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International Cryogenic Materials Conference 2024
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Cooling system for the MEESST MHD heat flux and radio blackout mitigation HTS Magnet probe

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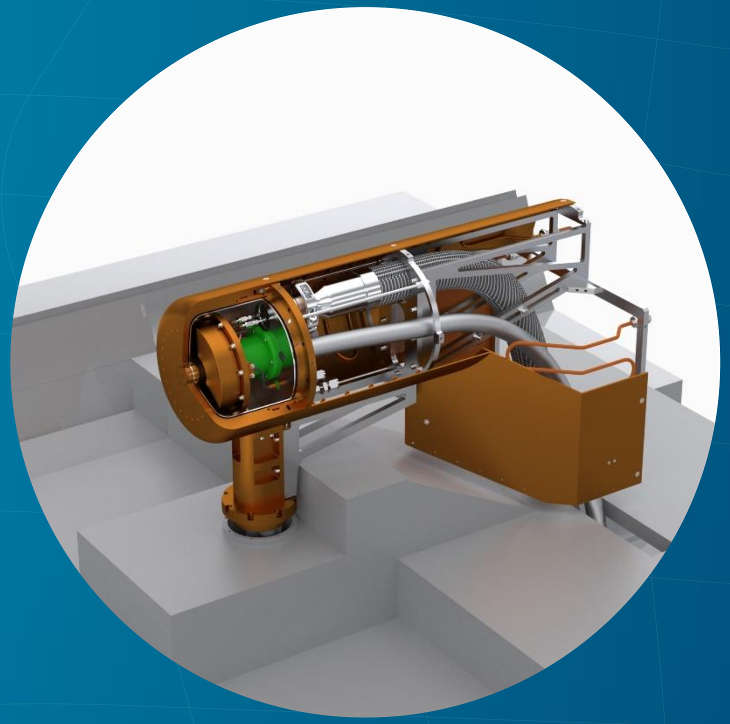

Date : 24/07/2024

Presented by Matthieu DALBAN-CANASSY
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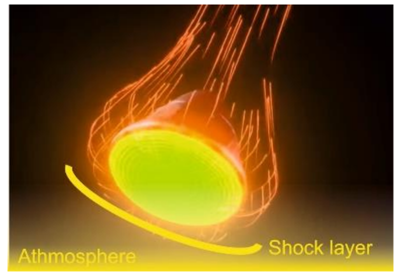
INTRODUCTION

Target Interplanetary entry missions:

High energy loads up to hundreds of MJ/kg to be dissipated

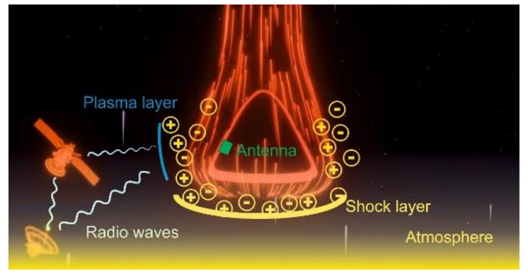
Typical entrance velocities from 11 to 50 km/s

Thermal protection system requirements



- Survivability of the payload
- Lightweight
- Low catalycity
- Chemical and mechanical resilience against the extreme aerothermal loads

Radio communication black-out issues



- High plasma densities
- Black-outs of a few minutes are common during entry phases

Magnetohydrodynamic Enhanced Entry System for Space Transportation (MEESST)

