)

con il supporto di: M. Guerzoni, M. Furini, C. Gessi, A. Margotti, R. Michinelli

LNS: G. Castro, O. Leonardi, G. D'Agostino, L. Celona, S. Gammino,
F. Chines, G. Costanzo, F. Russo, D. Siliato

ECR ion source/plasma trap: working principles



Plasma confinement to increase plasma lifetime τ_i and so mean ion charge state $\langle q \rangle$:

- 2-4 coils for axial confinement;
- A multiple (generally a sextupole) for radial confinement
- Plasma formation if $\omega_{RF} = \omega_{cyclotron} = \frac{eB}{m} \rightarrow$ free electrons get energy to ionize the gas

$I \propto \frac{n_e}{\tau_i}$

$\langle q \rangle \propto n_e \tau_i$

n_e electron density

Plasma Diffusion in ECRIS

electrons
are mainly
lost axially

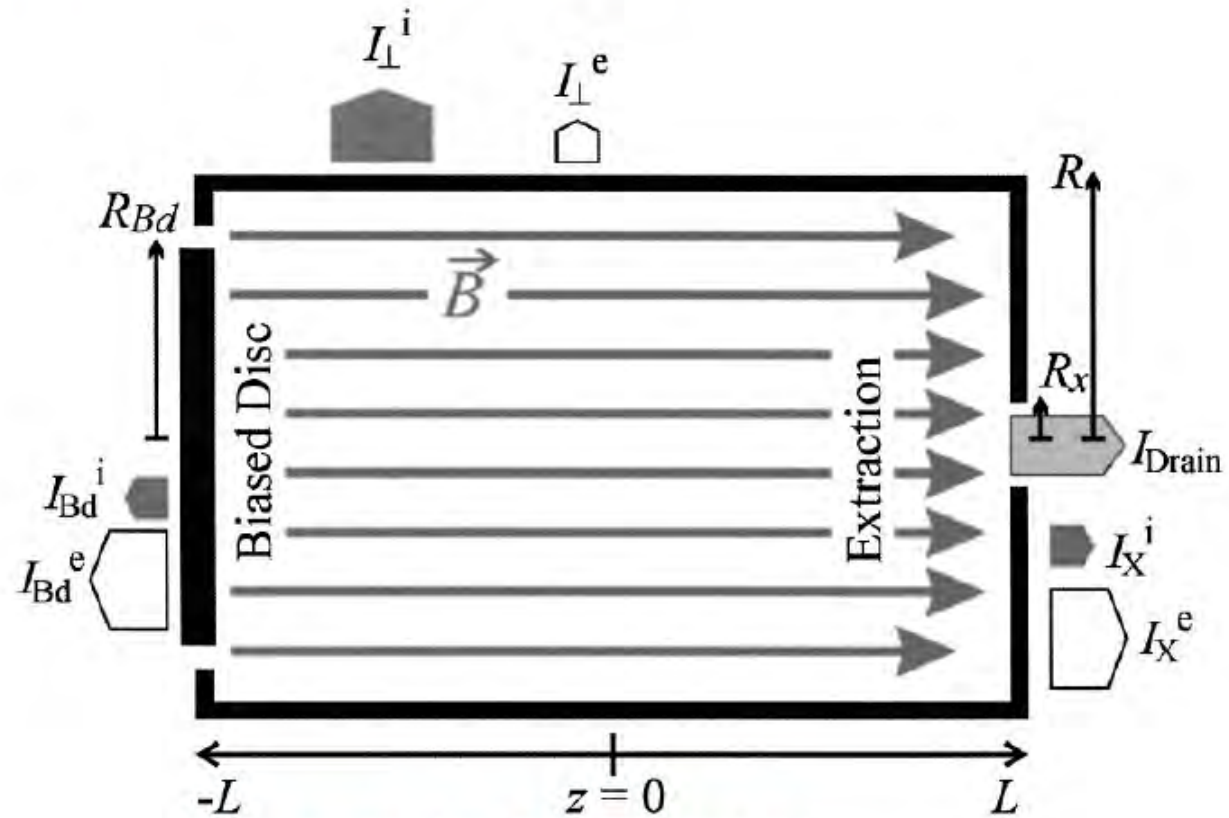
$$I_X^e > I_X^i$$

ions are
mainly lost
radially

$$I_{\perp}^i > I_{\perp}^e$$

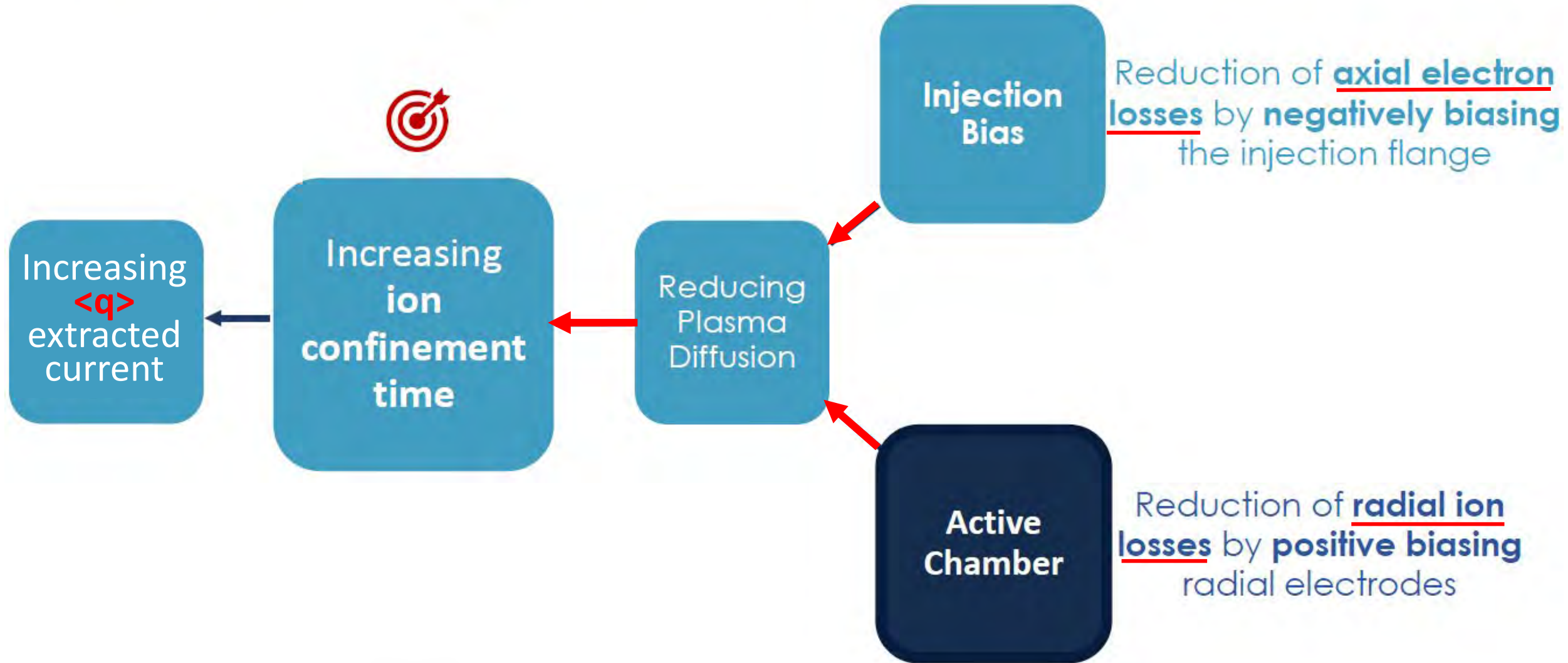
From the **quasineutrality** of the plasma:

$$I_{\perp}^i + I_{\perp}^e + I_{Bd}^i + I_{Bd}^e + I_X^i + I_X^e + I_{Drain} = 0$$



