The PANDORA active Plasma Inner Chamber (PIC)
Status update

OUTLINE:

- Physics motivations for an «**Active**» Plasma Chamber in ECR ion traps (or sources)
- Design and test of a reduced scale prototype (~1:3) for the AISHa ECR ion source @ LNS
- Inner Chamber design options for the PANDORA apparatus
- Next activity & Timelines

Physics motivations for an Active Plasma Chamber

- **GOAL: maximize the mean ion charge state <q>**. This is **proportional to the ion lifetime** in plasma

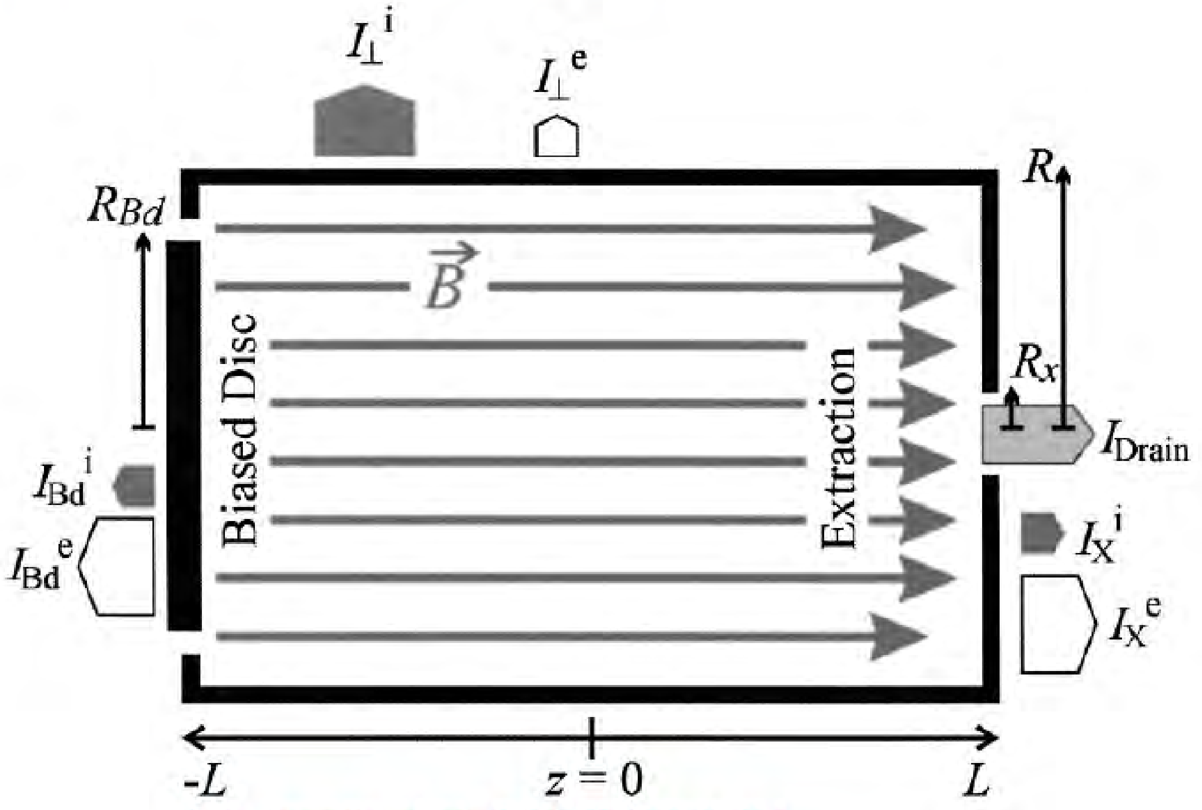
We must **reduce plasma losses** that are due to unavoidable imperfections in the magnetic trap

electrons are mainly lost **axially**: $I^e_X > I^i_X$

ions are mainly lost **radially**: $I^i_\perp > I^e_\perp$

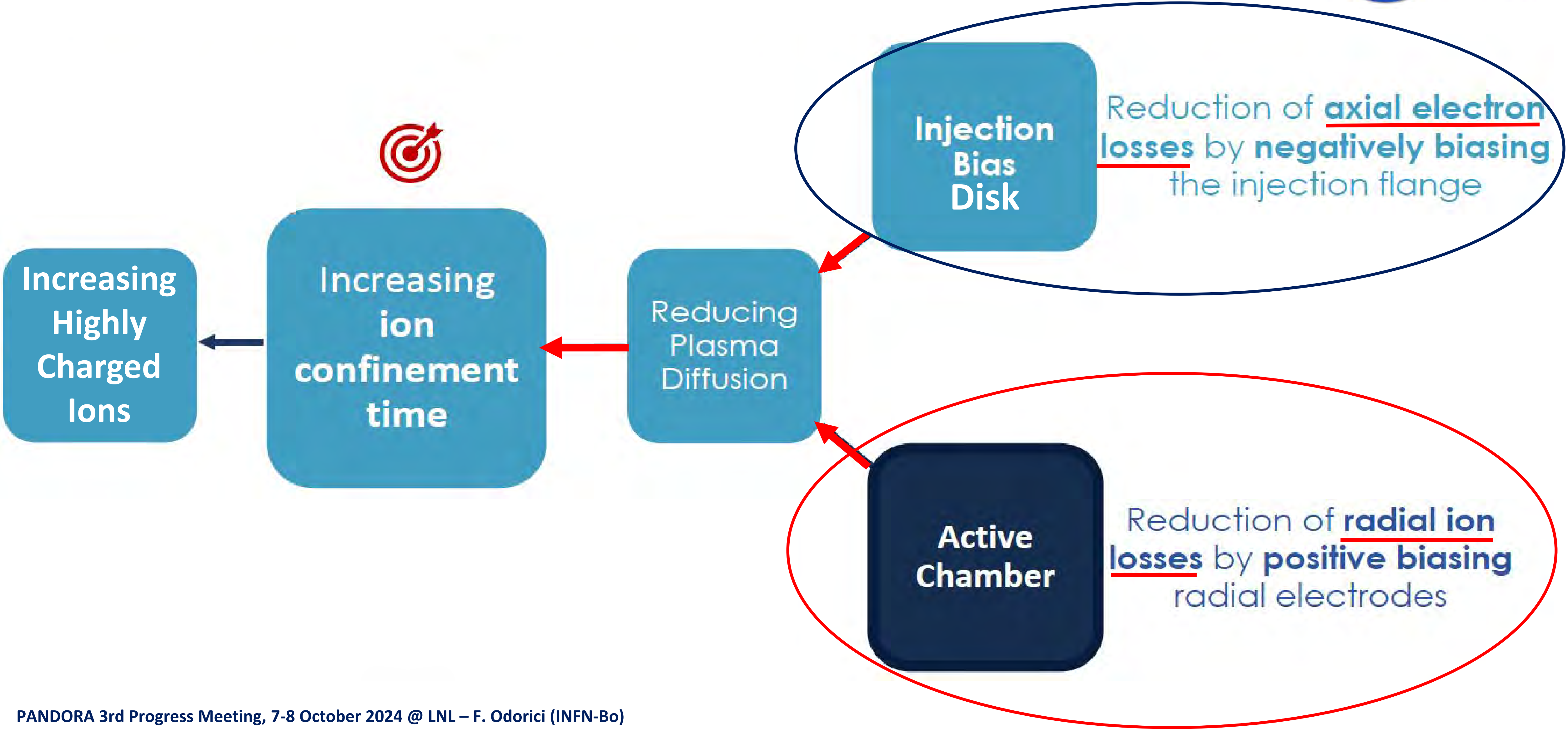
From the **quasineutrality** of the plasma:

$$I^i_\perp + I^e_\perp + I^i_{Bd} + I^e_{Bd} + I^i_X + I^e_X + I_{Drain} = 0$$



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

How to reduce plasma losses



Increasing Highly Charged Ions

Increasing **ion confinement time**

Reducing Plasma Diffusion

Injection Bias Disk

Reduction of **axial electron losses** by **negatively biasing** the injection flange

