High power continuous wave test of RF couplers for the RFQ of the Linear IFMIF Prototype Accelerator.

DE FRANCO Andrea for the LIPAc team

第20回日本加速器学会年会 - 29th August – 1st September 2023

Linear IFMIF Prototype Accelerator (LIPAc)

Rokkasho Fusion Institute (BA Site)

Author list

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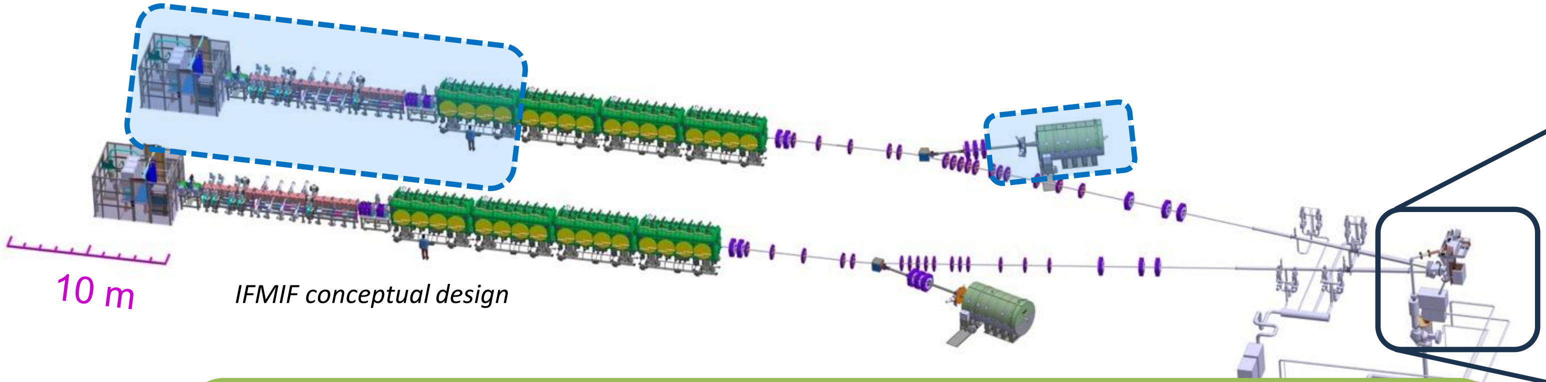
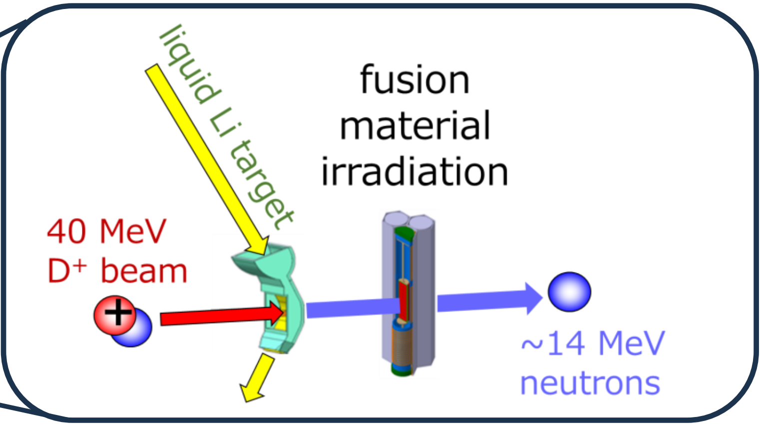
Linear IFMIF Prototype Accelerator

International Fusion Materials Irradiation Facility (IFMIF) will address the need of a neutron source for material tests toward future Fusion Power Plant

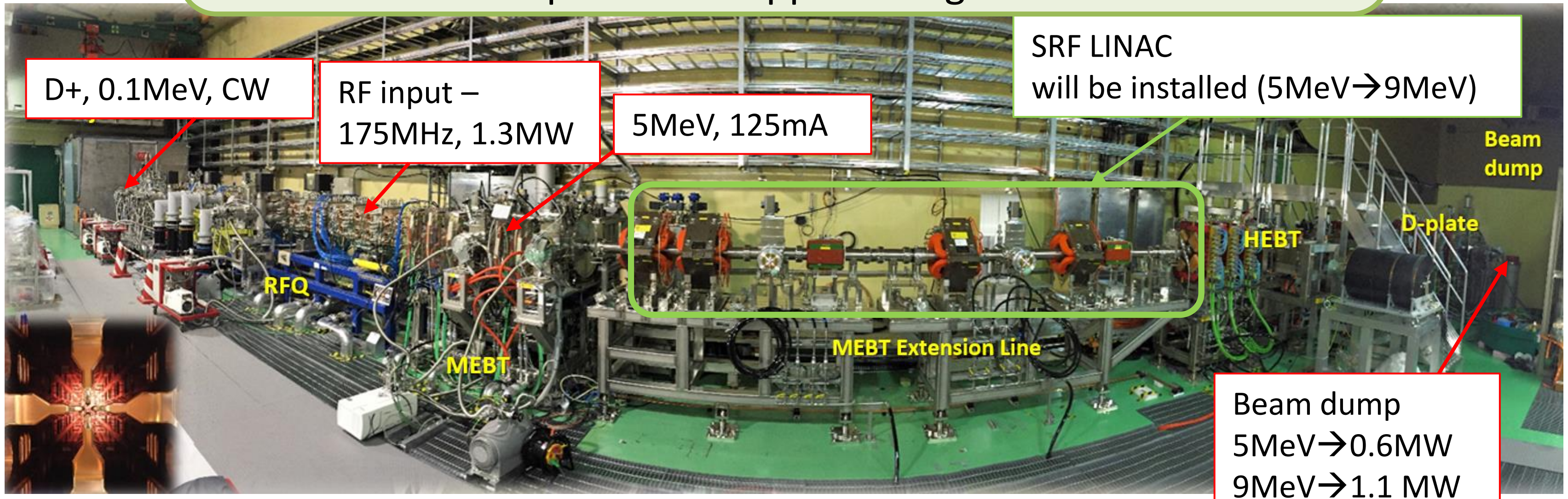


IFMIF conceptual design



Linear IFMIF Prototype Accelerator (LIPAc)
@QST in Rokkasho, Aomori, Japan
EU-Japan Broad Approach agreement

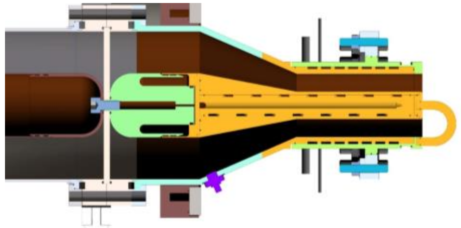
More on LIPAc/IFMIF:
Masuda: "Status of Linear IFMIF Prototype Accelerator in 2023" – TWSP16
Hirosawa: "High-Power tests of repaired circulator for LIPAc RFQ" – FRP33