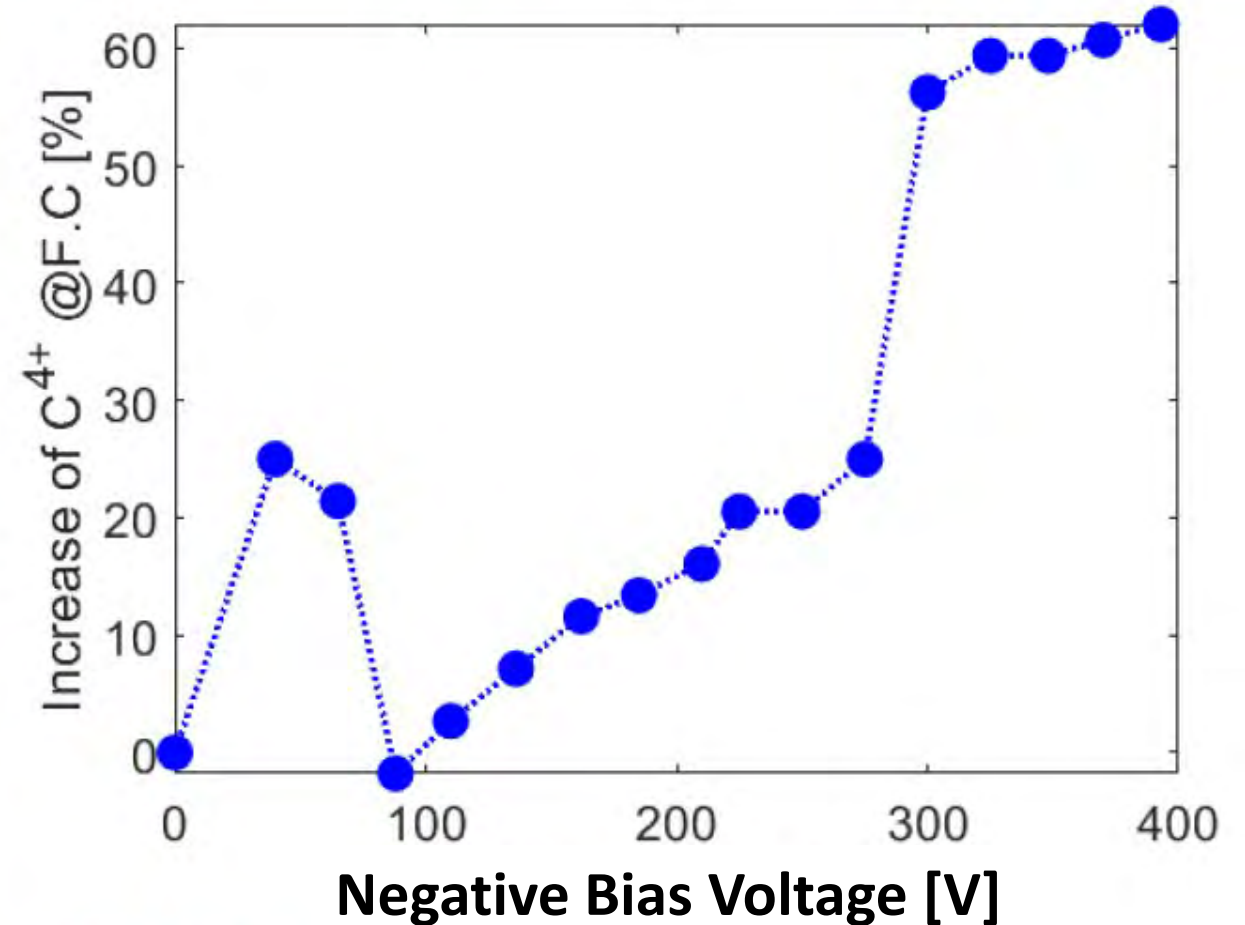
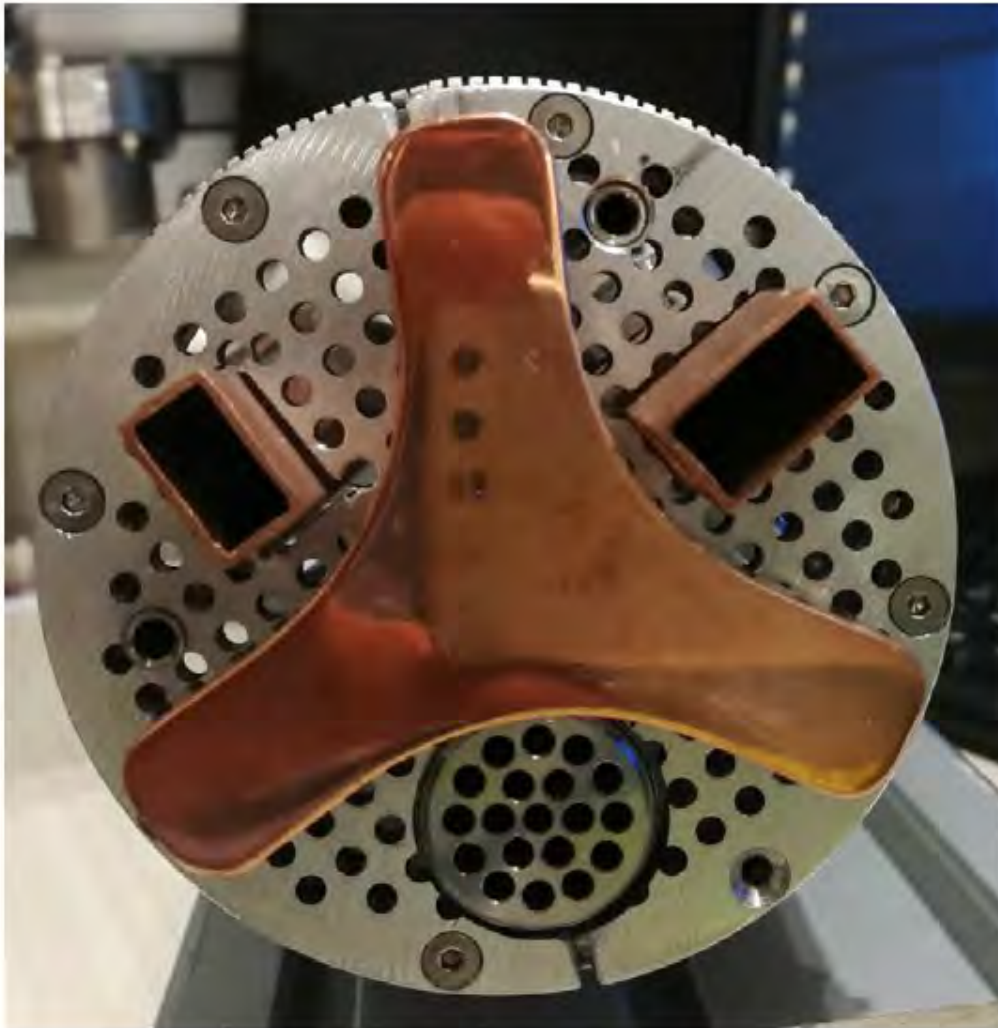
A.G. Drentje et al., R.S.I. 73 (2002) 516