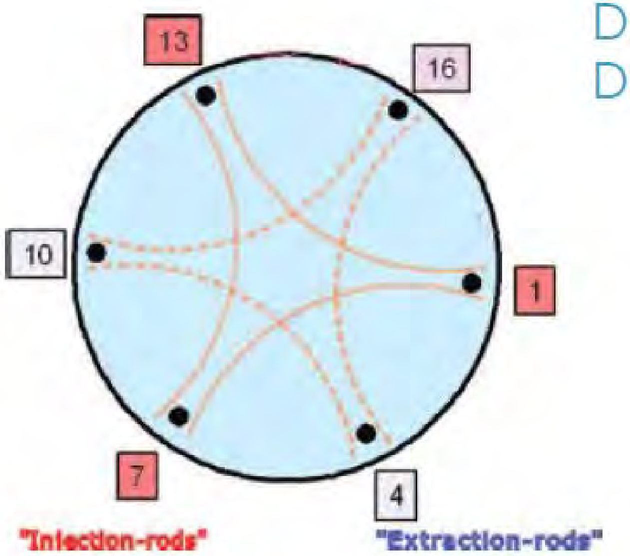
Active Chamber

Reduction of **radial ion losses** by **positive biasing** radial electrodes

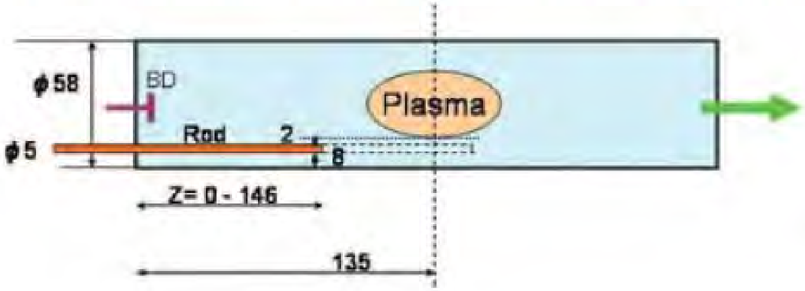
Active Plasma Chambers in previous experiments

Drentje, A. et al. IEEE Transactions on Plasma Science 36, 1502-1506 (2008)
Drentje, A. et al. RSI. 85. 02A921 (2014)

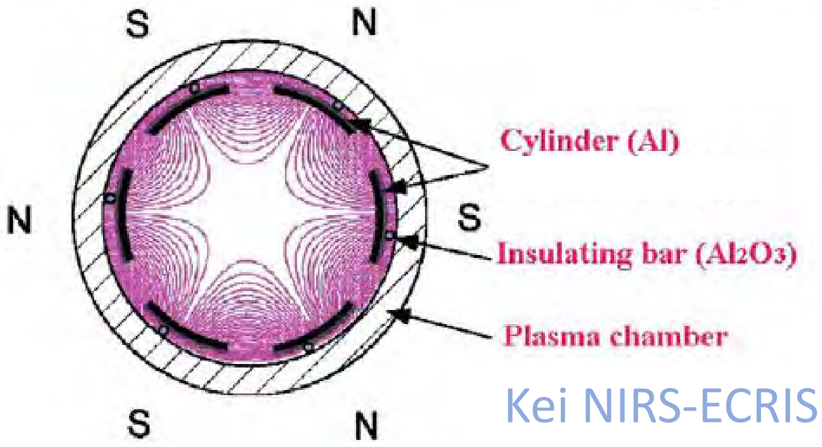
+	−
Performance improvement: 35-40%	Short Circuit, Melting

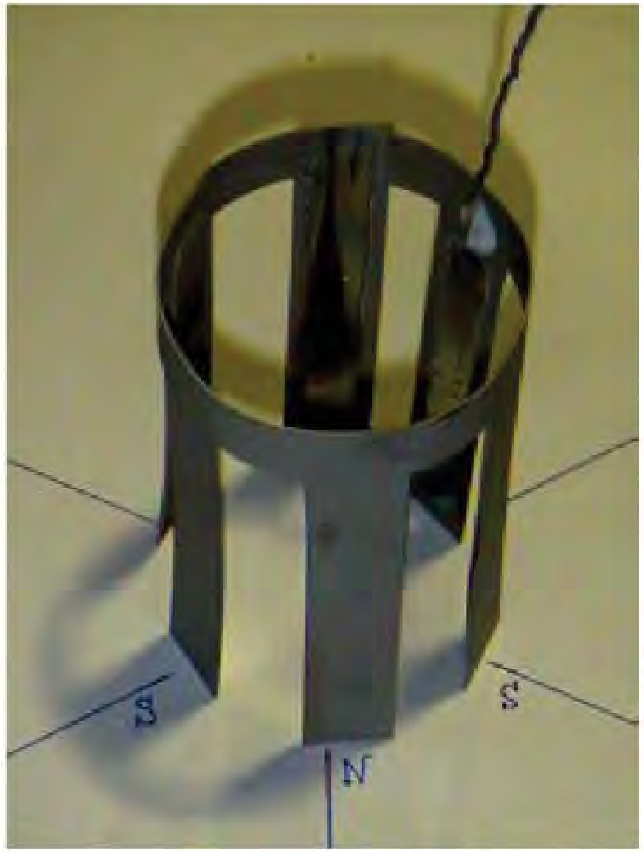


BioNano-ECRIS @ Toyo University (JAP)



Atomki ECRIS @ Debrecen (Hungary)

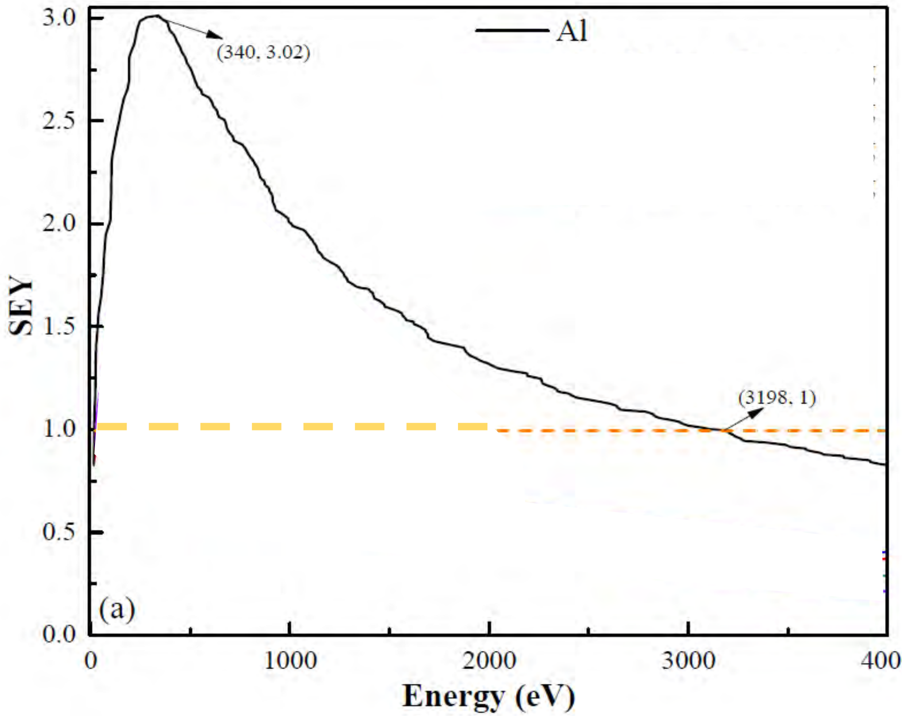




Kei NIRS-ECRIS @ Chiba (Japan)

Benefits from a Plasma Inner Chamber

1. Reduce radial ion losses with an **active control** of each tile bias; could have an automatic search for the best bias map, for any PANDORA working condition (pressure, RF, etc)
2. Real-time **monitoring of** plasma losses (detect/avoid **unstable working points)**
3. The **replacement of the inner chamber** can be done in a relative «short time», allowing to remove chamber contamination from radioactive isotopes (switch to a new physics case)
4. Aluminum chamber gives a **Secondary Electron emission** Yield (SEY) greater than 1 for a large energy range (< 3.2 keV) of impinging electrons → permits to operate with lower pressure and RF power, thus limiting charge exchange process and recombination’s in the plasma, important to produce highly charged ions.