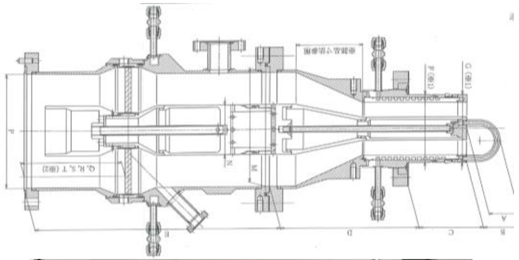


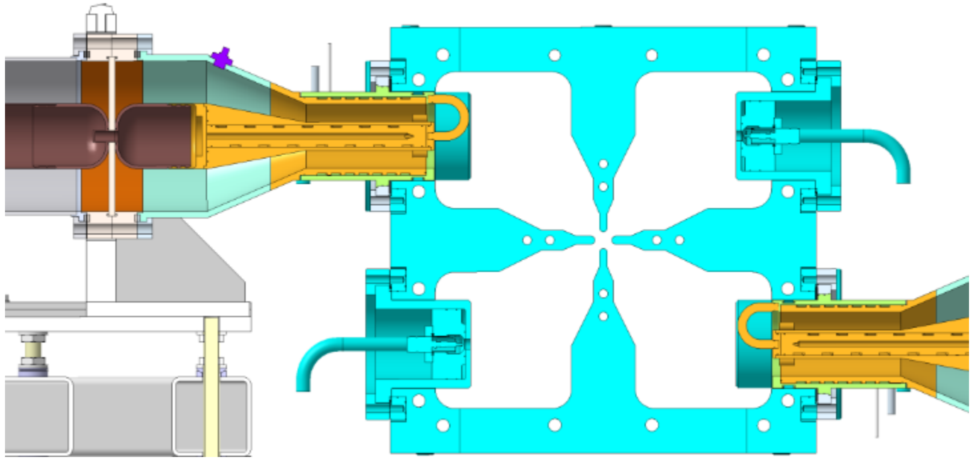
Fisheye view of LIPAc

4 of the 8 coaxial lines supplying RF to RFQ

RFQ RF couplers







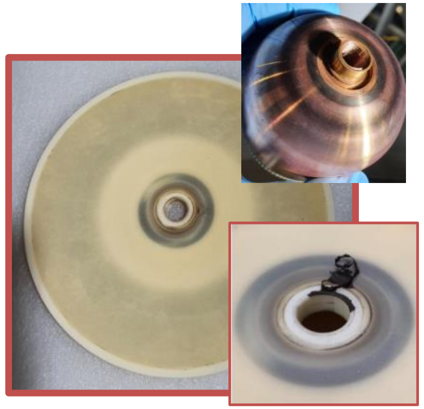
2D cut view of RFQ and its O-ring couplers before cooling enhancement.

Ceramic seal	O-ring	Brazed
Material	All Cu	Mostly SUS + 50µm Cu
Vacuum gauge	X	O
Arc sensor	Optical fibre + PD	APD on window
Antenna depth	34.86 mm	45 mm
Cooling	Loop + jacket + cold finger + forced air	Loop + around ceramic + inner conductor
Inner near window	Round near ceramic	Perpendicular near ceramic

O-ring couplers damaged during RF conditioning at high duty cycle.

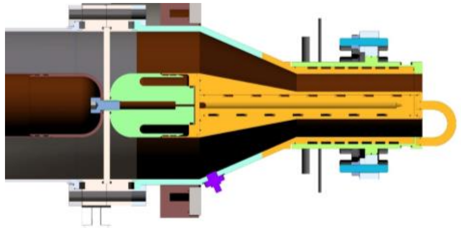
Improved heat extraction design and re-installed in RFQ.

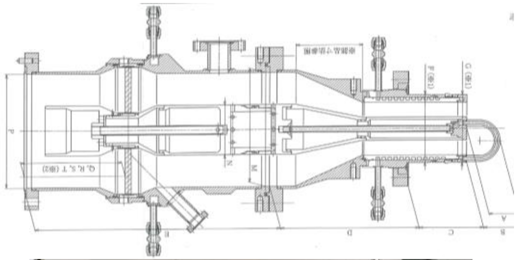
High-power test of Brazed couplers started.



Alumina window after O-ring melt. Visible O-ring debris. Cu black deposits at high filed region on ceramic and anchor.

RFQ RF couplers





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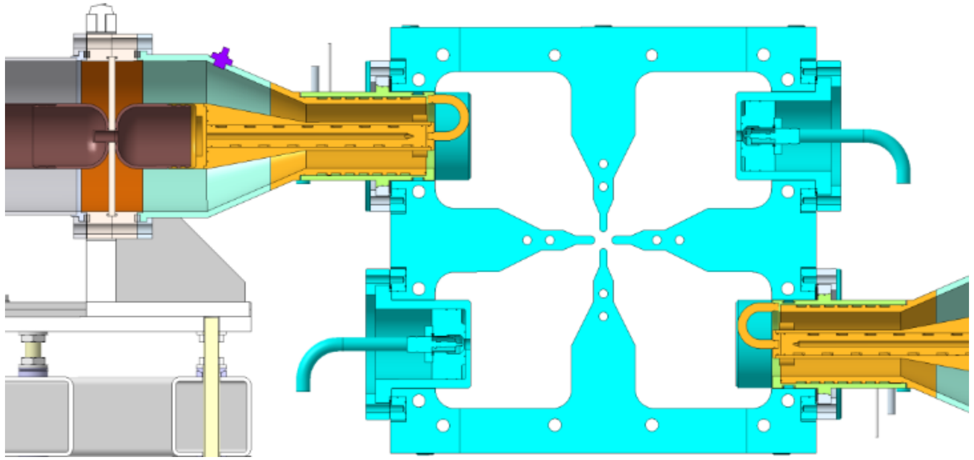

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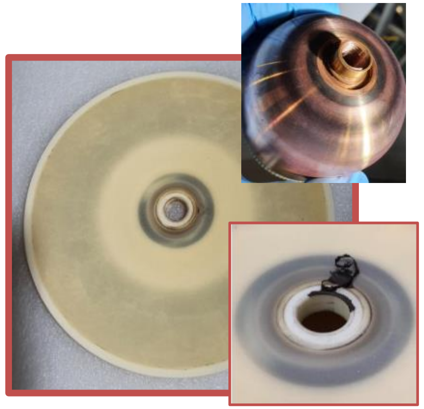
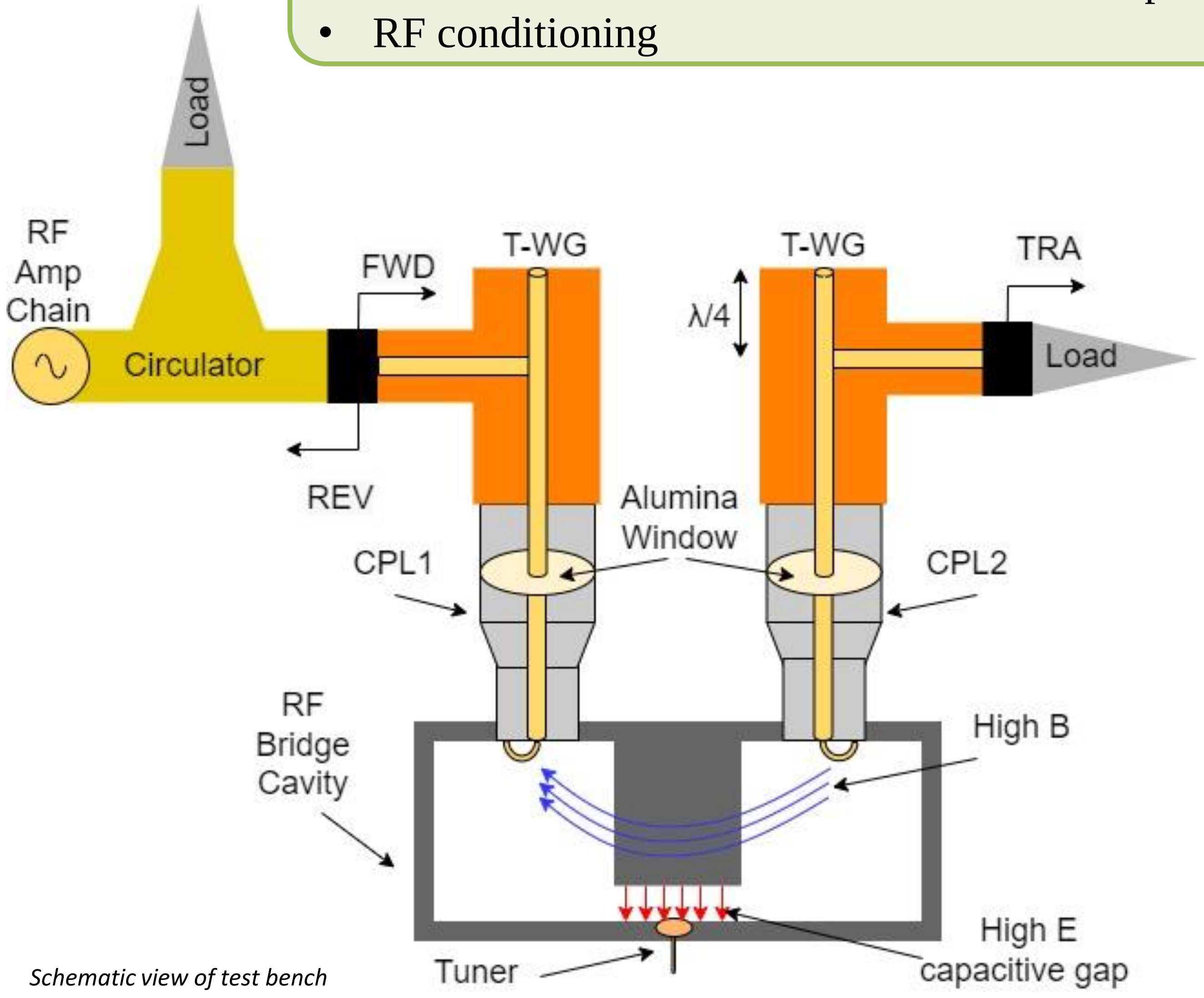


Alumina window after O-ring melt. Visible O-ring debris. Cu black deposits at high filed region on ceramic and anchor.