→ **Heat load decrease**

→ **Open the communication window**

Financed through Europe H2020

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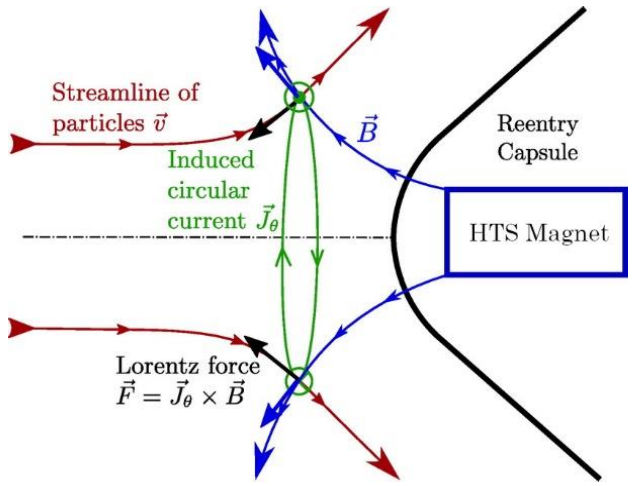
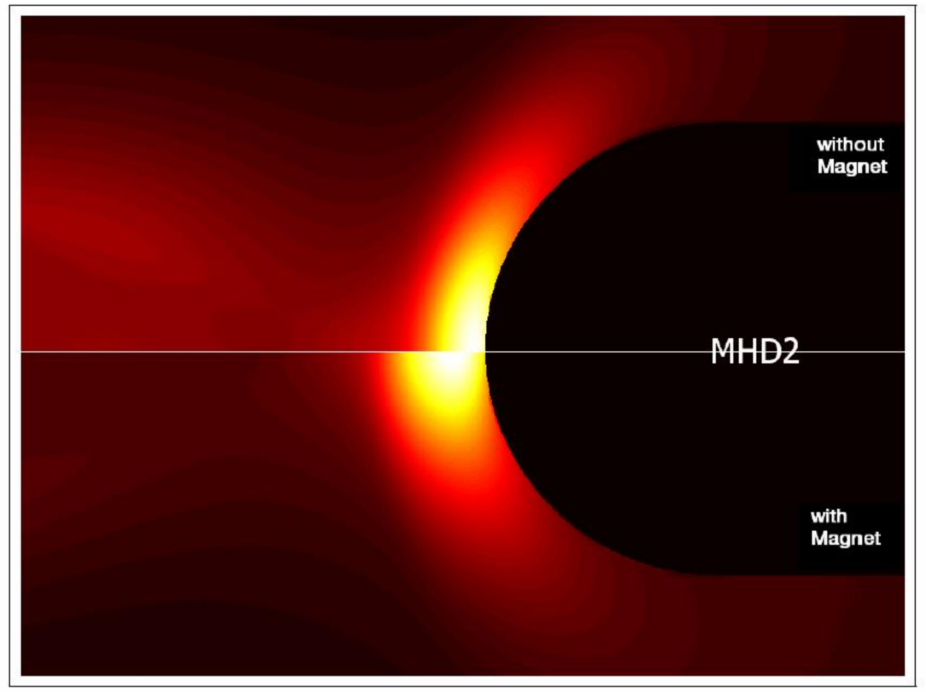
MEESST - Goal

• Plasma Flow Manipulation with MHD

Past experiments with permanent magnets have shown the positive impact of a magnetic field on the plasma, pushing away the shock stand-off

Magnetic field configuration and acting forces:





Knapp 2012, The Open Plasma Physics Journal
Measurements done at IRS, Stuttgart

• MEESST Objective

Design a probe using an HTS magnet to increase the field generated at the stagnation point to increase the field effect on the plasma

Probe dimensions to be implemented in numerical models for later real-life entry capsules dimensions estimations

Two plasma chambers for testing in air:

=> @IRS in Stuttgart, Germany, for the heat flux measurements in PWK1 supersonic conditions available

=> @VKI in Sint-Genesius-Rode, Belgium for the black-out experiment in the plasmatron, subsonic flow

EU funding: grant agreement N°899298

Call/topic: FET-Open Challenging Current Thinking

Duration: 10/2020 – 09/2024 (incl. Extension)

Budget: 3.48M€

Consortium:

Modeling

- **KU Leuven (BE)** Project coordinator, Code harmonization
- **University of Luxembourg (LU)** Radio blackout modelling
- **University of Southampton (UK)** Code harmonization
- **AEDS SARL (CH)** Radiative heat transfer modelling

HTS Magnet and cryogenic System

- **Theva Dünnschichttechnik (DE)** HTS tape design and production
- **Karlsruhe Institute of Technology (DE)** HTS Magnet design and production
- **Absolut System (FR)** Cryogenic system design and production