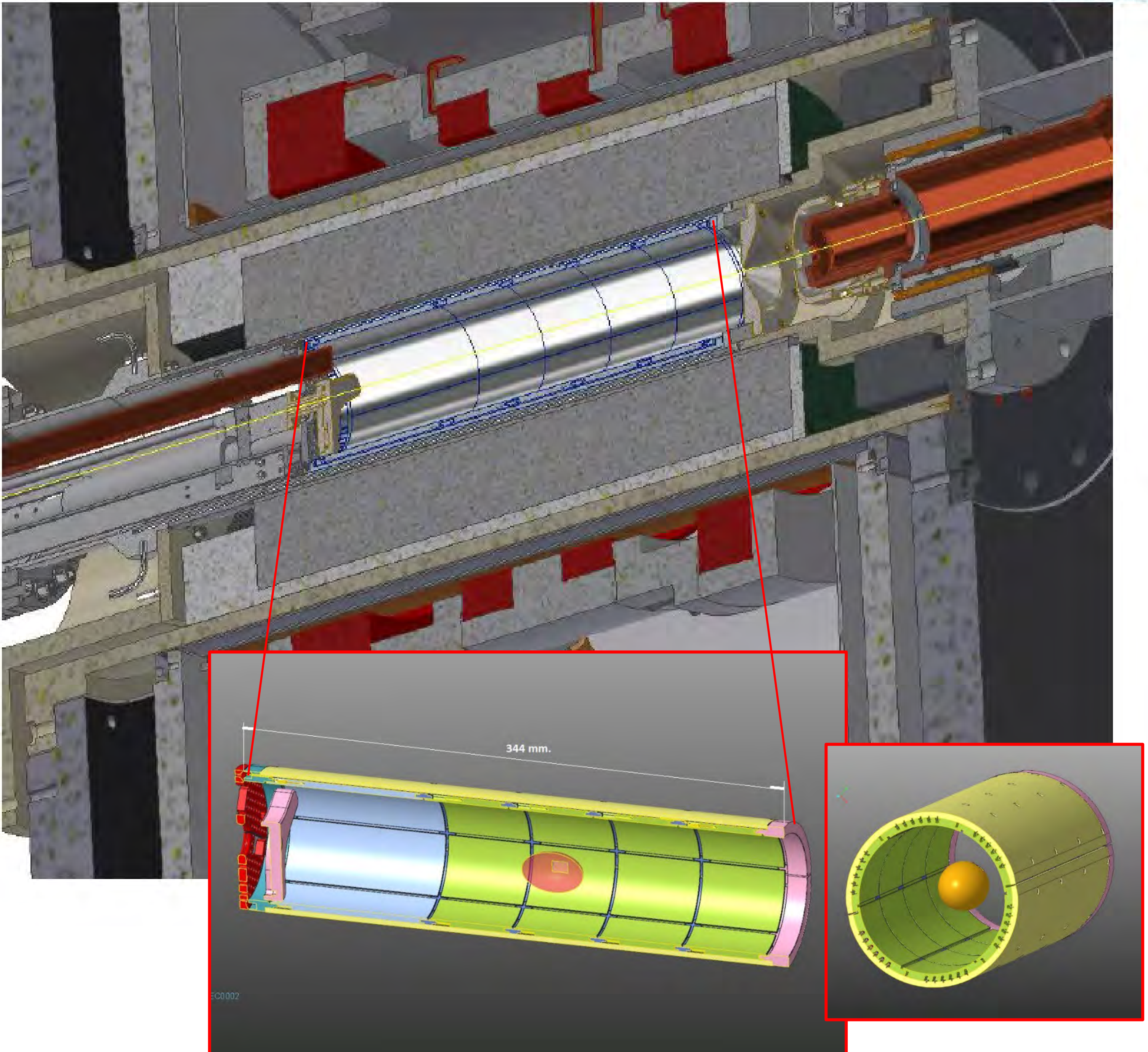


Prototype of an Active Plasma Chamber

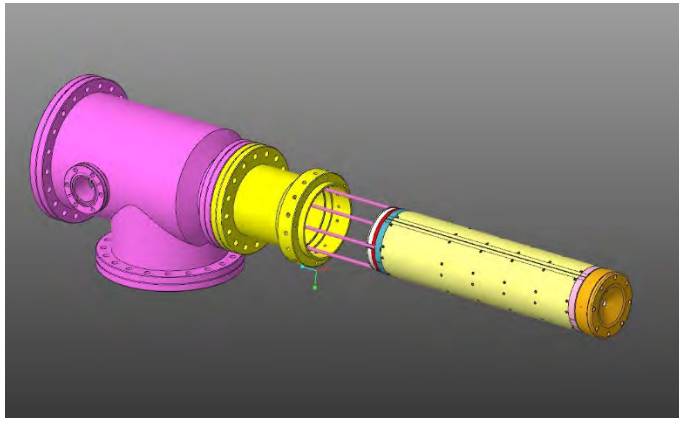
for the AISHa ECRIS @ LNS

Developed under the **IONS experiment** (CSN5):

- Segmentation into 30 «tiles» (5 axial x 6 radial electrodes) of Aluminum-6082
- Electrical insulation among tiles (anodization)
- Positive bias (20 ÷ $50V$)
- Efficient cooling
- Temperature measurements
- Current measurement on each tile (ion losses), via the bias channel



Active Plasma Chamber: prototype construction



Critical aspects:

- Electrical insulation
- Wiring @ high T
- Efficient cooling

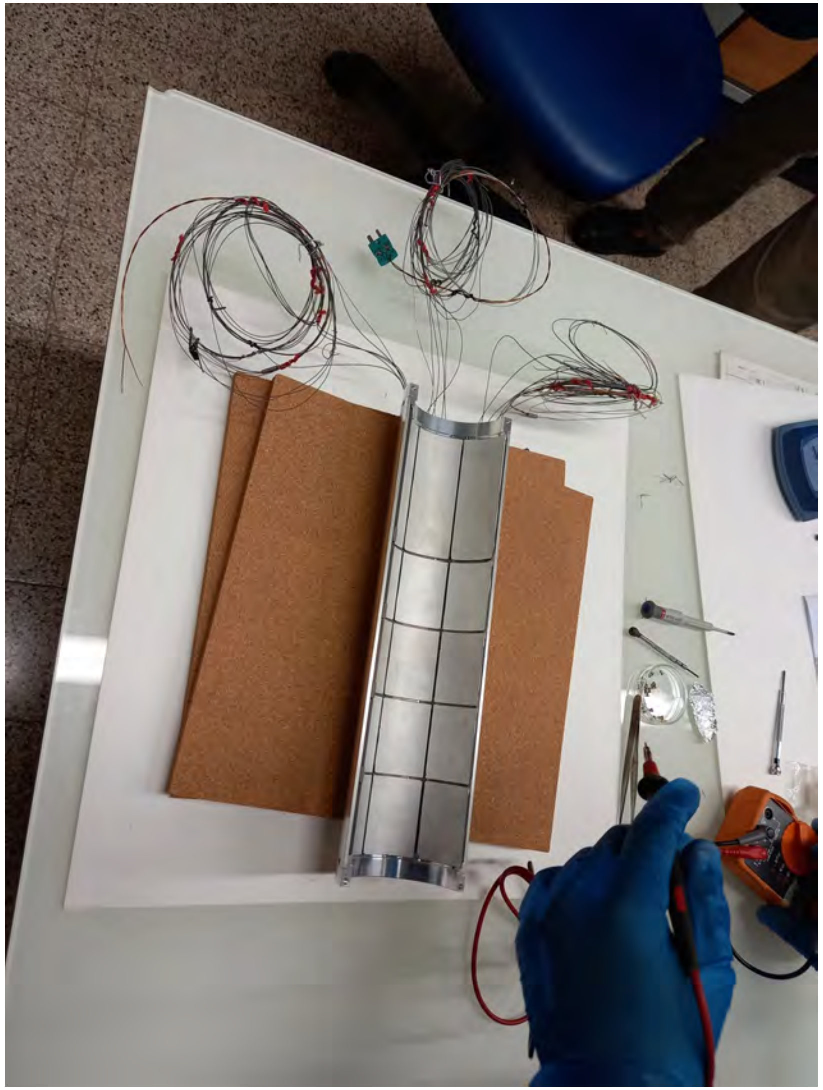
Electrical insulation of tiles and rings: nano-porous anodization

Tiles' internal view (conductive aluminum)

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

Assembling & wiring

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

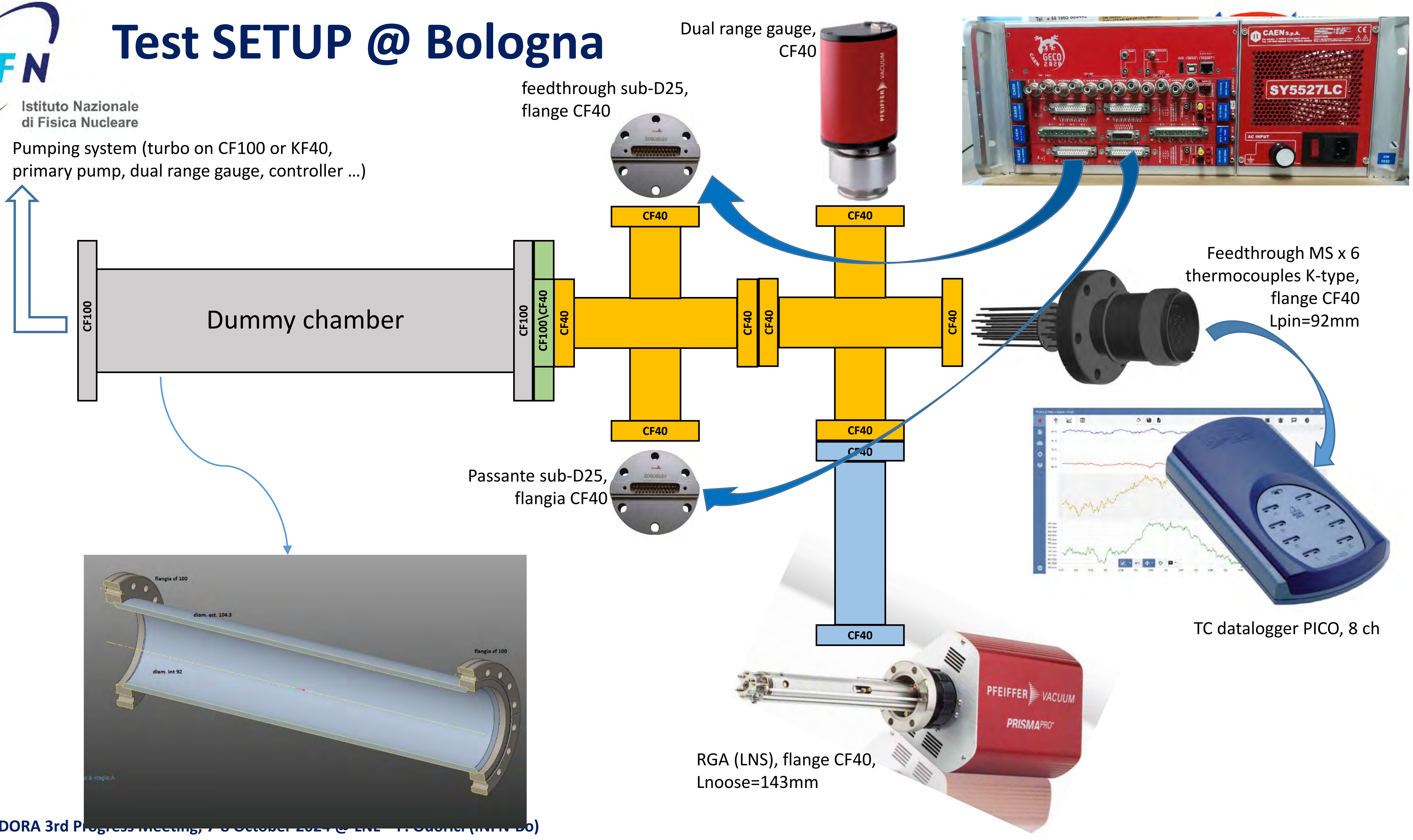


Tests of the prototype of the Active Plasma Chamber

- Test planned on AISHa in 2022 has been postponed to early 2025, as the installation of AISHa in the new experimental room has been delayed for almost 2 years.
- To mitigate the effects of this delay, a pre-test of the Active Chamber prototype has been conducted at the Bologna Section in **2023 & 2024 using a dummy chamber** identical to that of AISHa, specially built for this purpose.

- Test sessions in sep 2023, jan 2024
- Tests conducted so far:
    - mechanical coupling with the dummy chamber;
    - operate @ different temperatures with external baking + halogen lamp (along the chamber axis) to emulate the plasma heat;
    - measure outgassing in vacuum;
    - electrical behaviour.