High Power Test Bench

Before can be used in RFQ need:

- Thermomechanical validation with forward power > 200kW in CW
- RF conditioning



Schematic view of test bench

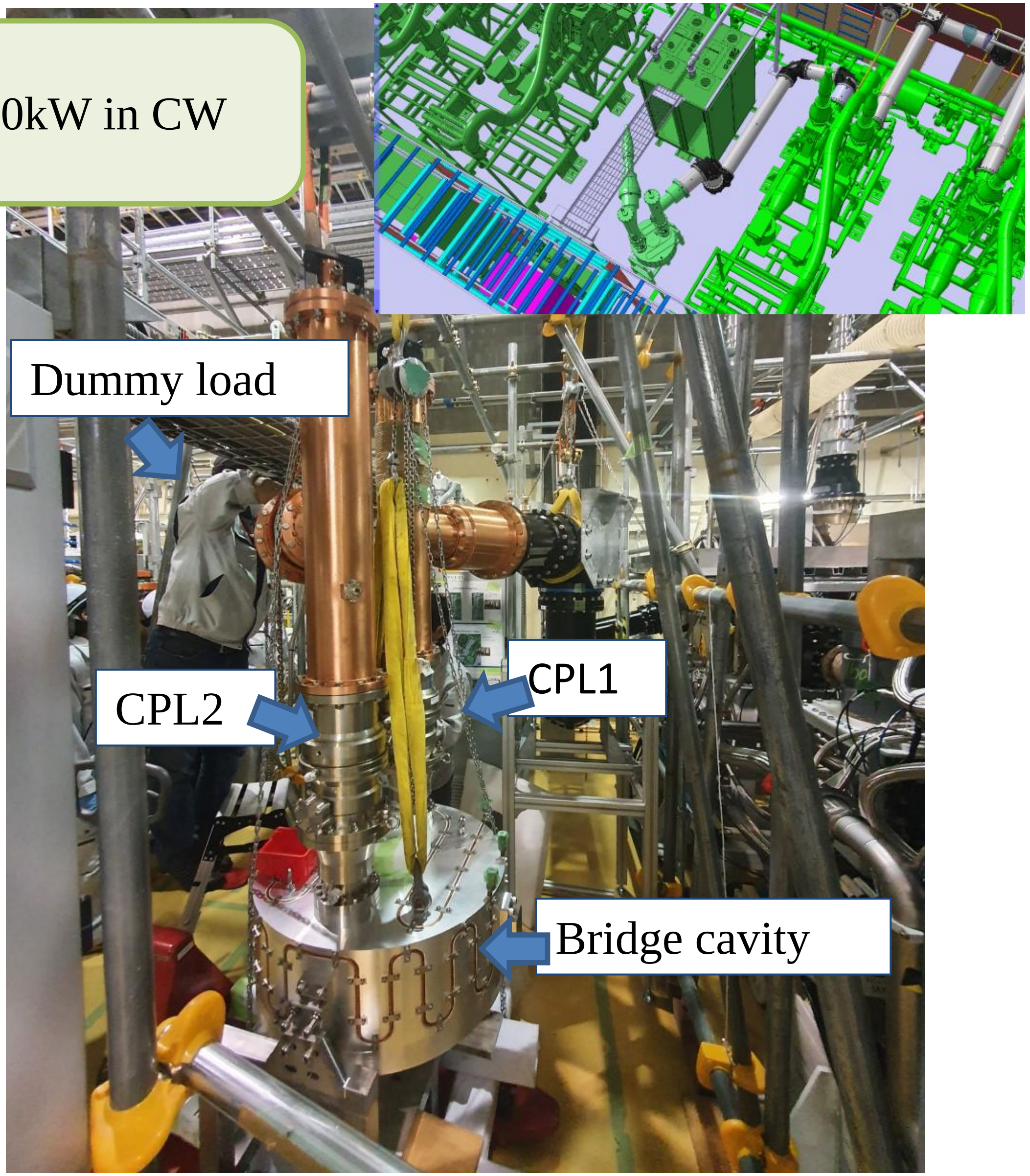
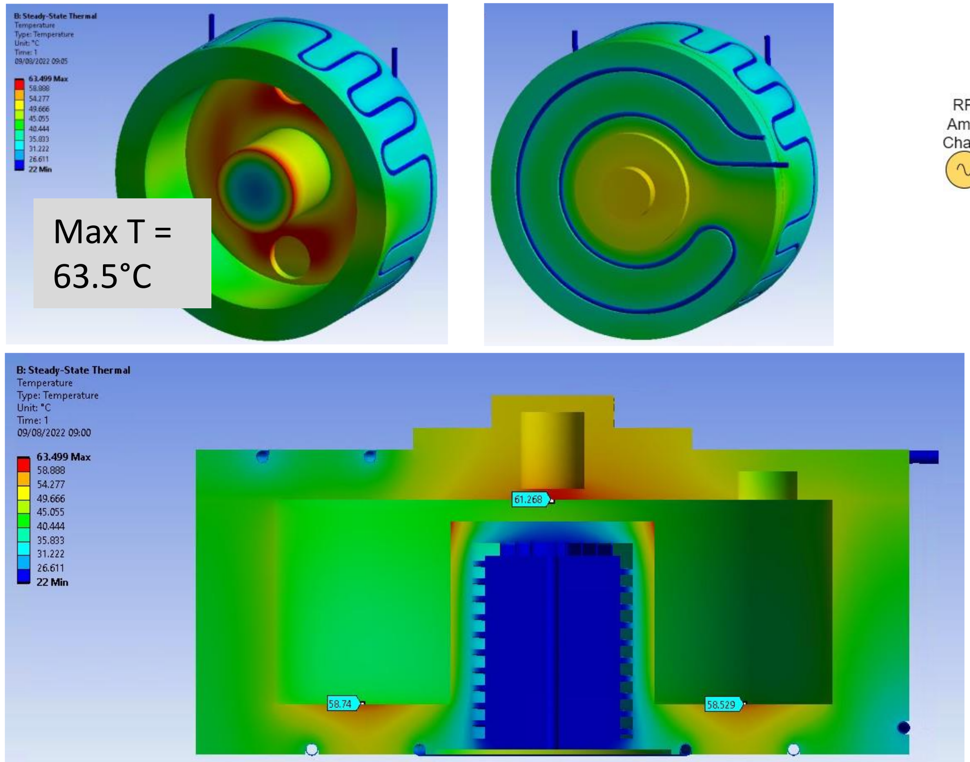


Photo during test bench assembly

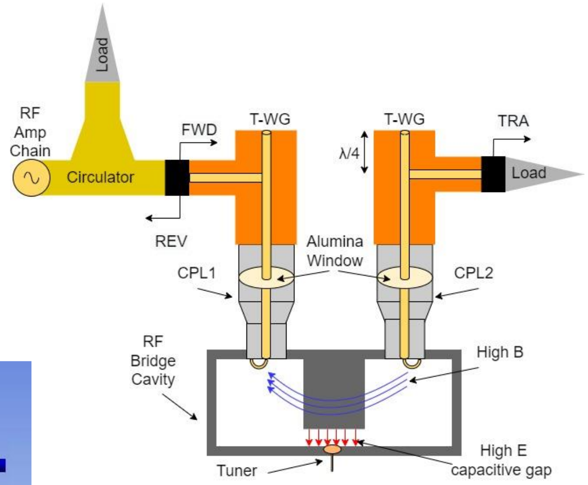
High Power Test Bench - 2

Cooling
Loss in cavity ~12%
12 L/min each coupler (3 circuits)
55 L/min cavity cooling (4 circuits)