Plasma Experiments

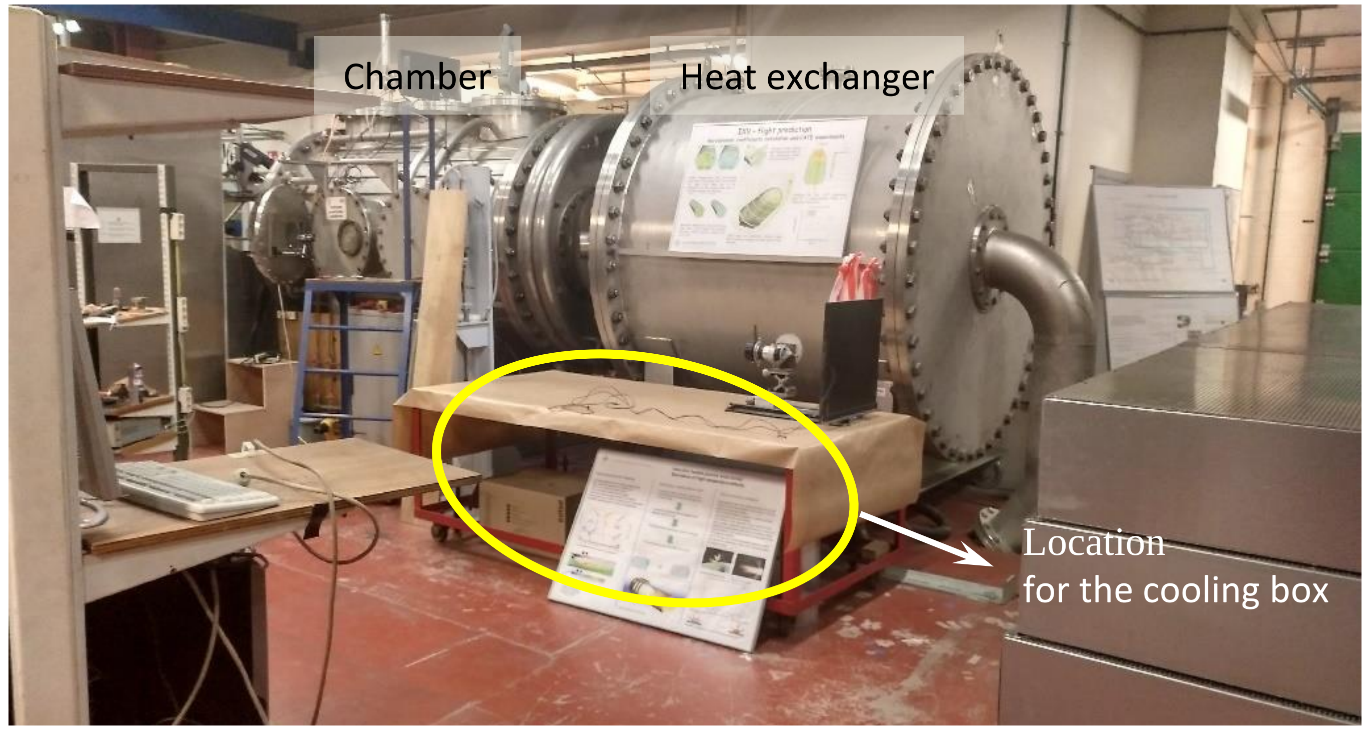
- **Von Karman Institute (BE)** Experimental radio blackout research
- **Institute of Space Systems (DE)** Experimental heat flux research, Code harmonization