Test SETUP @ Bologna



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

feedthrough sub-D25, flange CF40

Dual range gauge, CF40

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

TC datalogger PICO, 8 ch

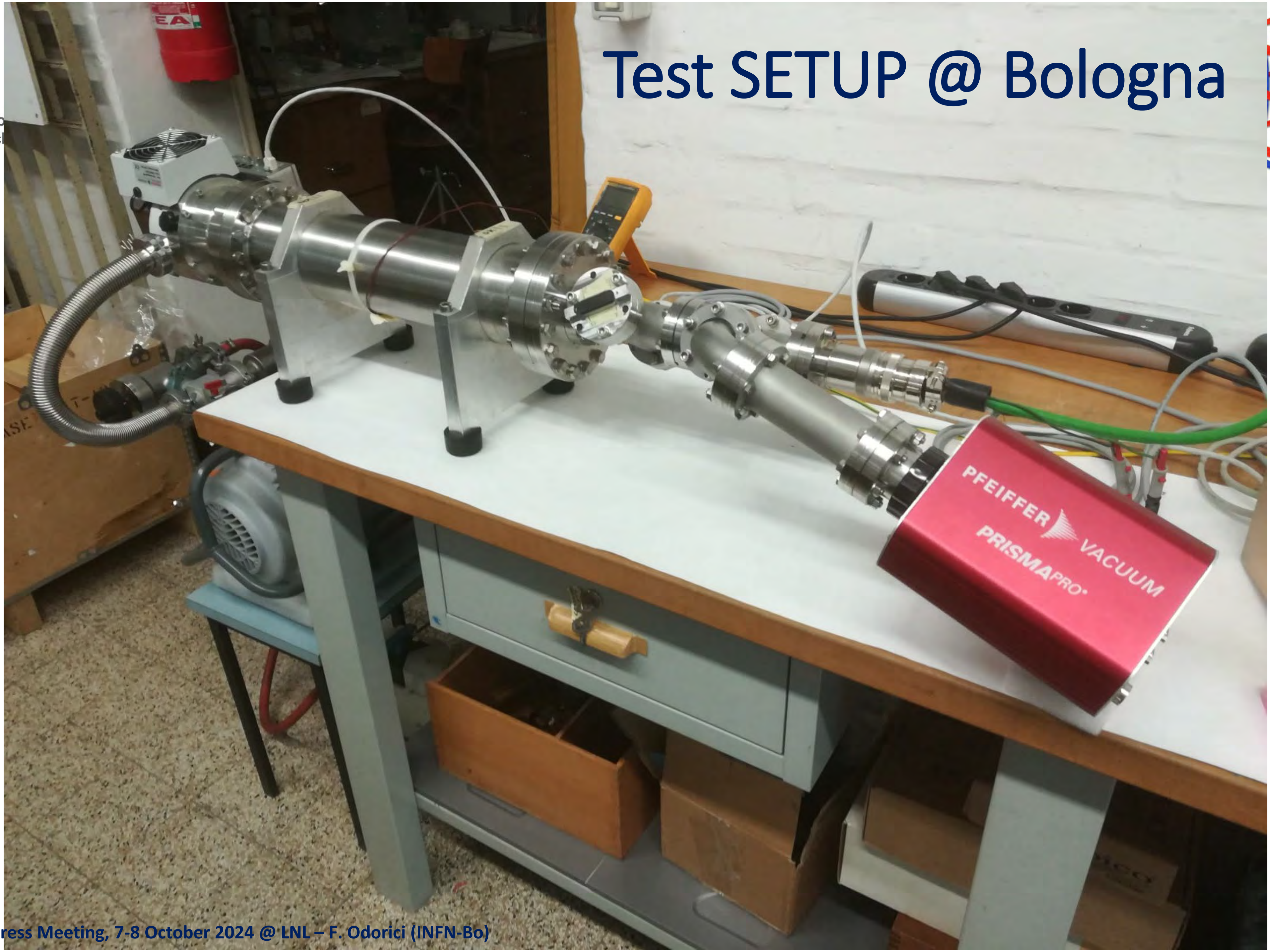
Passante sub-D25, flangia CF40

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

Istituto Nazio
di Fisica Nuc

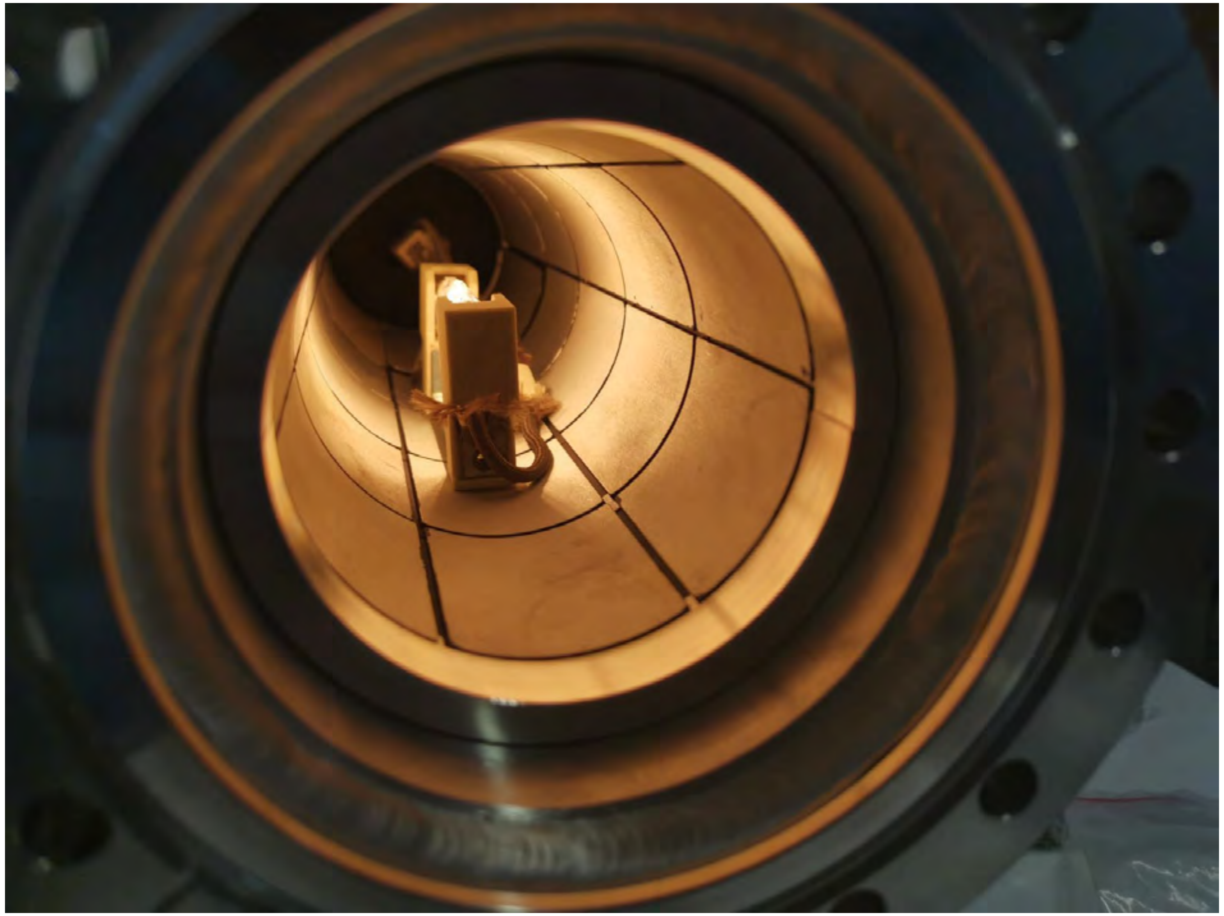
Test SETUP @ Bologna

Plasmas for
Astrophysics
Nuclear
Decay
Observation and
Radiation for
Archaeometry



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



Baking with halogen

Plasmas for
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Nuclear
Decay
Observation and
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Archaeometry