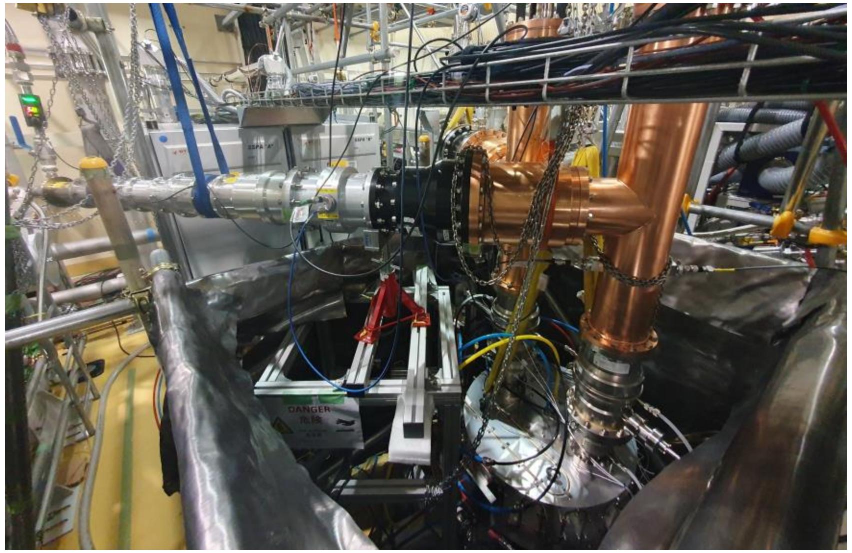


Thermal simulations of cavity at CW with FWD 220kW.

Vacuum
80 L/s TMP + scroll pump
72 hours baking at 100°C



Shielding
2 x 1 mm thick Pb curtain



Pb shielding around test bench.

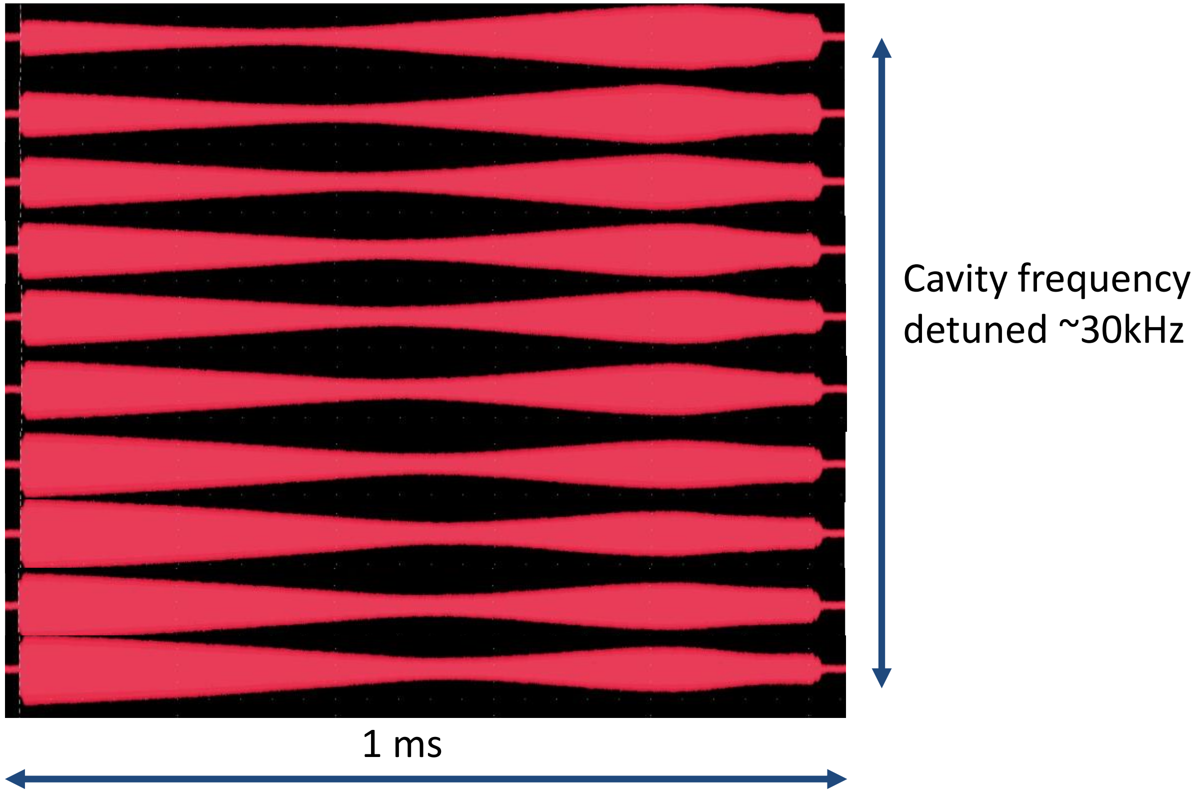
Instrumentation
RGA+ Cold cathode vacuum gauge
Arc sensor in each coupler
9 PT100
2 IR camera
Dose counter (outside shield)
Remote movable tuner
Calorimetry on CPL1

RF conditioning

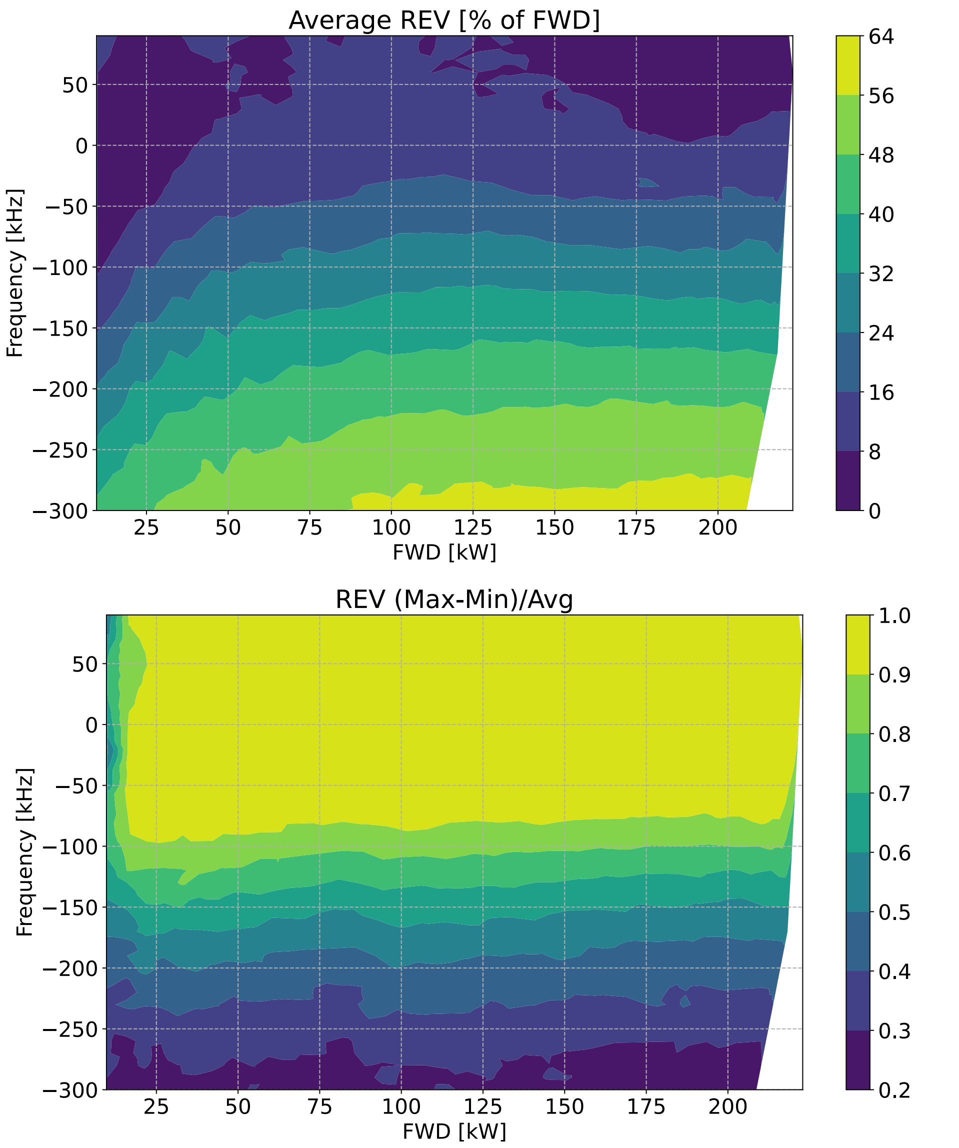
1. Increase FWD to 220 kW, 10 μs pulse width, 1 s rep. period
2. Decrease rep. period to 10ms
3. Elongate pulse width