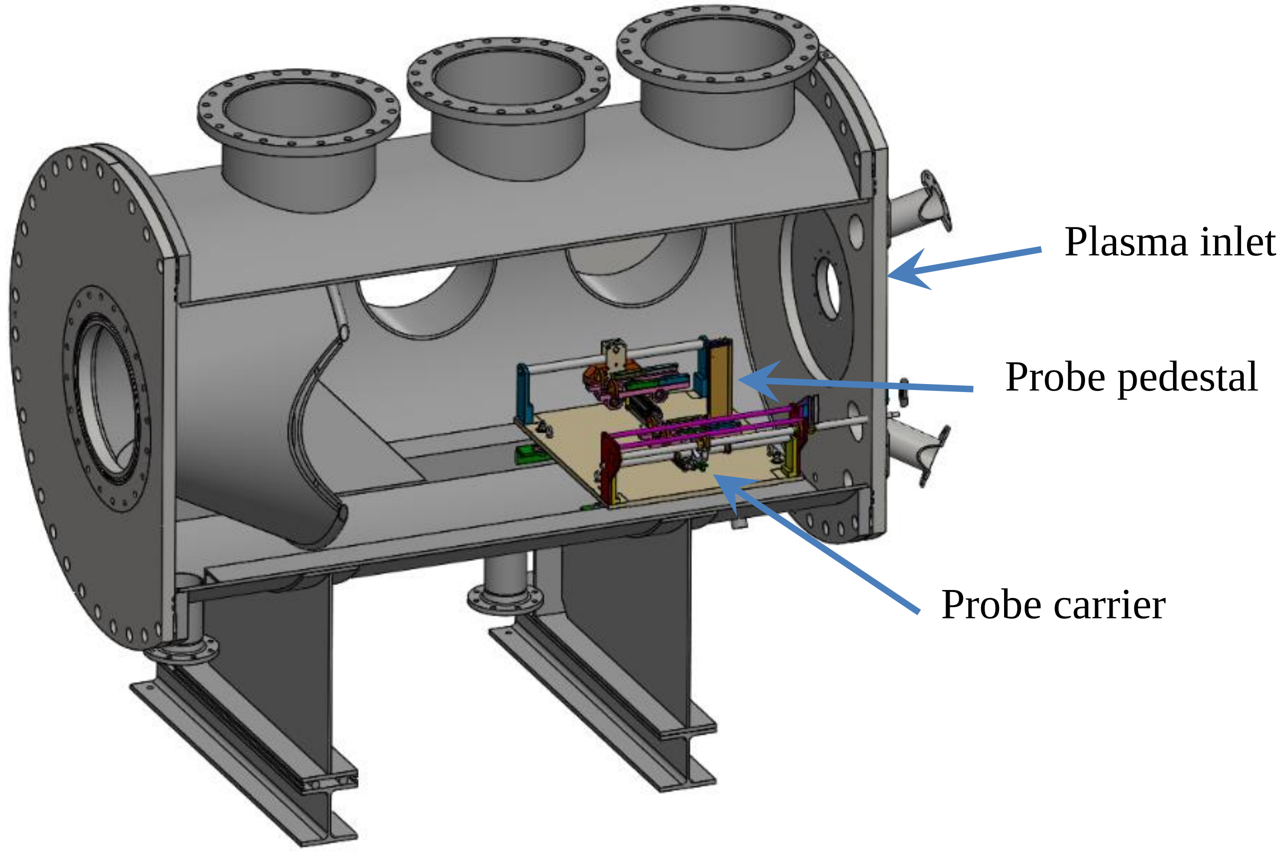
Dissemination

- **Neutron Star Systems** Project dissemination

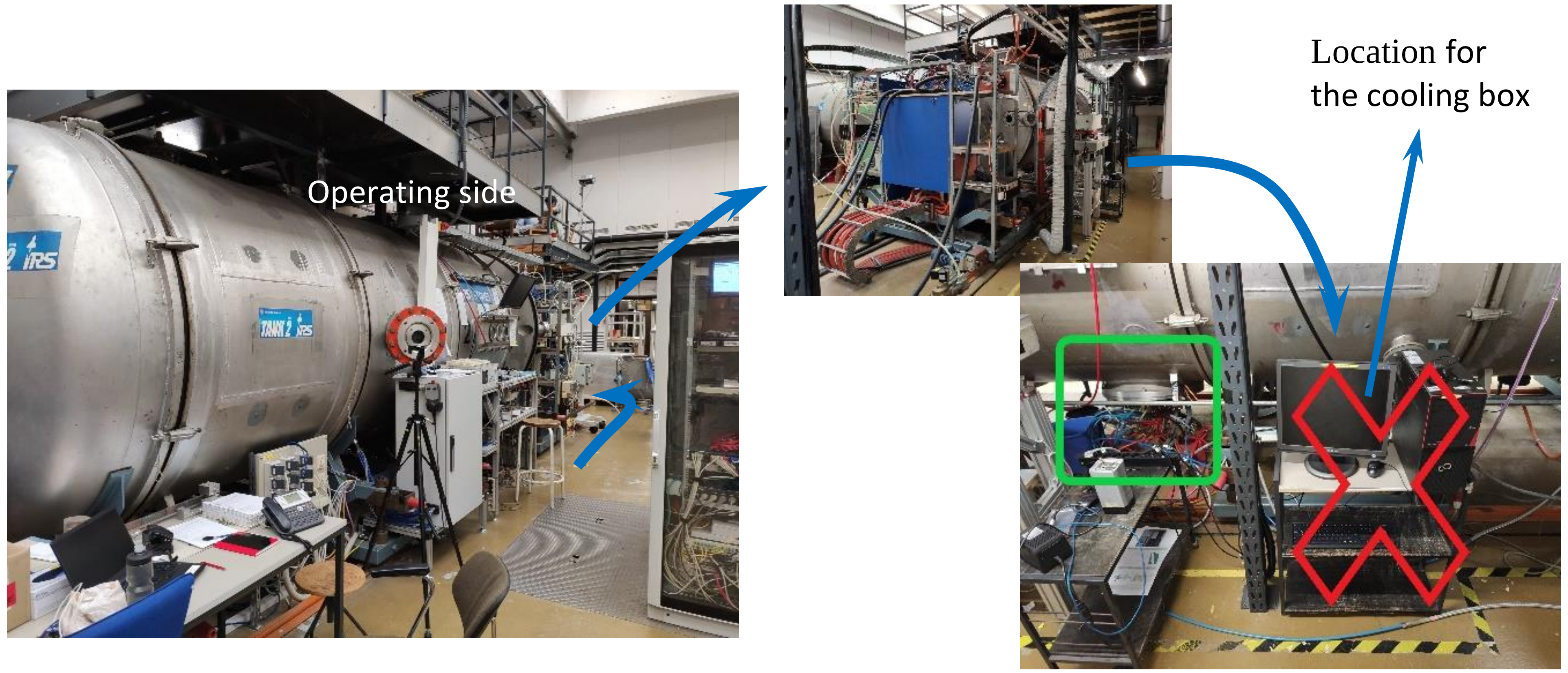
Environment Definition - Test Chambers

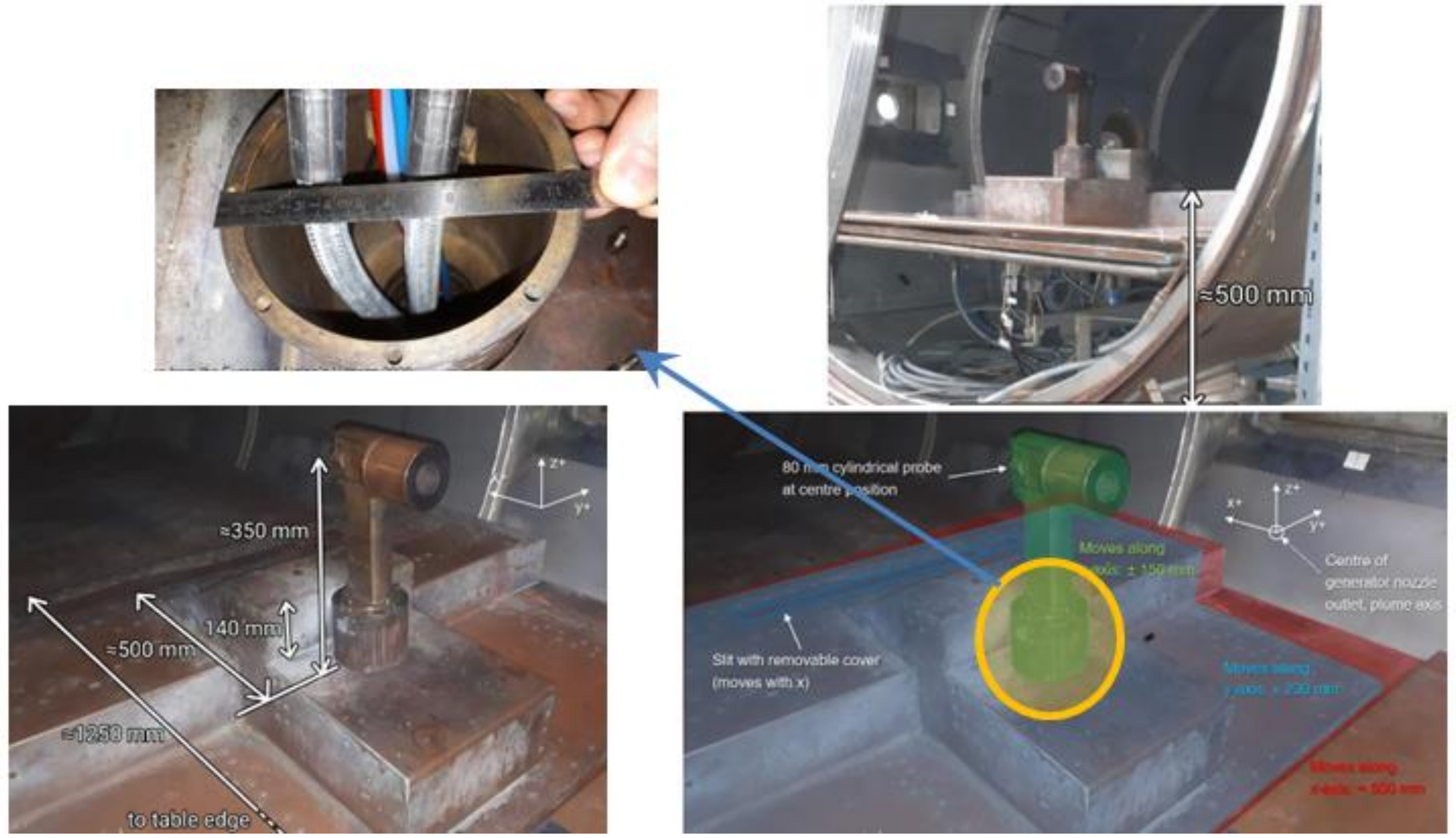
VKI – Blackout Mitigation Experiment





IRS – Heat Flux Experiment





Both are vacuum chambers with primary vacuum levels