Increasing ion confinement time



Injection Bias in ECRIS: previous experiments

S. Gammino et al. RSI 63, 2872–2874 (1992)

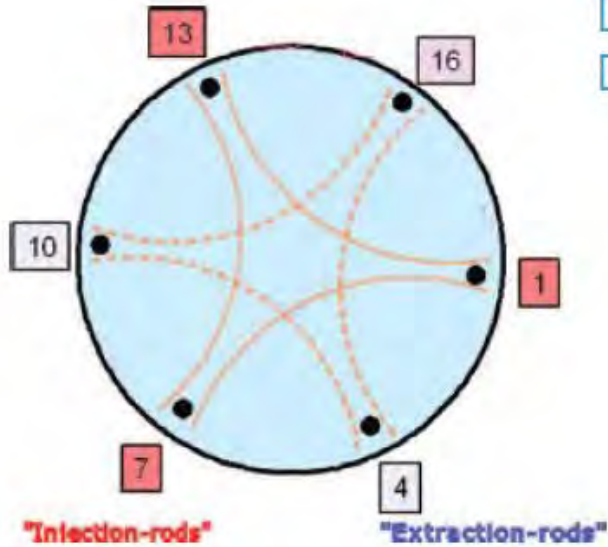


G. Castro et al. RSI 90, 113316 (2019);

Active Chamber in ECRIS: previous experiments

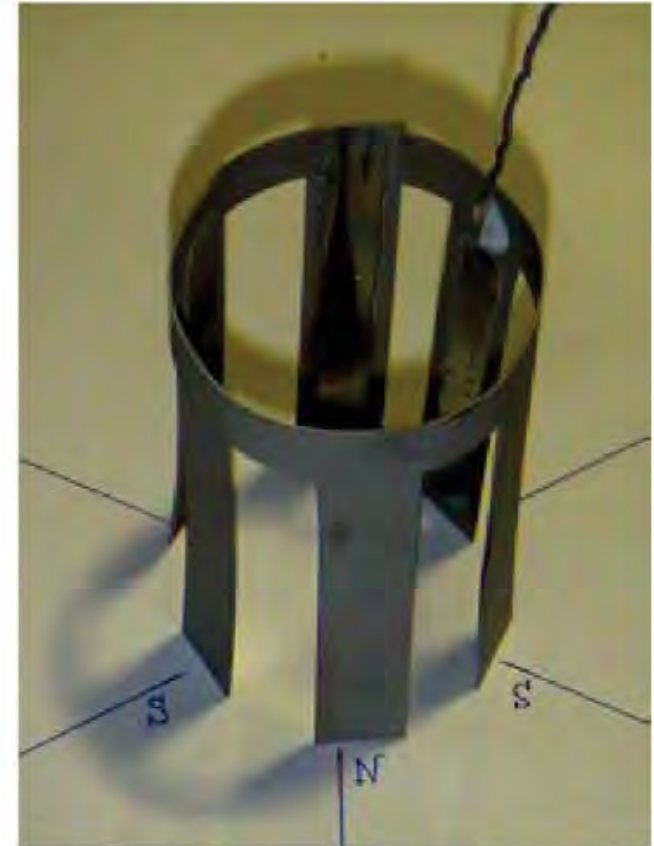
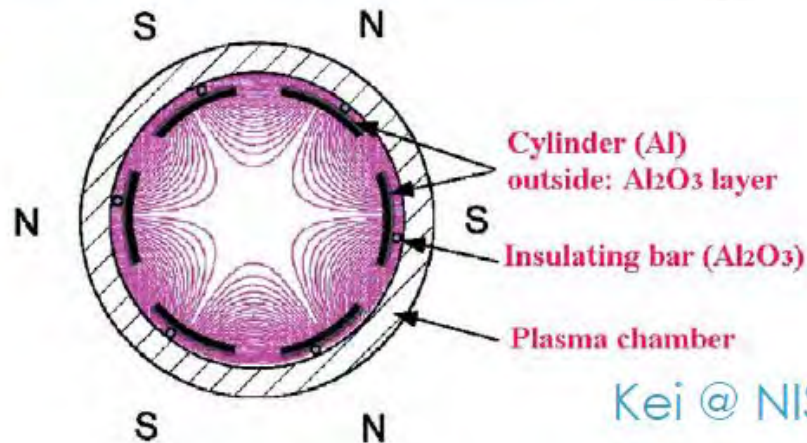
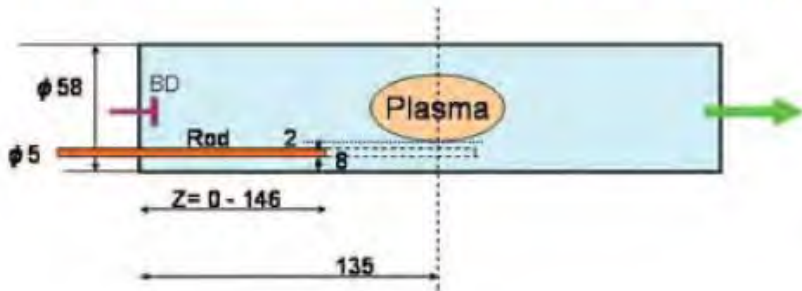
Drentje, A. et al. IEEE Transactions on Plasma Science 36, 1502-1506 (2008)

Drentje, A. et al. RSI. 85. 02A921 (2014)



+	-
Performance improvement: 35-40%	Short Circuit, Melting

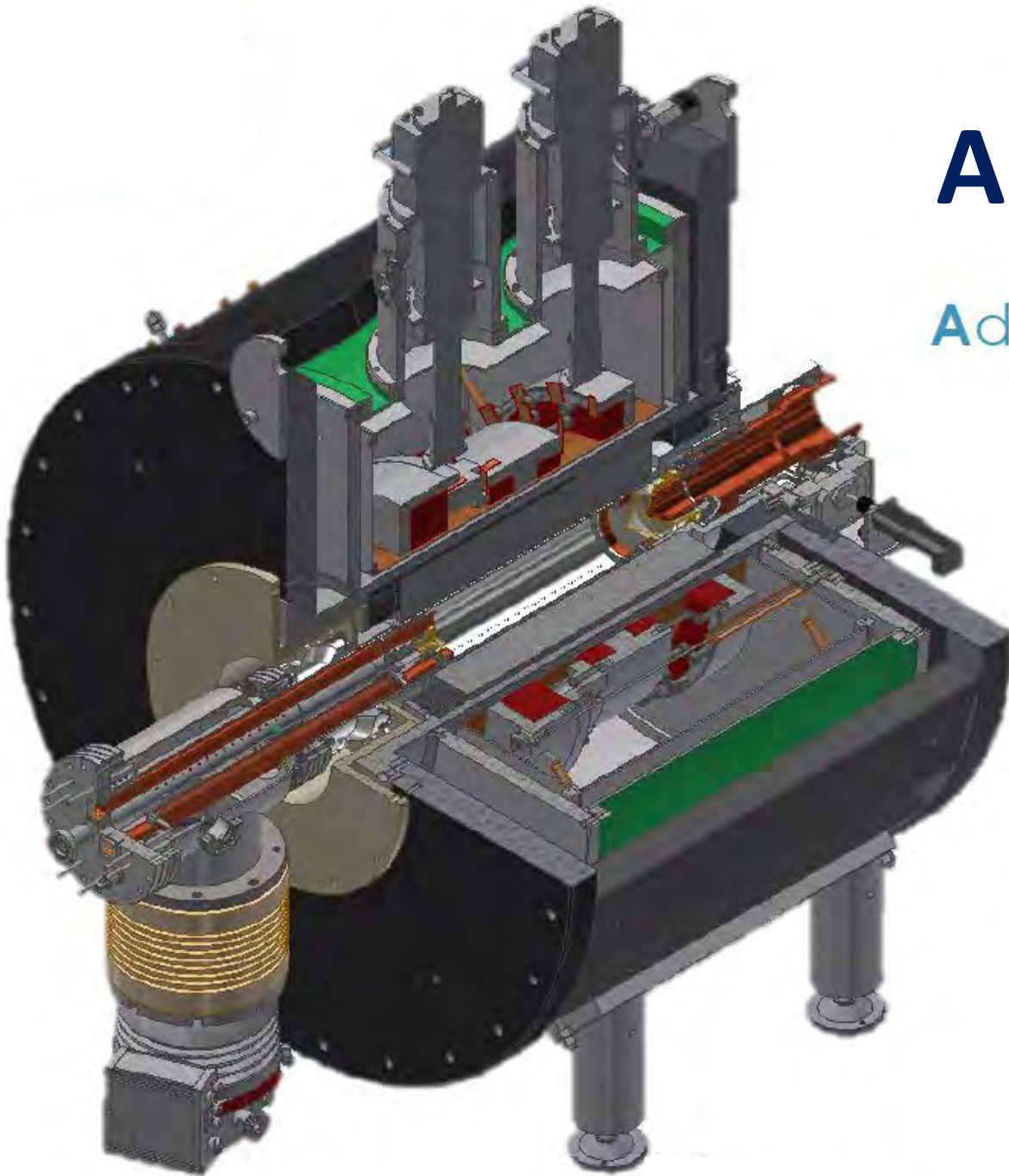
BioNano-ECRIS @ Toyo University (JAP)



Kei @ NISRS - Chiba (JAP)

AISHa (ECRIS @ LNS)