REV pulse shape + vacuum $H_2 0$ splits in O and H

→Multipacting/Plasma?

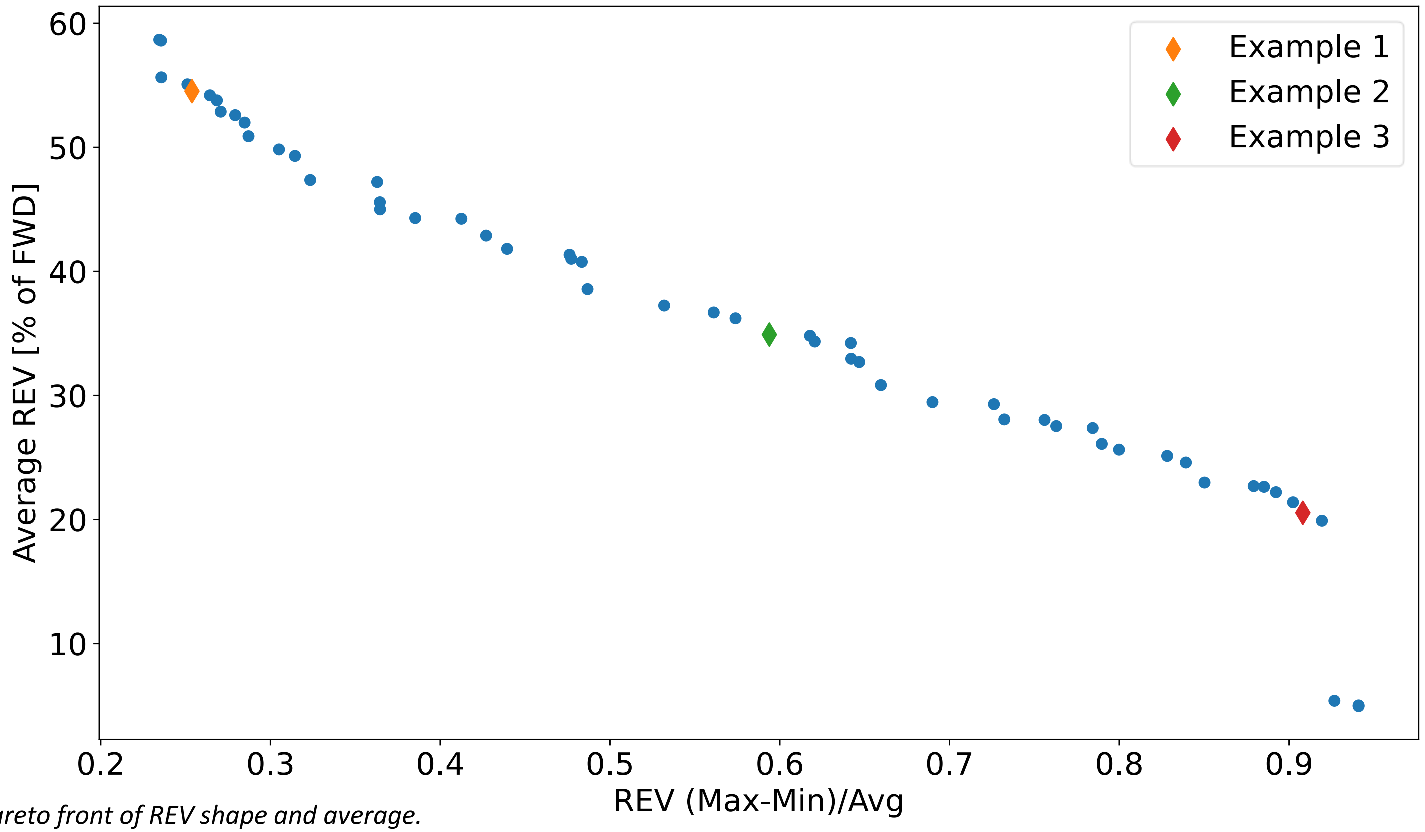


Rev pulse shape for different resonant frequency adjusted with tuner.



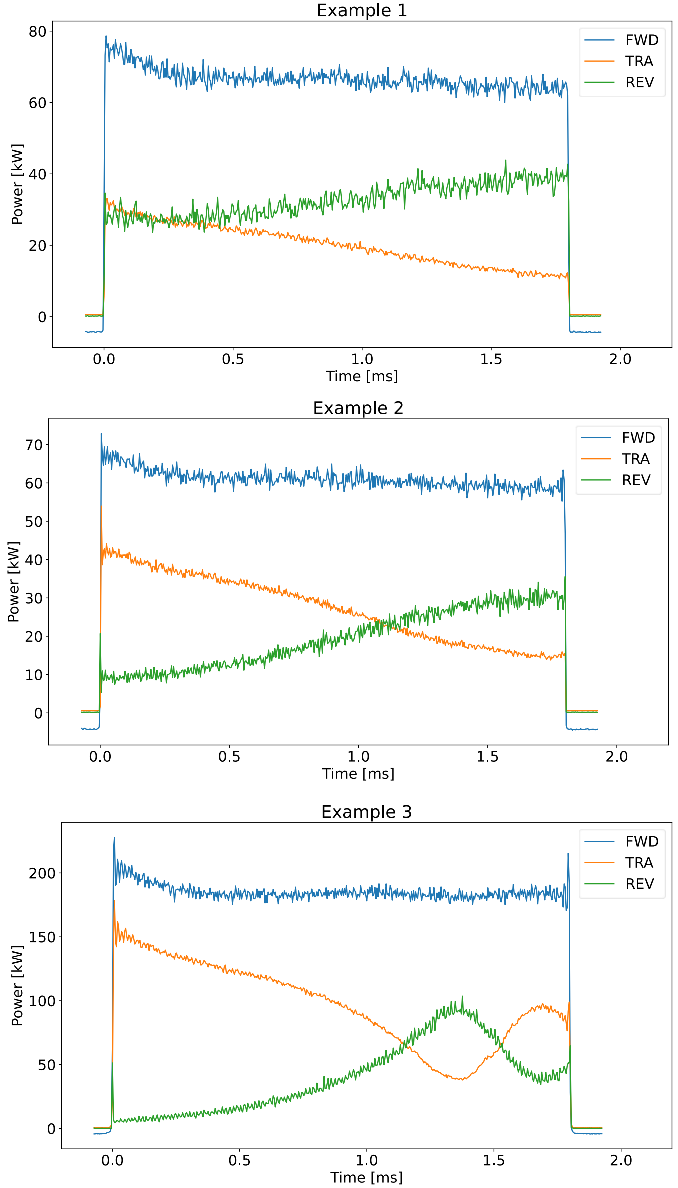
2D scan of FWD and its frequency. No overlap with flat and small on average REV.

Multipacting



Pareto front of REV shape and average.

Multipacting is present in any combination of FWD/frequency the system is capable to operate at. End of the test?