Test Probe

• Challenges

Adapt the system to both plasma chambers

Manage the complexity of the interfaces

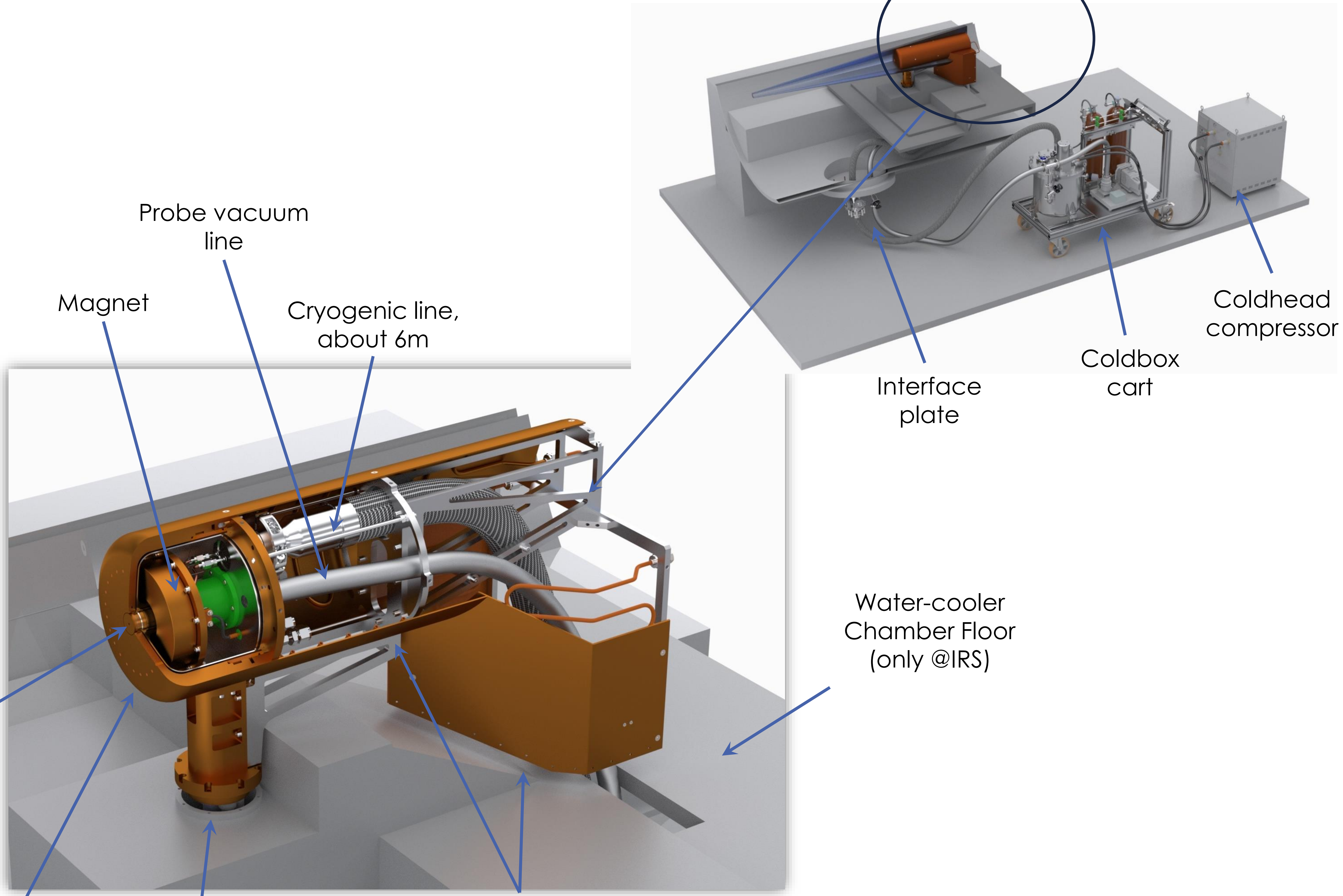
Both chambers are under primary vacuum

Necessity of a water-cooled shielding system for protection during operations

- 1500K in front of the probe vs. 30K on the magnet

Compacity of the probe

- 230 mm diameter coaxial probe
- Remain within a representative situation of atmospheric entry
- Remote helium cooling loop
- YBCO conduction-cooled magnet



More on the MEESST Magnet: S. Schlachter et al., Wed -Or-9-5

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Global Architecture - Heat Flux Experiment