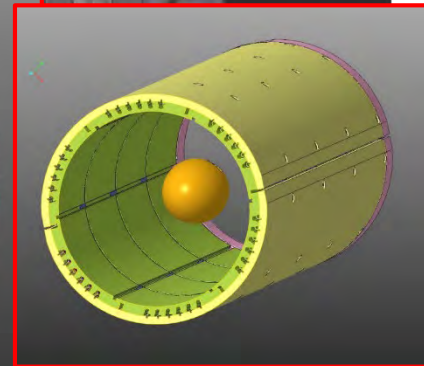
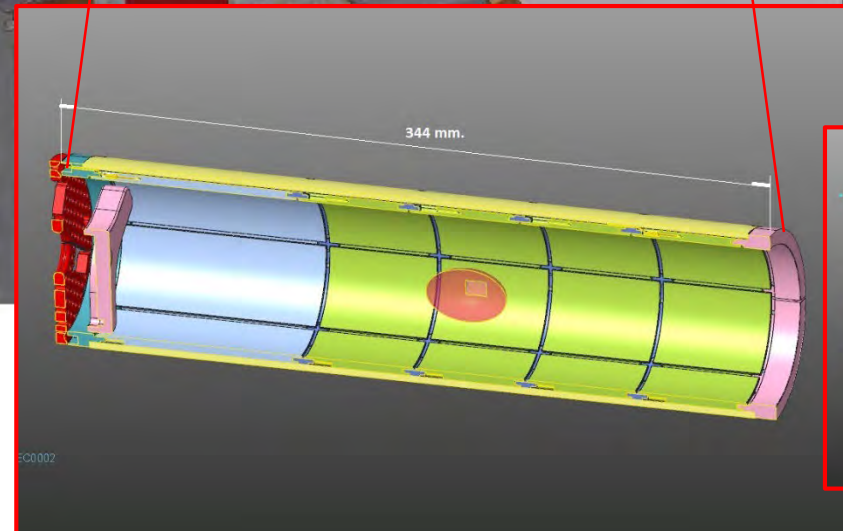
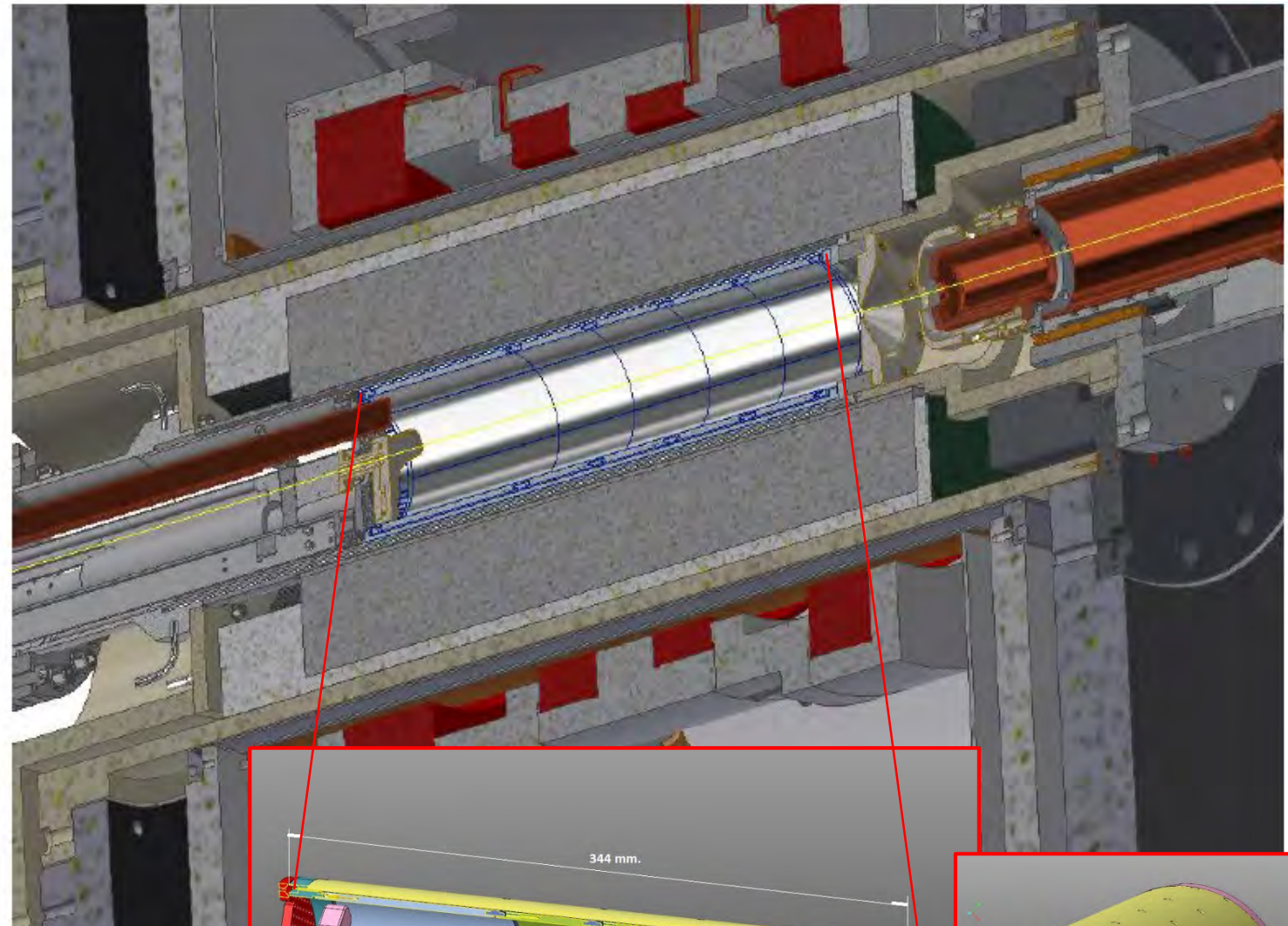
Advanced Ion Source for Hadrontherapy



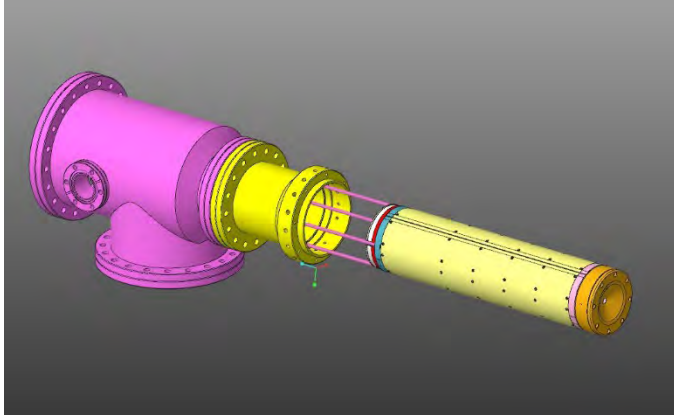
Radial field (max)	1.3
Axial field (max)	2.6/0.4/1.7
Operating frequency (GHz)/power (kW)	17.3–18.3/1.5
Cryostat length/diameter (mm)	620/5650
Extraction voltage (kV)	20–40
Plasma chamber \varnothing (mm)	92 mm
Extraction hole \varnothing (mm)	7.2
Distance between maxima of the axial field (mm)	370
Distance between microwave port and B_{\min} (mm)	203
Length of the resonance zone (mm)	<10
Distance between the plasma electrode and B_{\min} (mm)	167

The Active Plasma Chamber

- Positive Voltage bias
- 30 Anodized Al-6082 Electrodes (5 axial sections x 6 radial electrodes)
- 2 half cylinders as shells
- 12 half rings
- Temperature measurements
- Electric insulation
- Cooling
- Current (plasma losses) measurement on each electrode, in order to optimize the plasma confinement vs the working parameters (gas-pressure, RF-power etc.)



The Active Plasma Chamber: design & construction @ BO



From the valuable work of:

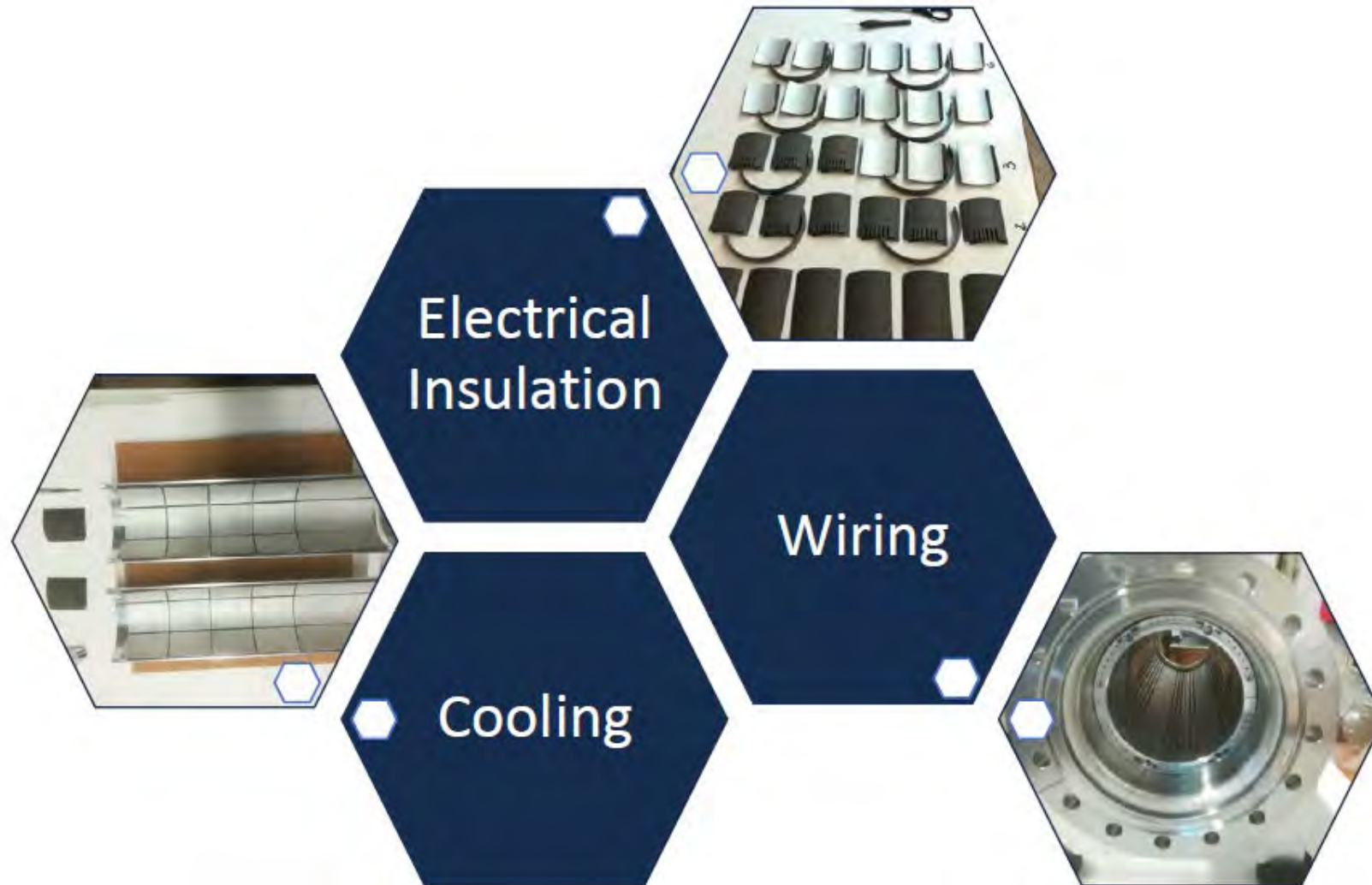
- Roberto Michinelli
- Michele Furini
- Cristiano Gessi

With the coordination of:

- Marco Guerzoni
- Anselmo Margotti



Technical aspects



Electrical insulation of tiles and rings: nano-porous anodization

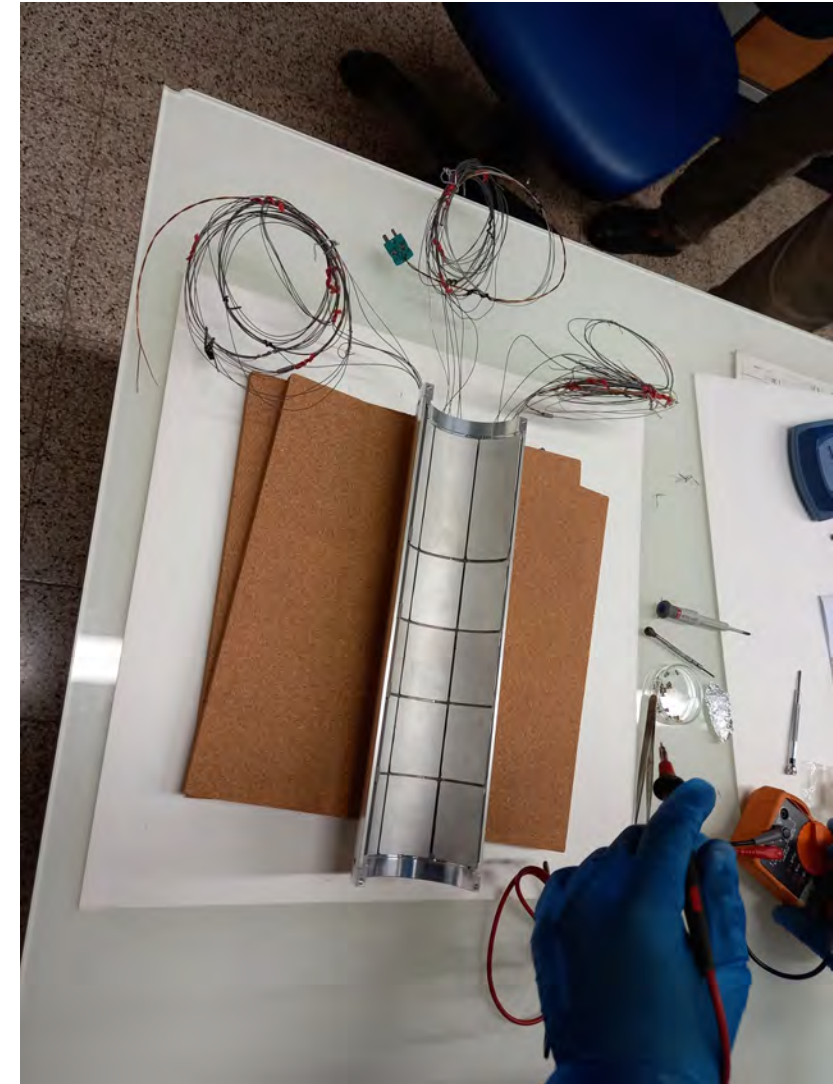


Tiles' internal
view (conductive
aluminum)

Tiles' external view
(anodized Al, 50 μm
thick isolation)

Assembling & wiring

Cu/Ni wires diam. 0.5 mm with ceramic insulation
+ thermocouples diam. 0.5mm for T monitoring



Preliminary tests of the Active Plasma Chamber @ BO

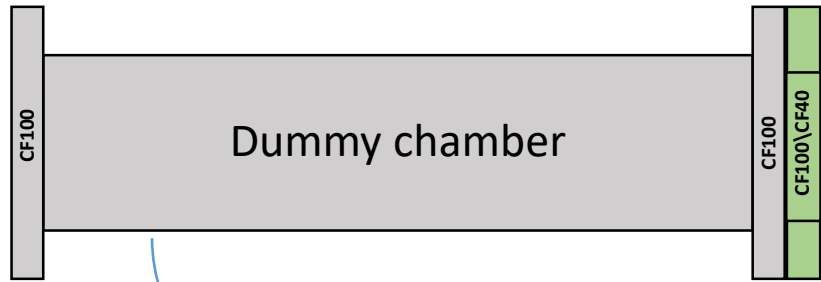
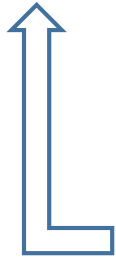
Sessions: september 2023, january 2024

Topics:

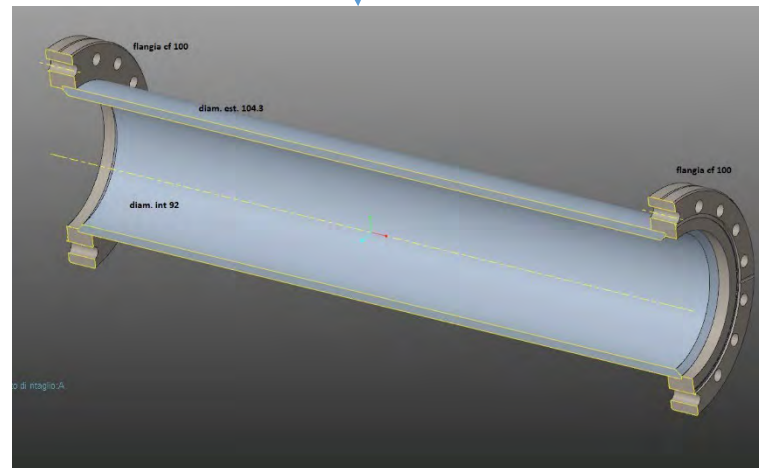
- mechanical coupling with a dummy chamber;
- outgassing in vacuum;
- thermal behaviour;
- electrical behaviour.

TEST SETUP @ Bologna

Pumping system (turbo on CF100 or KF40, primary pump, dual range gauge, controller ...)