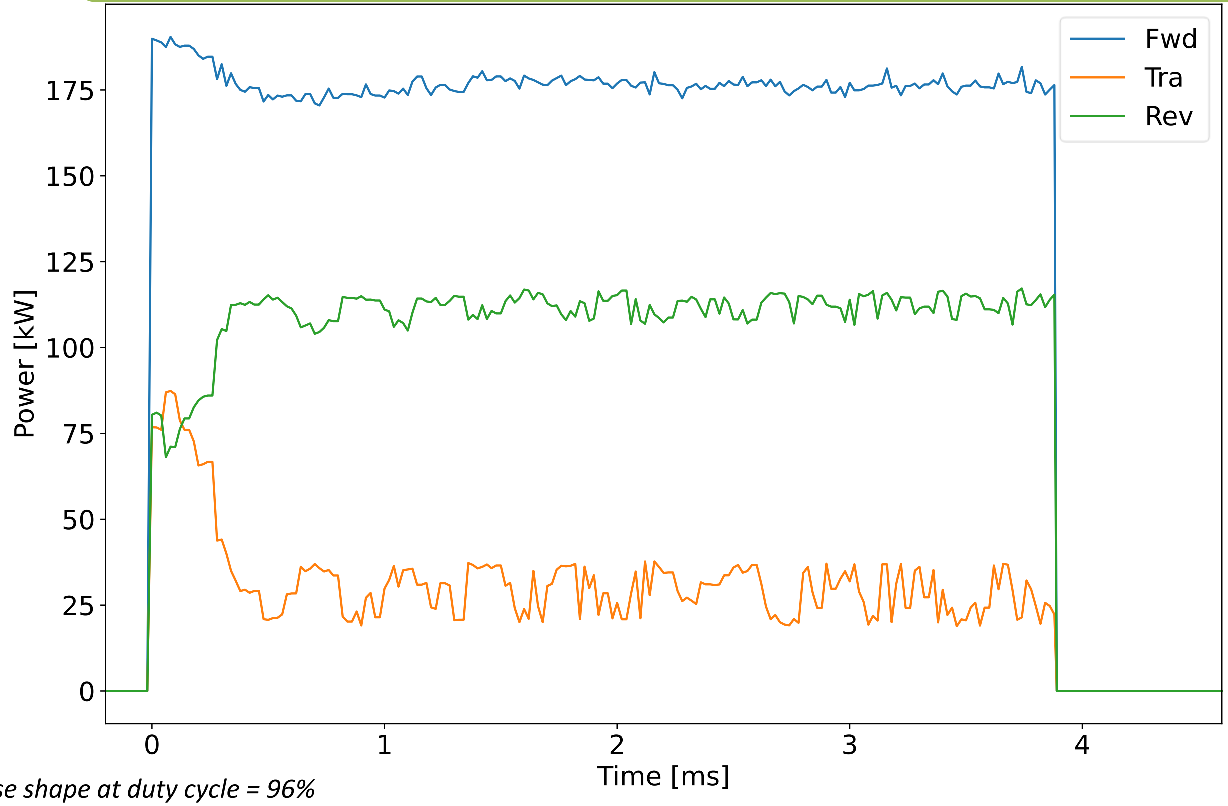


Example pulse shapes along the Pareto front of REV shape and average.

Thermomechanical design validation

TRA too low to conclude on CPL2
CPL1 in much stricter conditions than originally intended.
→ sufficient for design validation!

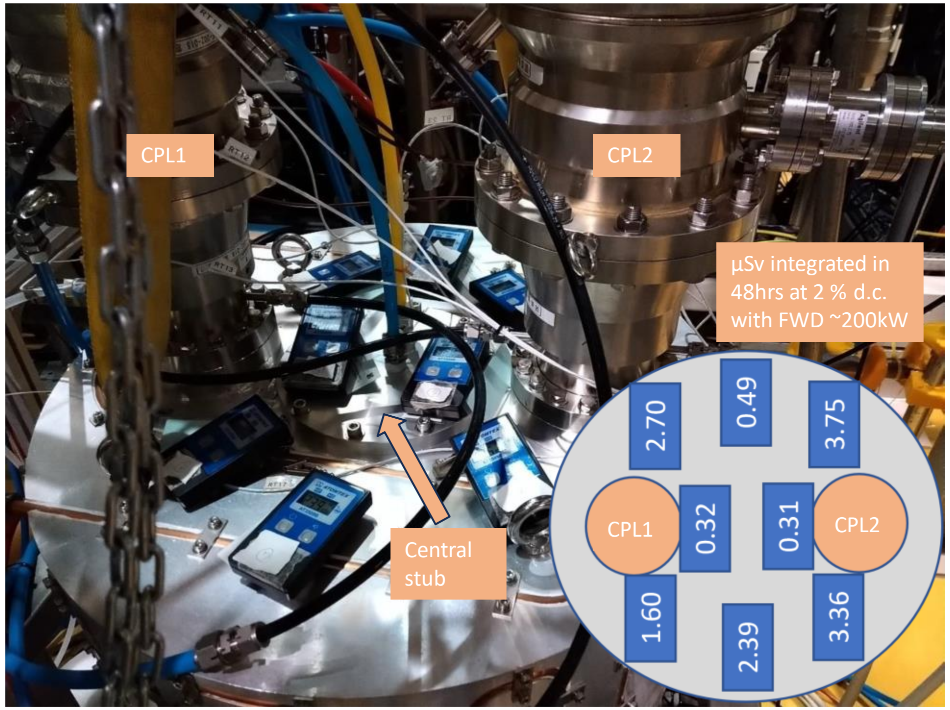
Pulse shape at 96% d.c. with at PW ~ 3.8 ms, RP = 4 ms.



Pulse shape at duty cycle = 96%

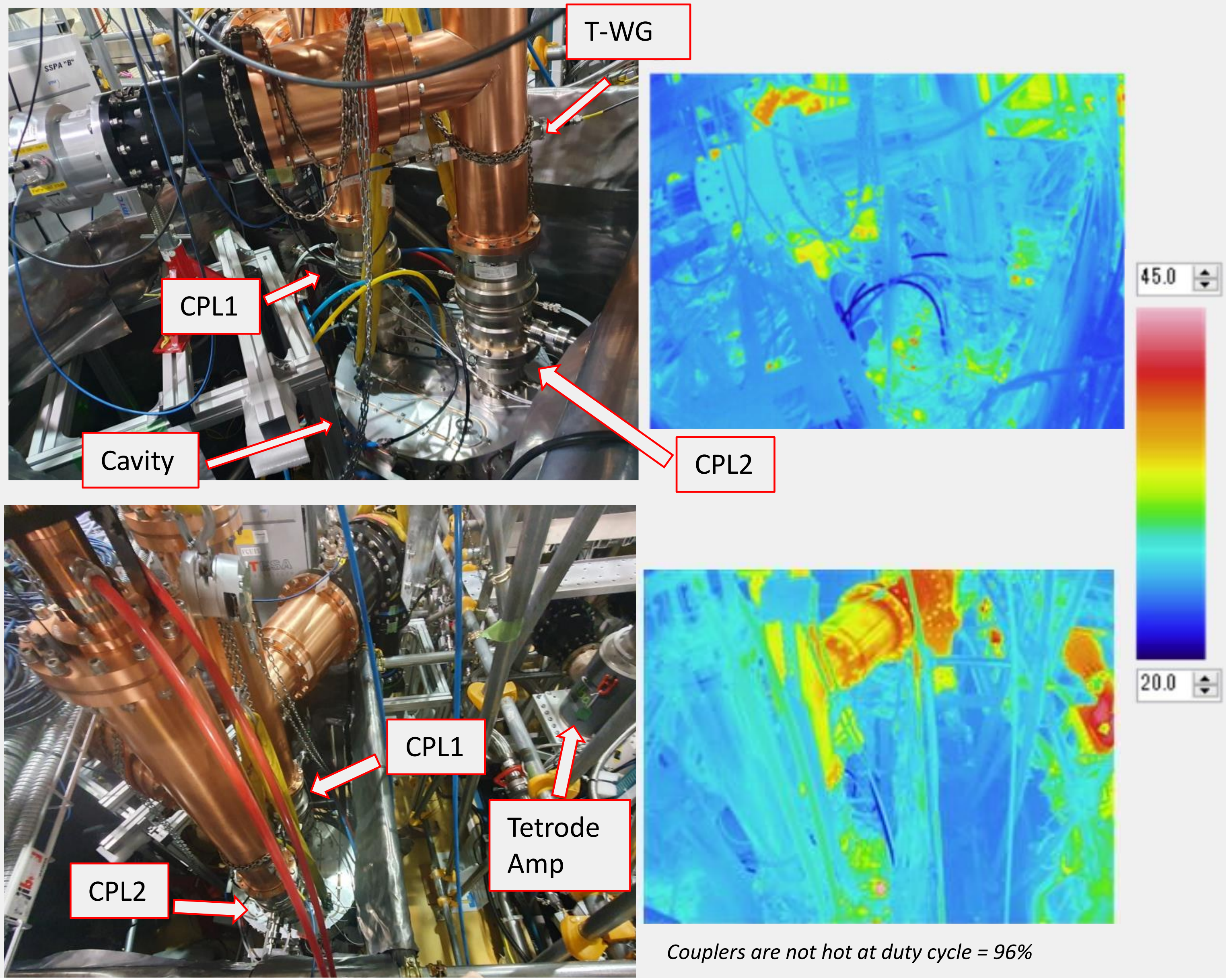
<u>MP in cavity, not in CPL1 because:</u>