Monitoring of 6 thermocouples on different tiles

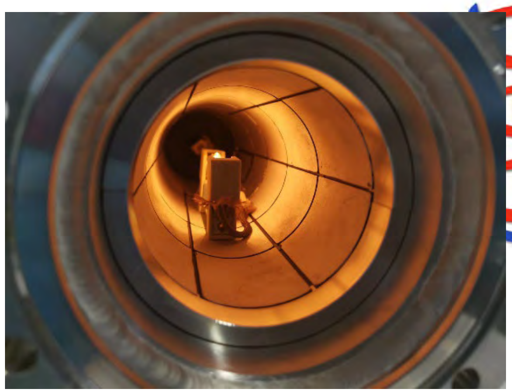
Upper shell – inner view

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

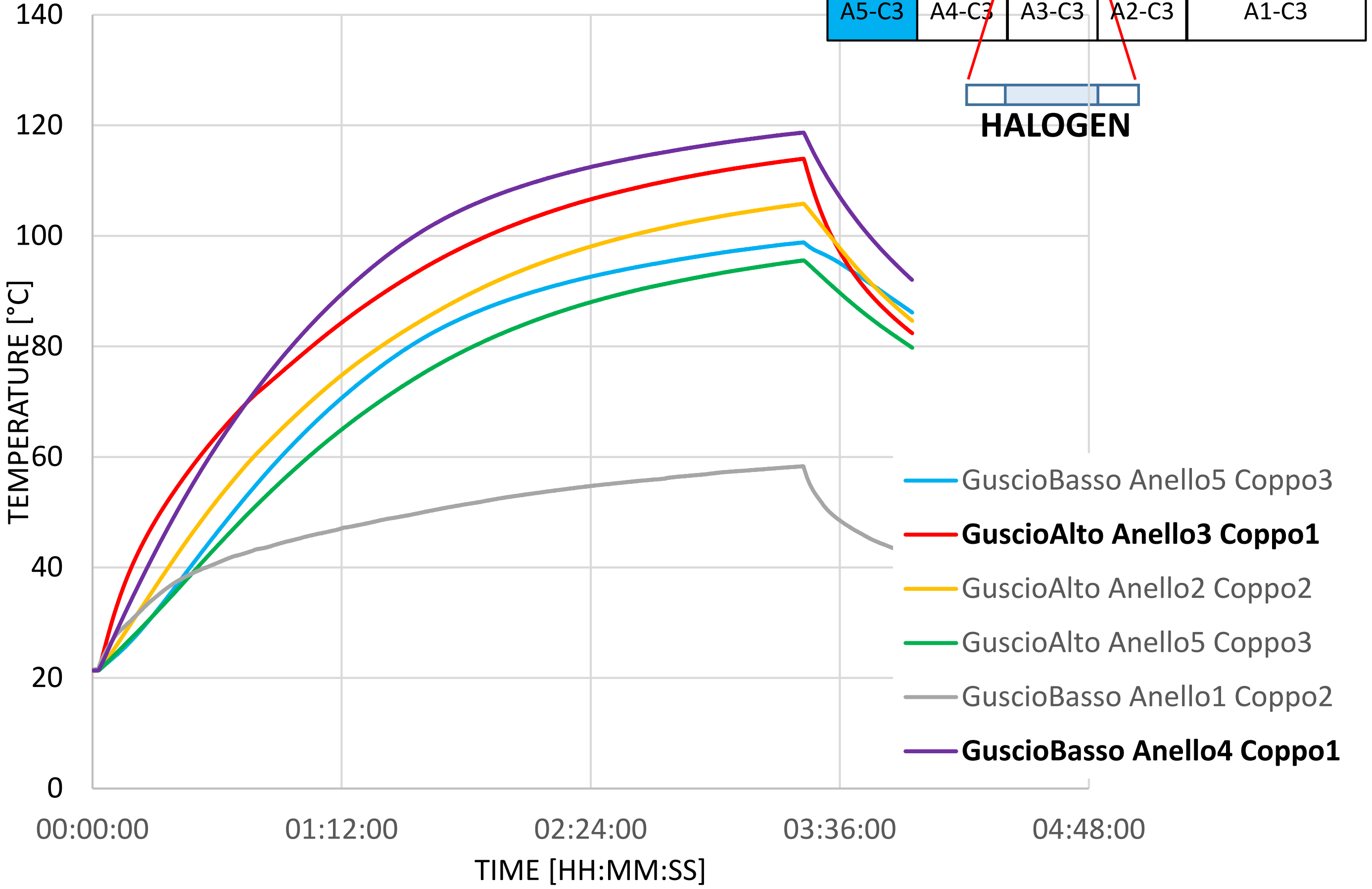
Lower shell – inner view

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

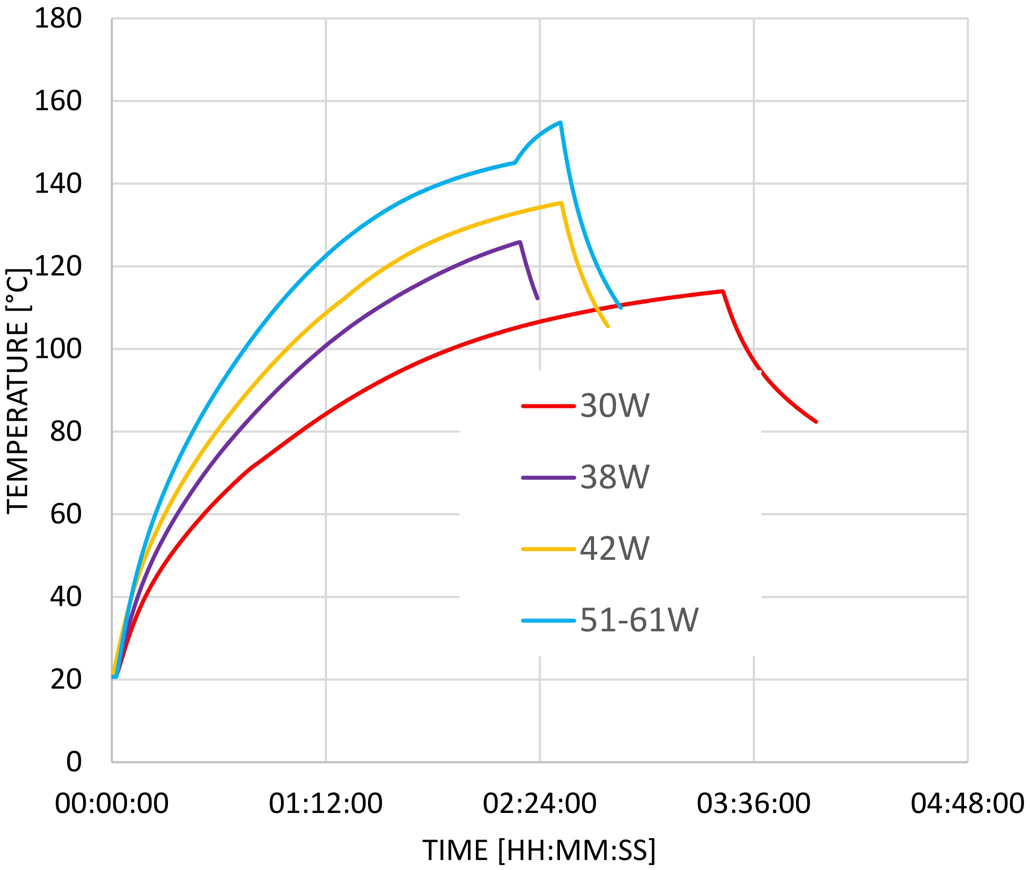
HALOGEN



Baking with halogen @ 30W



Upper shell - Ring3 - Tail1 @ various W



Baking and outgassing tests

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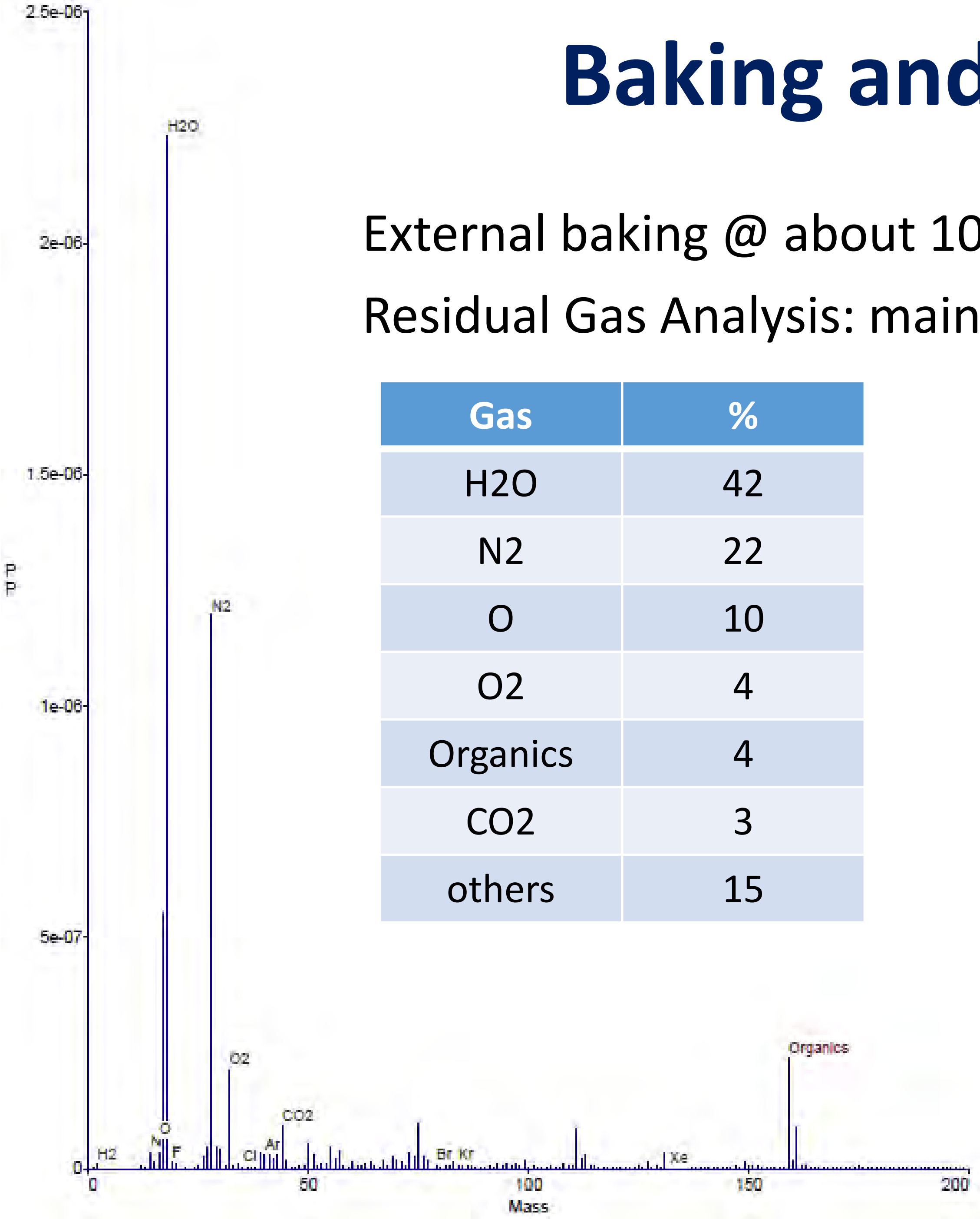


External baking @ about 100°C for 30’

Residual Gas Analysis: main outgassing @ P=1x10E-5 mbar

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

Pressure (mbar):

- 1x10E-4 in 90’
- 7.4x10E-6 after 17h
- Internal baking with halogen @ 77W