- **Installation setup**

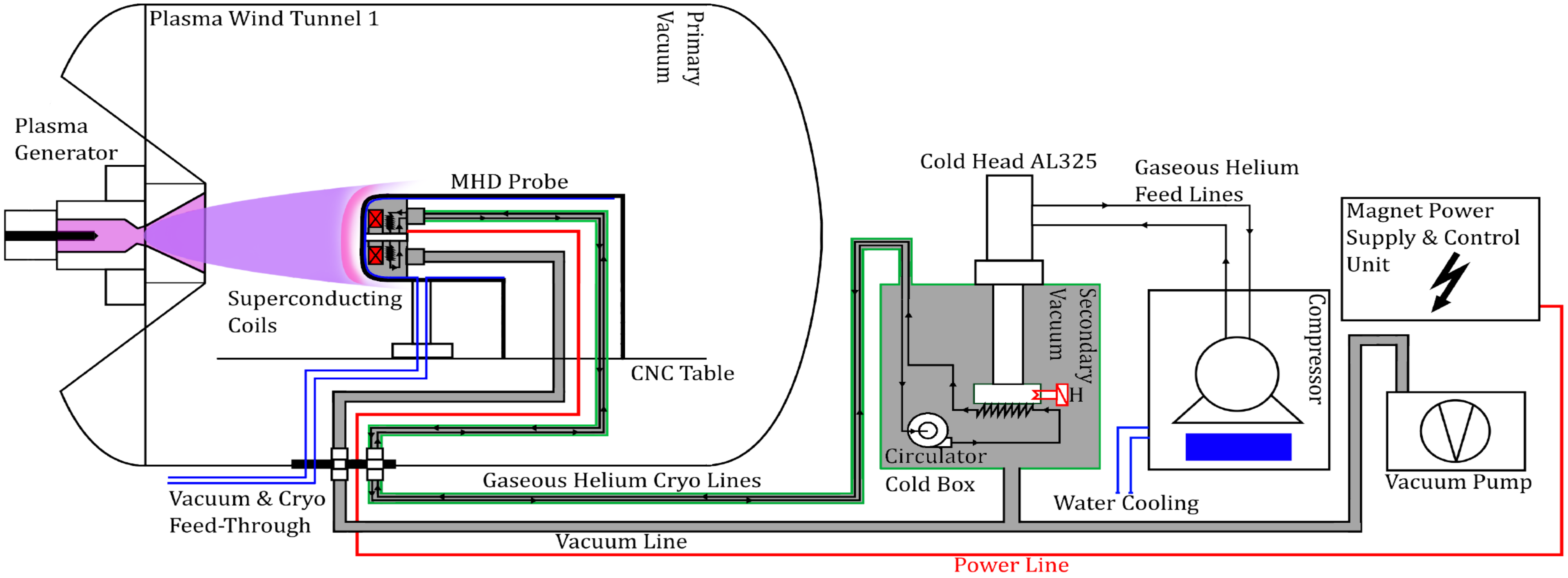


Fig. 5.: System architecture schematic of the MHD plasma probe with indications of the required peripheral systems to operate the HTS magnet.

J.W. Oswald *et al.* "MHD Flow Manipulation Experiments in High Enthalpy Air Plasma", submitted to Proceedings of International Symposium on Space Technology, June 3-9, 2023, Kurume, Japan