- CPL1 T increase minimum
- Cavity tuning changes pulse shape
- No light observed at CPL1 view port
- High SEY of Al
- Cavity visual inspection after test

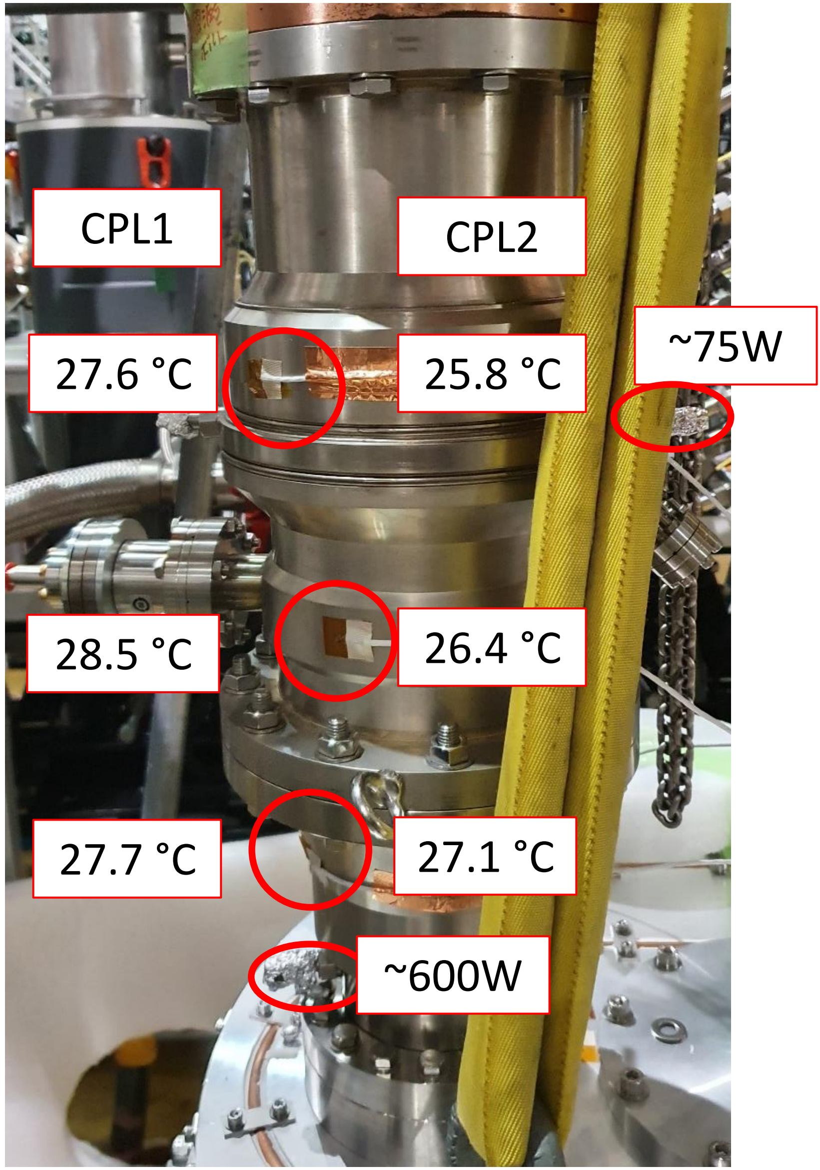


Integrated dose at d.c. 2% FWD 200kW over 48hrs. Low dose on central stub.
→X-ray from gap in cavity (no MP in CPL1)

Surface Temperature at 96% duty cycle



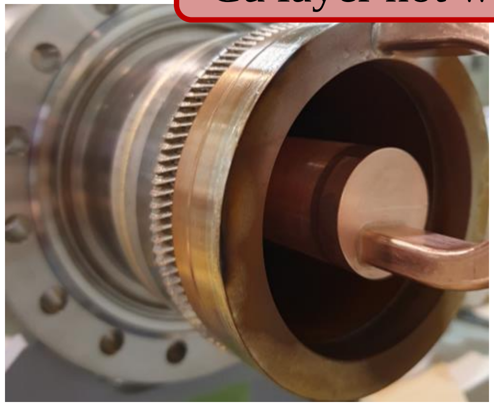
Couplers are not hot at duty cycle = 96%

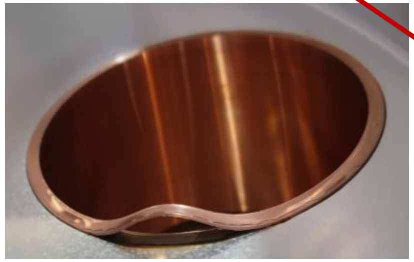


Couplers not hot at duty cycle = 96%. Heat measured with calorimetry hardly compatible with MP in CPL1.

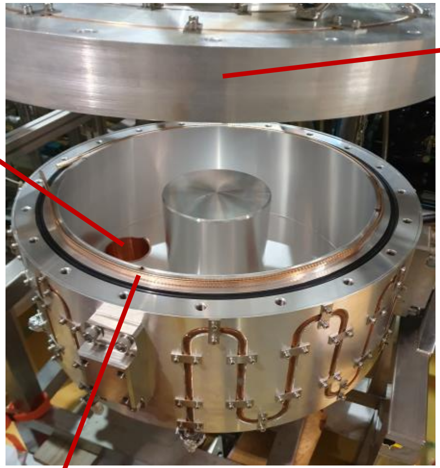
Cavity visual inspection

Cu layer not well attached - melted

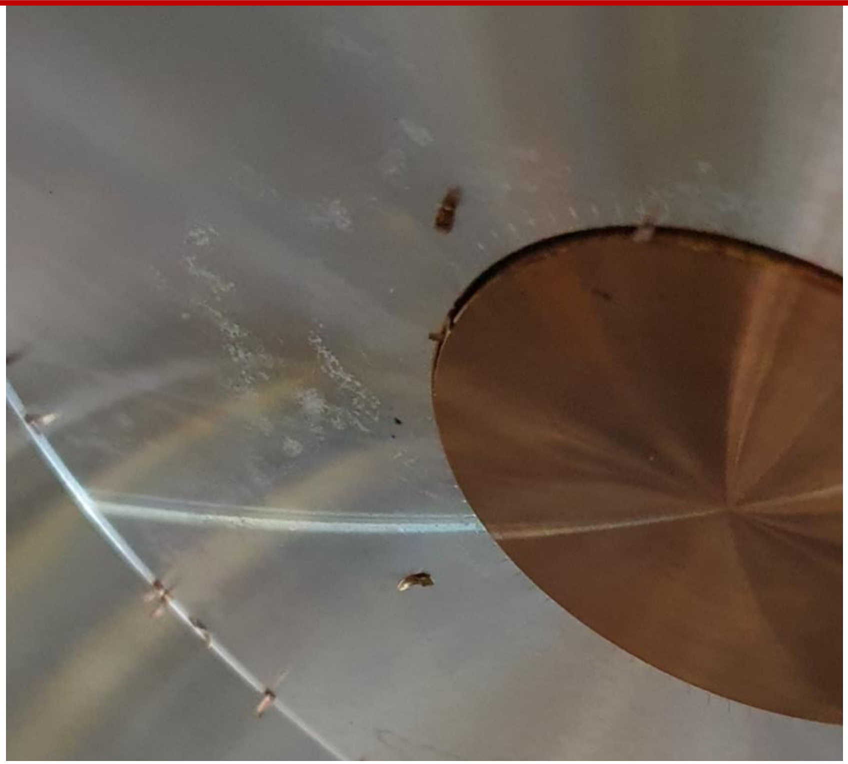




Cu layer on SUS input flange not well attached, RF enter gap and create loop, which further melt and deform. Heat marks on the nearby coupler are visible.