  - ➔ 8.6x10E-4 @ **tail Tmax 212°C**
  - ➔ 4.0x10E-6 @ T ambient

Pressure after baking at various power

Pressure after baking at various halogen 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**

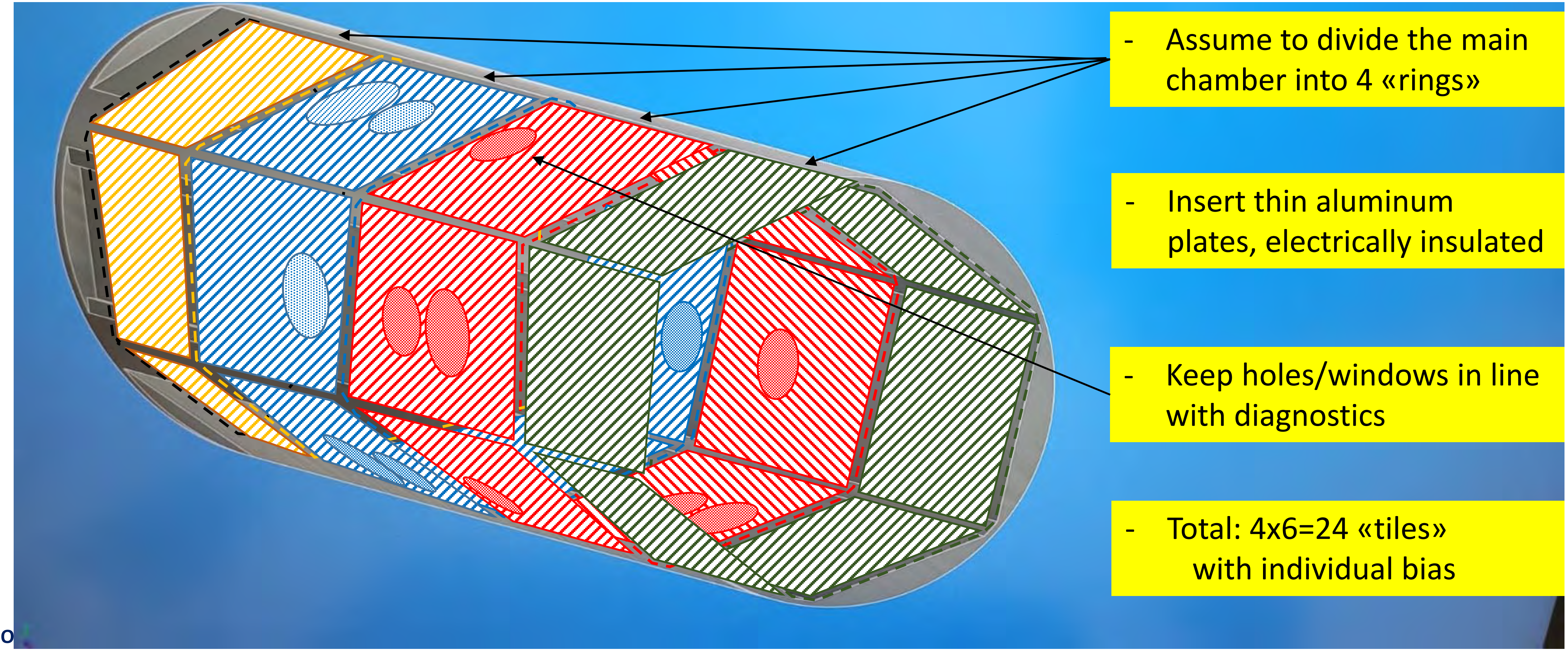
Electrical test before and after baking

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

➔ Insulation is stable

Active Plasma Inner Chamber: design options for the PANDORA apparatus

The design of the Main Plasma Chamber is ongoing (LNS + INFN-PD): design could change from a cylindrical geometry to an extrusion of an hexagonal section ➔ this geometry simplifies a lot the integration of detectors and of the Plasma Inner Chamber. The final design will be possible only when the technical specifications (dimensions) of the magnetic trap will be known.