Dummy chamber



magis

feedthrough sub-D25,
flange CF40



CF40

CF40

Passante sub-D25,
flangia CF40



CF40

Dual range gauge,
CF40

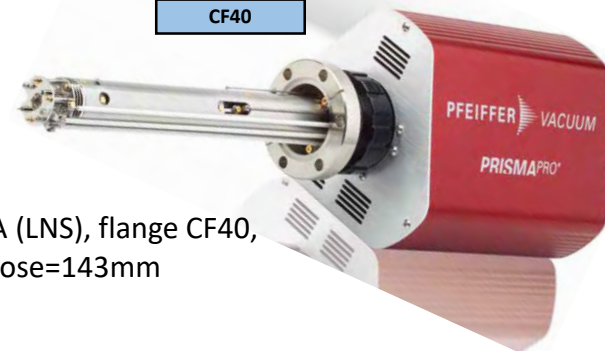


CF40

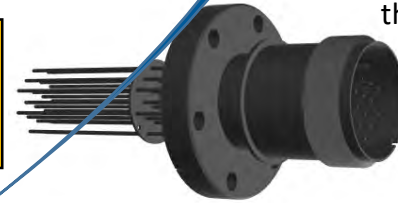
CF40

CF40

RGA (LNS), flange CF40,
Lnoose=143mm

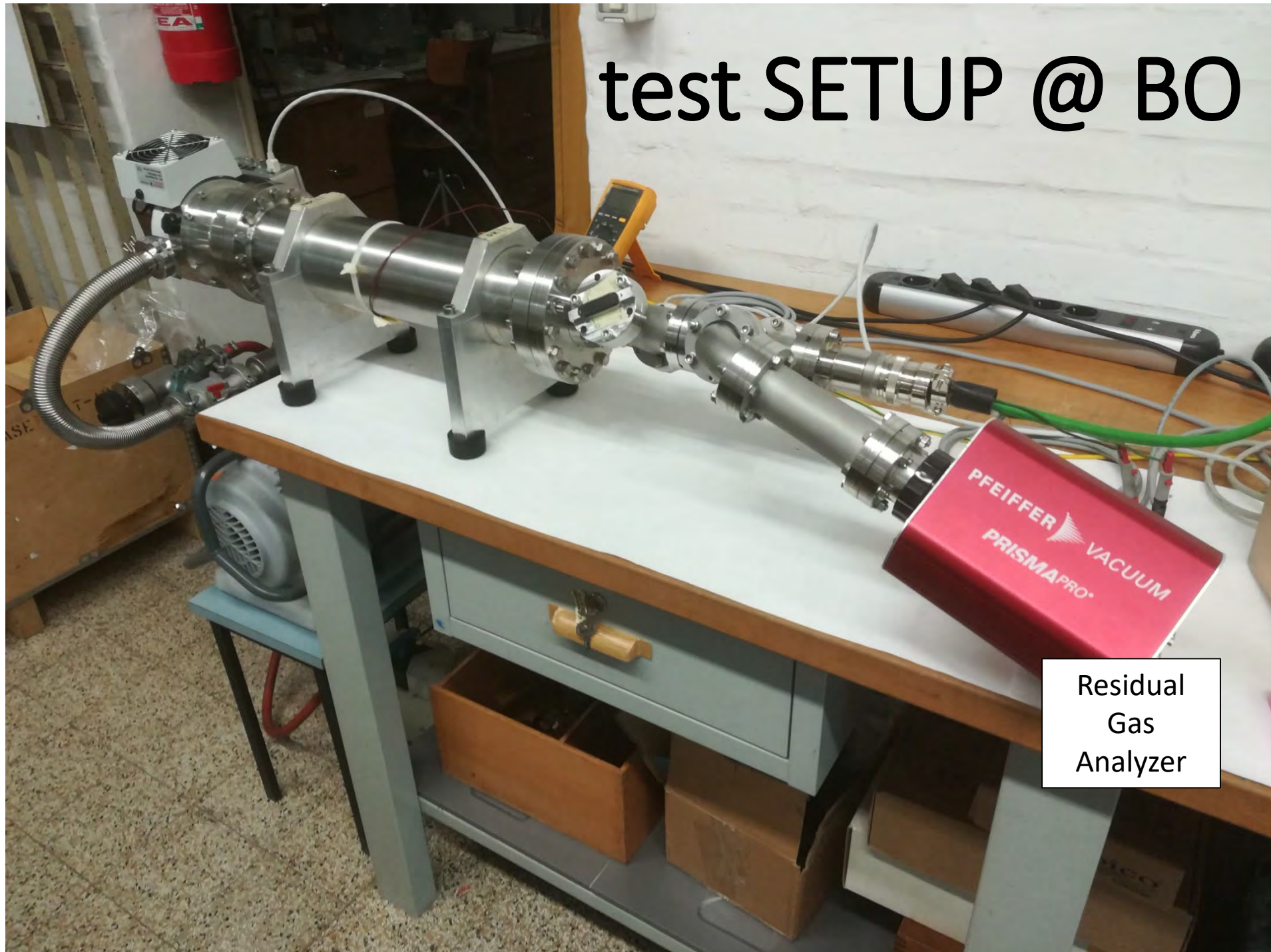


Feedthrough MS x 6
thermocouples K-type,
flange CF40
Lpin=92mm



TC datalogger PICO, 8 ch

test SETUP @ BO

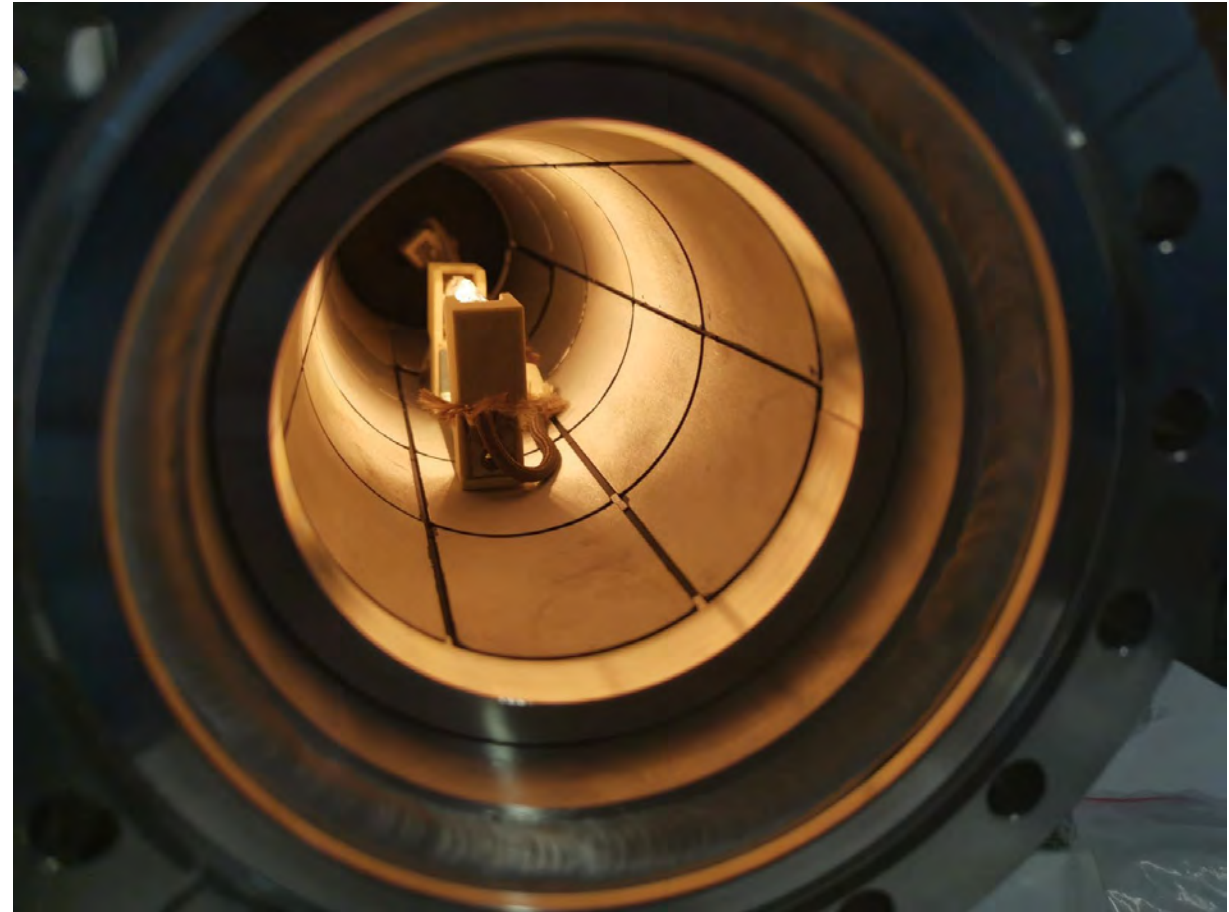


Residual
Gas
Analyzer

Dummy Chamber to emulate
the AISHa main chamber



Insertion of the Active Chamber into
the dummy chamber + halogen lamp
to emulate the plasma radiation heat