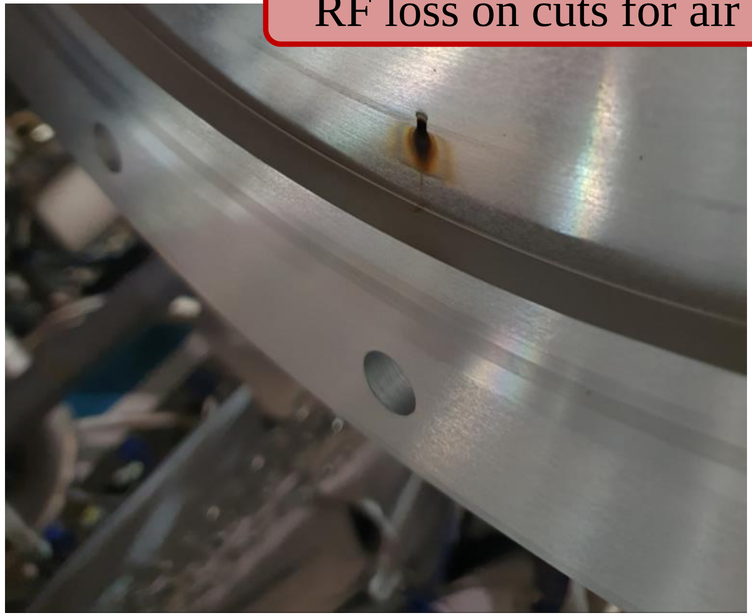


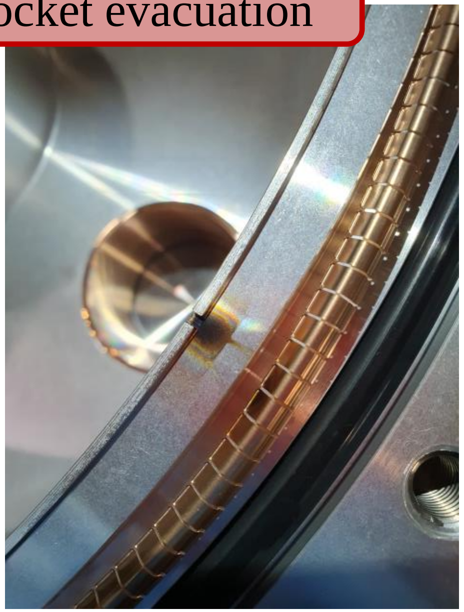
MP / Arcs , protruded and melted RF fingers



Traces of MP on cavity surface near tuner. Also,visible deformed and melted RF fingers.

RF loss on cuts for air pocket evacuation



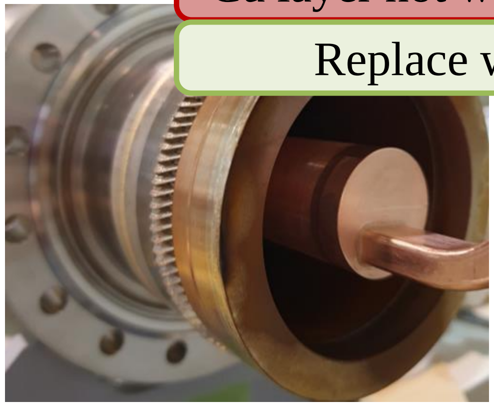


RF loss induced heat in the cuts used for evacuation of air pocket near O-ring.

Cavity visual inspection

Cu layer not well attached - melted

Replace with Cu plating



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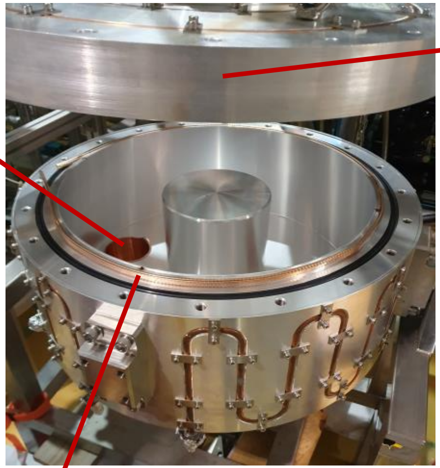


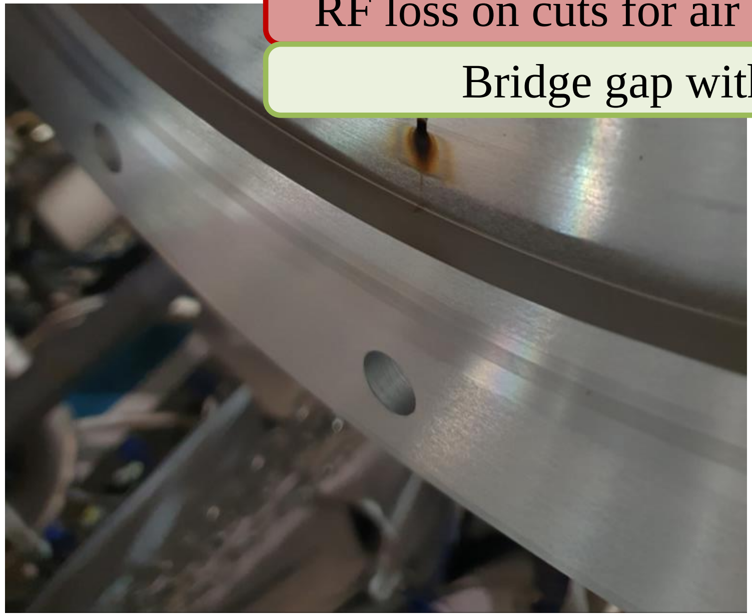
MP / Arcs , protruded and melted RF fingers

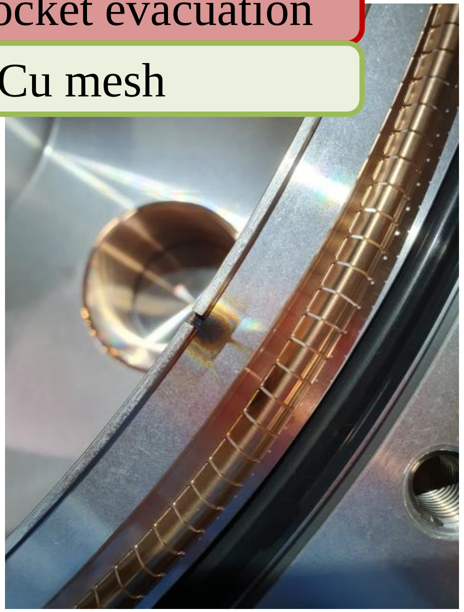
Edges/gaps of tuner in high E region not ideal.
Remove tuner and replace with flat lid.
Cu plating of entire inner surface.

Traces of MP on cavity surface near tuner. Also,visible deformed and melted RF fingers.

RF loss on cuts for air pocket evacuation

Bridge gap with Cu mesh





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Conclusion

- LIPAc RFQ RF conditioning and beam commissioning towards CW ongoing.
- RF couplers identified as critical system.
- O-ring based couplers used so far were improved and re-installed
- Original coupler`s thermal design validated with a high-power high duty cycle test bench
- Bridge cavity will be improved to complete test/conditioning of the series.