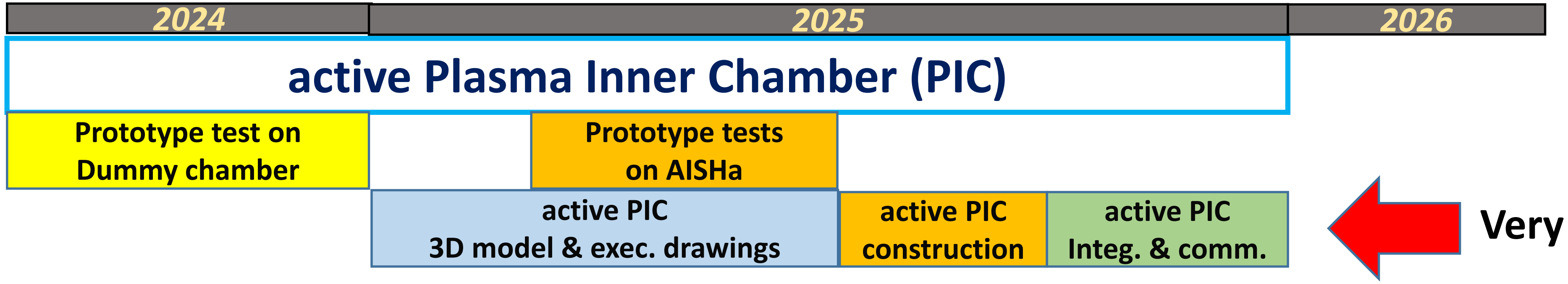


- Assume to divide the main chamber into 4 «rings»
- Insert thin aluminum plates, electrically insulated
- Keep holes/windows in line with diagnostics
- Total: 4x6=24 «tiles» with individual bias

Next activity & Timeline

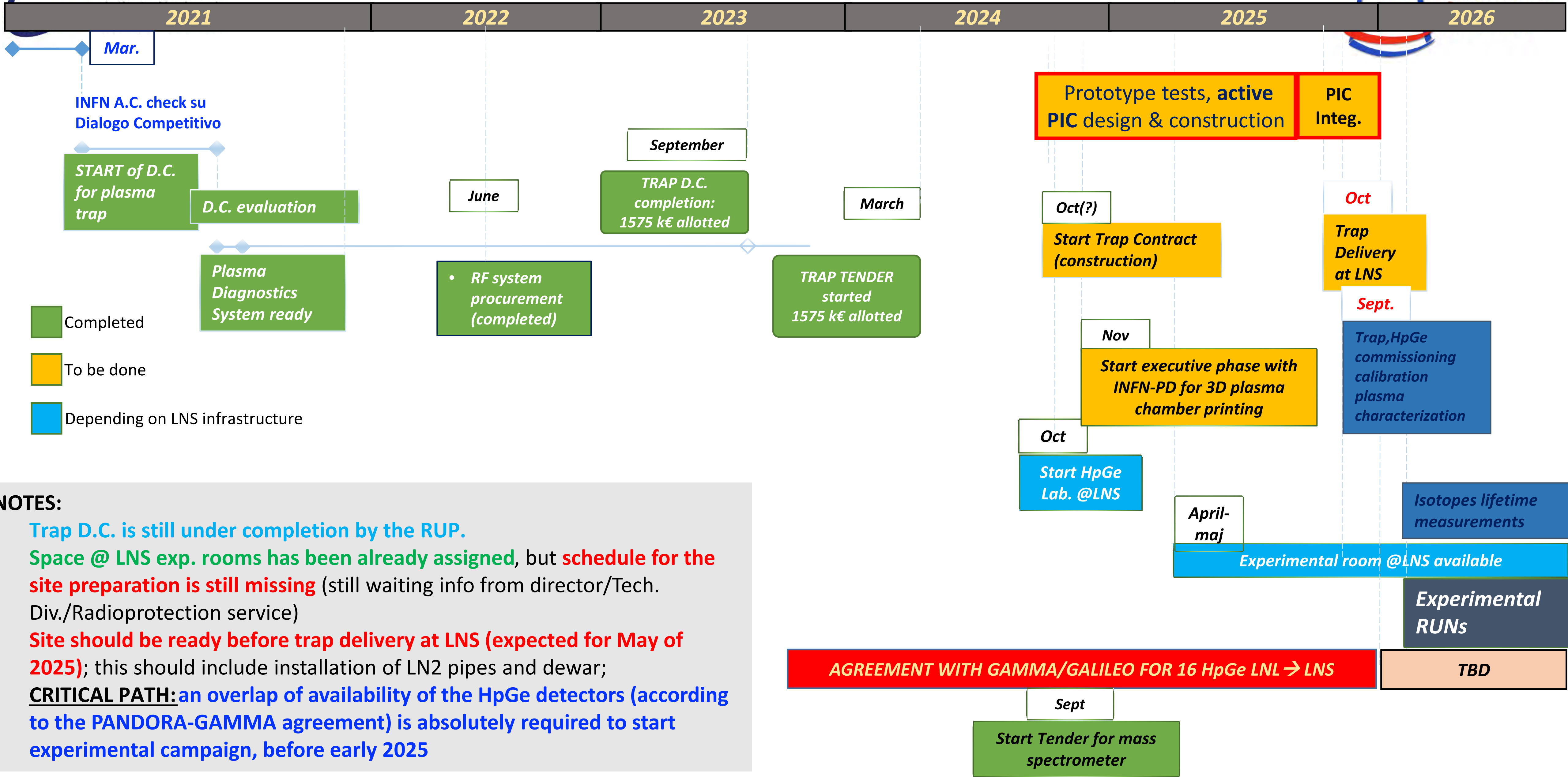
We would have results from prototype tests on AISHa before the PIC final design for PANDORA

PERIOD	NEXT ACTIVITY	RESP.	COMMENTS
nov-dec 2024	Prototype of active chamber: test on dummy ch.	BO & LNS	Emulate AISHa cooling
mar-july 2025	Prototype of active chamber: tests on AISHA	LNS & BO	Integration with AISHa
jan-feb 2025	PANDORA Active Plasma Inner Chamber: 3D model	BO & LNS & LNL	Integration with Trap design
mar-jul 2025	PANDORA Active PIC: executive drawings	BO	Integration with Trap design
aug-oct 2025	PANDORA Active PIC: construction	BO	
nov-dec 2025	PANDORA Active PIC: integration & test	LNS & BO	Integration & Commissioning



Very tight schedule!

Active PIC vs PANDORA Timeline



2021 | 2022 | 2023 | 2024 | 2025 | 2026

Mar.

INFN A.C. check su Dialogo Competitivo

START of D.C. for plasma trap

D.C. evaluation

Plasma Diagnostics System ready

June

- *RF system procurement (completed)*

September

TRAP D.C. completion: 1575 k€ allotted

March

TRAP TENDER started 1575 k€ allotted

Prototype tests, **active PIC** design & construction

PIC Integ.

Oct(?)

Start Trap Contract (construction)

Nov

Start executive phase with INFN-PD for 3D plasma chamber printing

Oct

Start HpGe Lab. @LNS

April-maj

Experimental room @LNS available

Oct

Trap Delivery at LNS

Sept.

Trap,HpGe commissioning calibration plasma characterization

Isotopes lifetime measurements

Experimental RUNs

AGREEMENT WITH GAMMA/GALILEO FOR 16 HpGe LNL→ LNS

TBD

Sept

Start Tender for mass spectrometer

🟩 Completed

🟨 To be done

🟦 Depending on LNS infrastructure

NOTES:

Trap D.C. is still under completion by the RUP.

Space @ LNS exp. rooms has been already assigned, but schedule for the site preparation is still missing (still waiting info from director/Tech. Div./Radioprotection service)

Site should be ready before trap delivery at LNS (expected for May of 2025); this should include installation of LN2 pipes and dewar;

CRITICAL PATH: an overlap of availability of the HpGe detectors (according to the PANDORA-GAMMA agreement) is absolutely required to start experimental campaign, before early 2025

Thank you
for your attention!