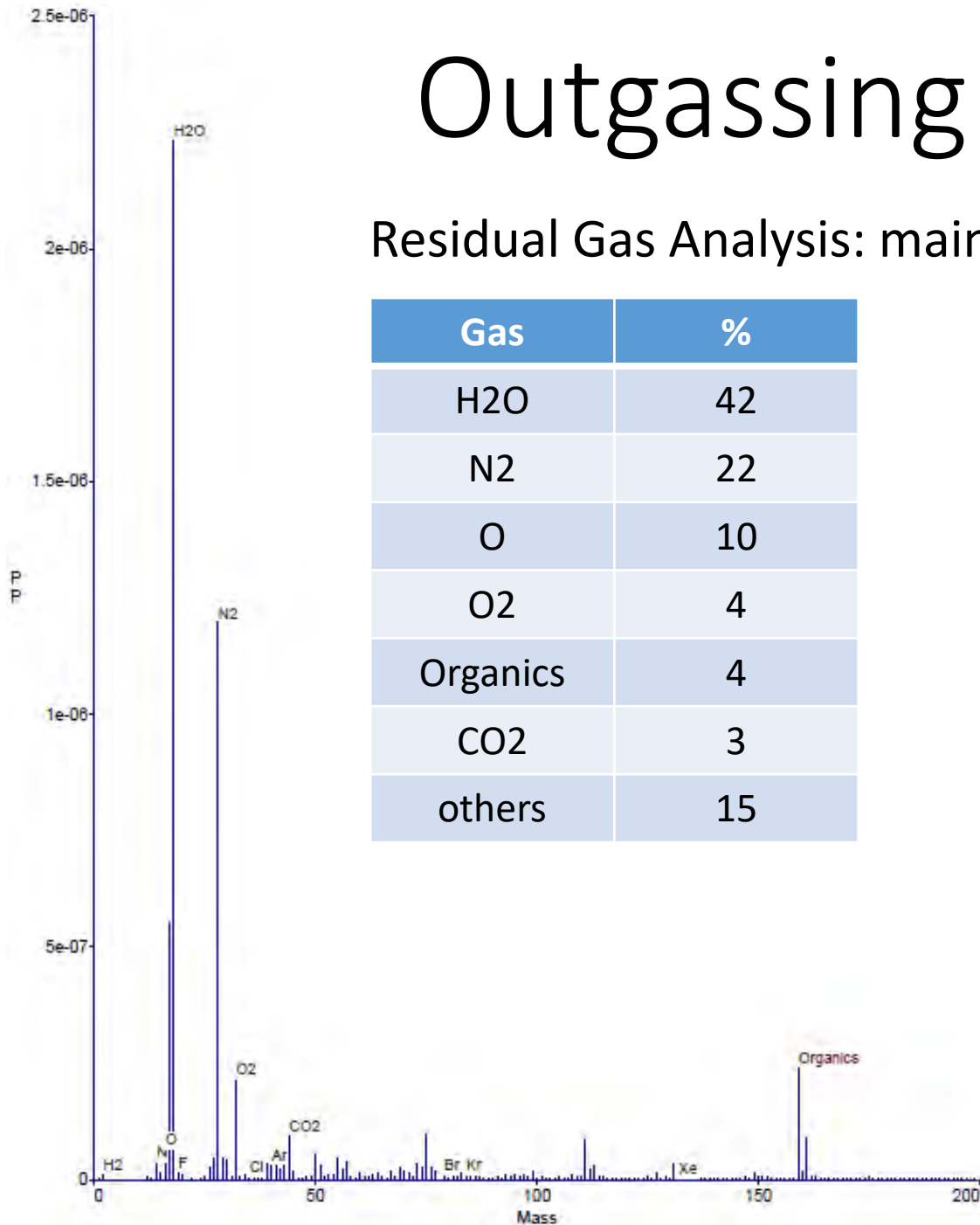
Outgassing and baking tests

Residual Gas Analysis: main outgassing @ $P=1 \times 10^{-5}$ mbar

Gas	%
H2O	42
N2	22
O	10
O2	4
Organics	4
CO2	3
others	15

Pressure (mbar):

- 1×10^{-4} in 90'
- 7.4×10^{-6} after 17h
- After halogen baking @ 77W
 - ➔ 8.6×10^{-4} @ **tail Tmax 212°C**
 - ➔ 4.0×10^{-6} @ T ambient



Baking with halogen

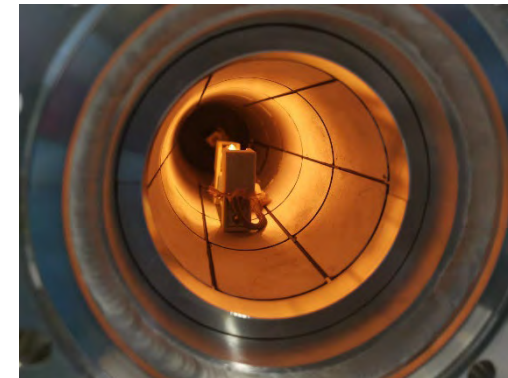
Monitoring of 6 thermocouples on different tiles

Upper shell – inner view

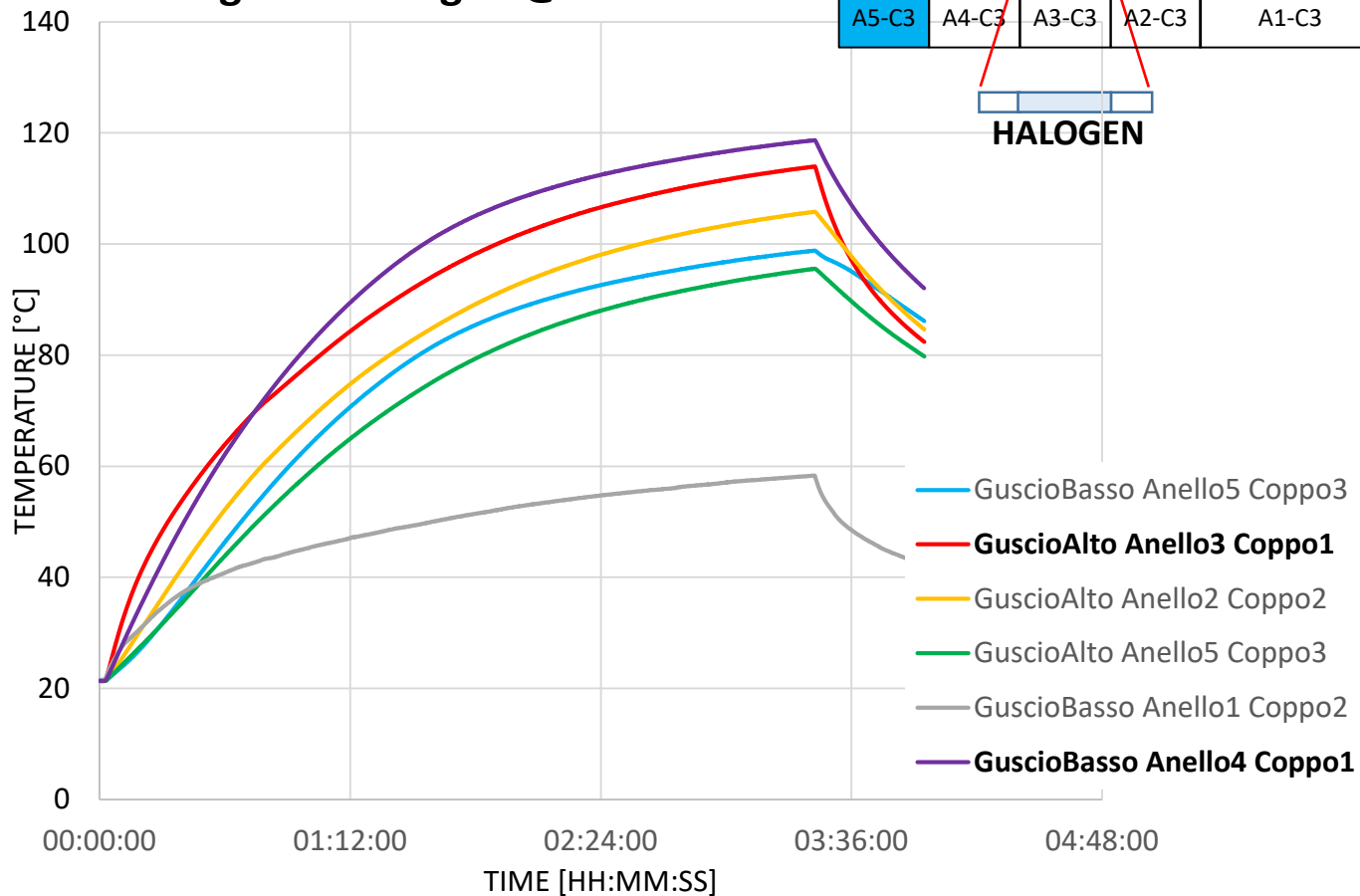
A5-C1	A4-C1	A3-C1	A2-C1	A1-C1
A5-C2	A4-C2	A3-C2	A2-C2	A1-C2
A5-C3	A4-C3	A3-C3	A2-C3	A1-C3

Lower shell – inner view

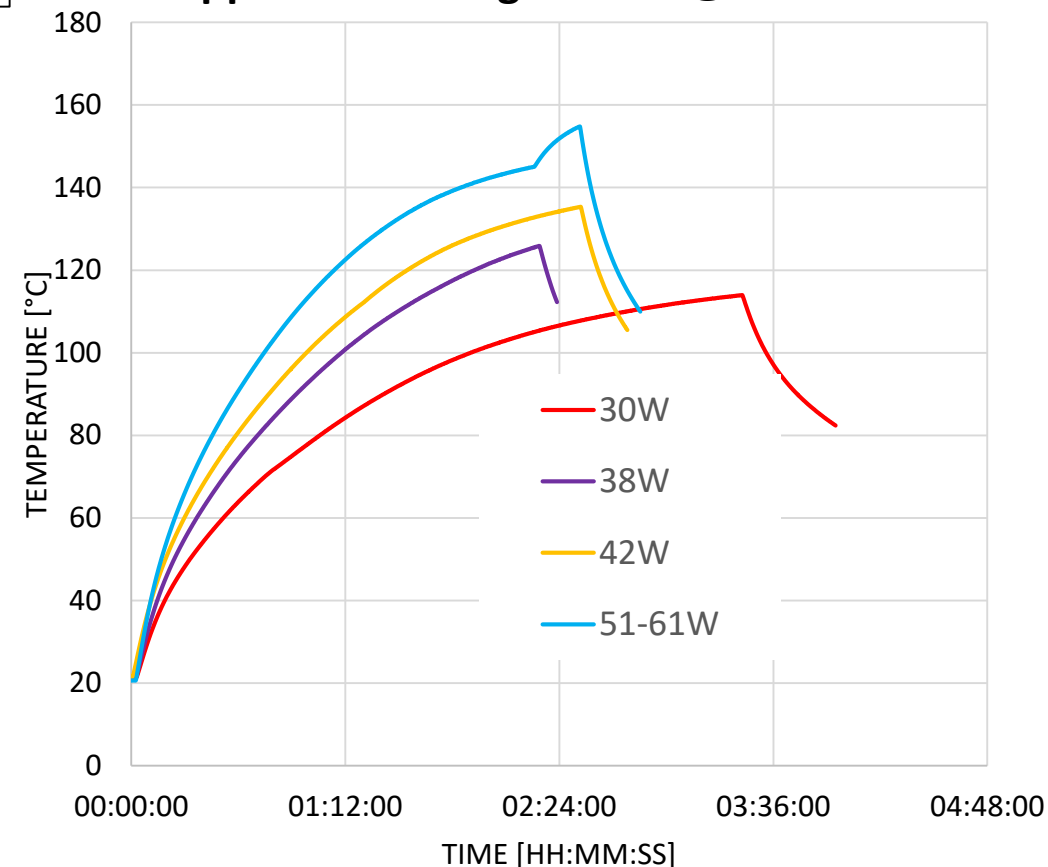
A5-C1	A4-C1	A3-C1	A2-C1	A1-C1
A5-C2	A4-C2	A3-C2	A2-C2	A1-C2
A5-C3	A4-C3	A3-C3	A2-C3	A1-C3



Baking with halogen @ 30W



Upper shell - Ring3 - Tile1 @ various W



Pressure after baking at various power

Pressure after baking at various power, after cooling at ambient temperature with pumping off, followed by pumping for about 20':

Baking	Tmax (ring3 tail1)	Pressure @ T _{ambient}
30 W	115°C	2.5x10E-6
38 W	127°C	1.0x10E-6
42 W	135°C	8.6x10E-7
51-61 W	145-155°C	7.4x10E-7
51-61 W	145-155°C	4.6x10E-7 after 3h pumping

Electrical test before and after baking

Electrical insulation among tails has been tested up to 100V, before and after baking
→ Insulation is stable

Conclusions and perspectives

Q3 - 2024

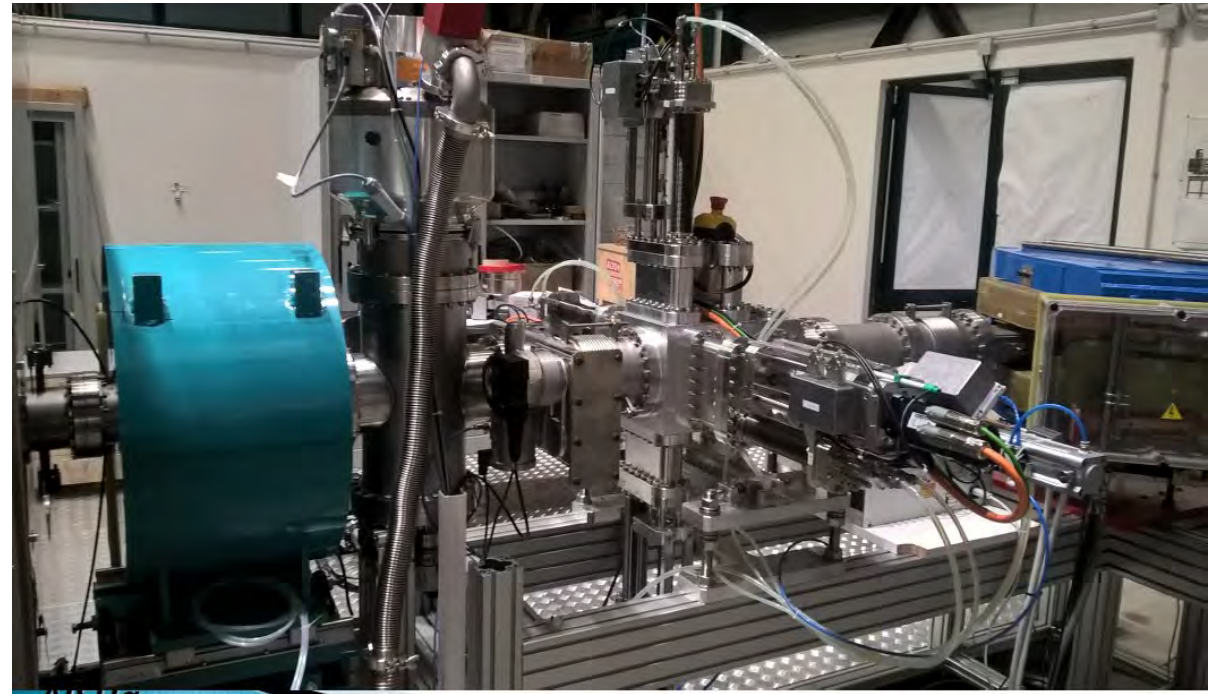
Installation and vacuum
test on AISHa @ LNS

Q4 - 2024

Test in plasma on AISHa
@ LNS

Q2 - 2025

Design of a full scale Active
Chamber for PANDORA



AISHa experimental setup