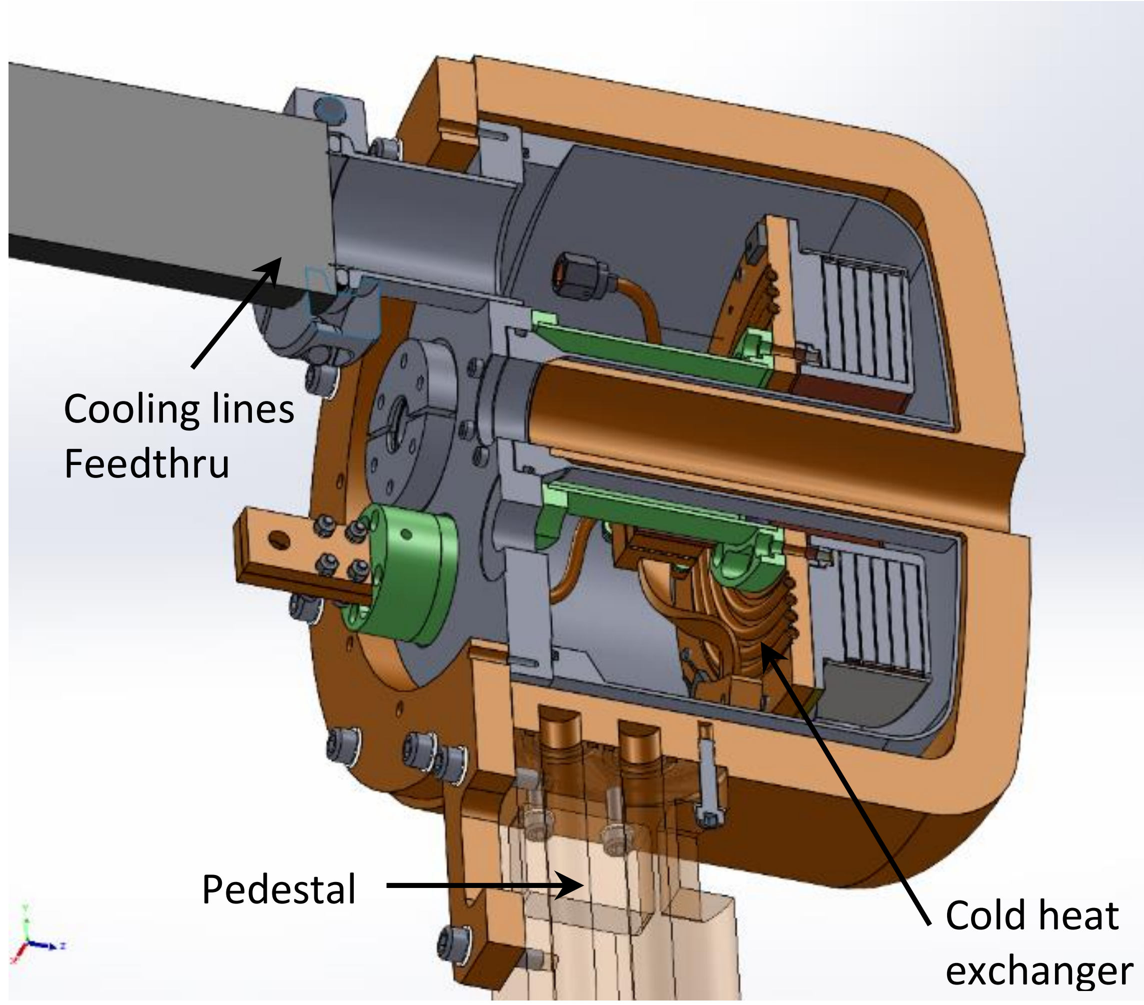
Probe Design and Dimensioning

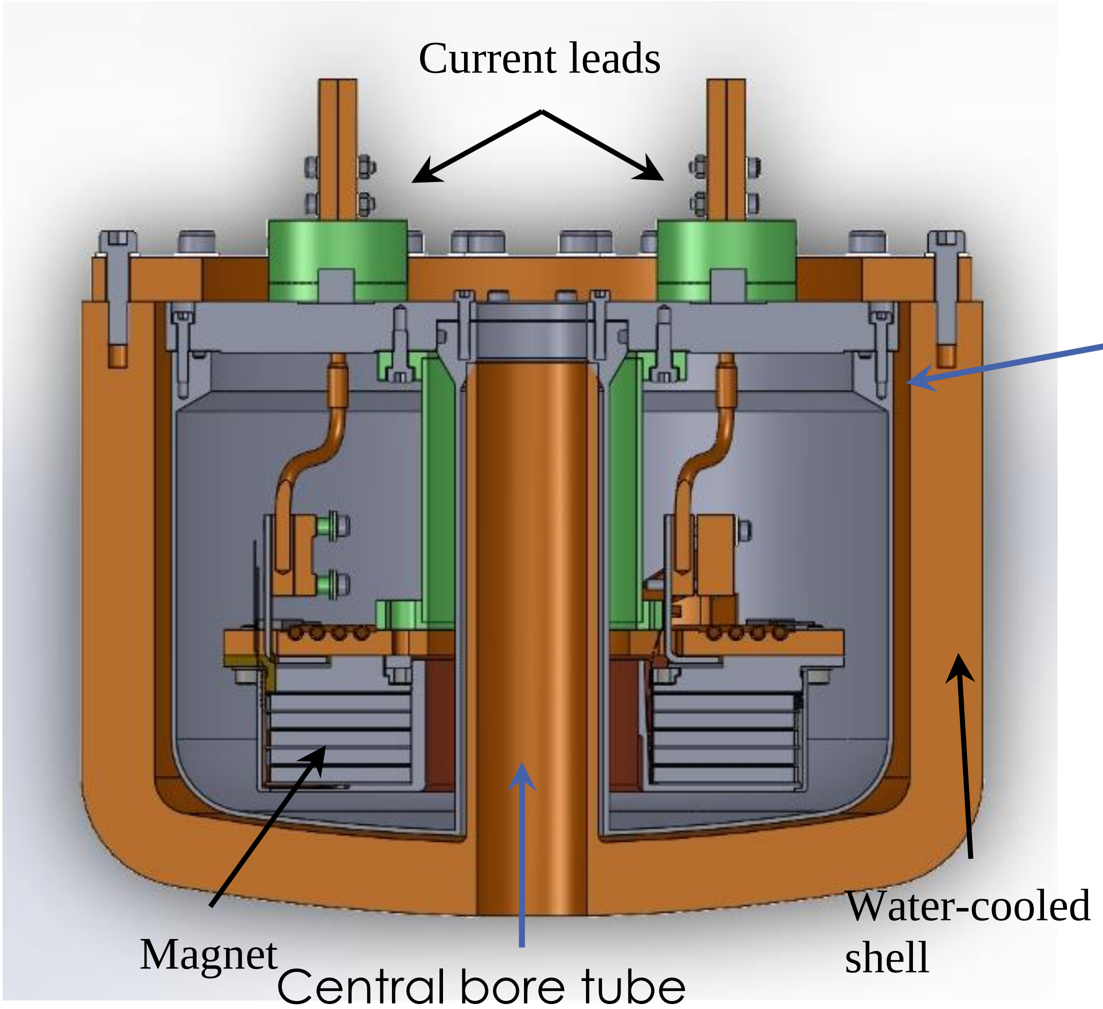
- **Heat losses estimation**

Cold plate temperature = 30K
Magnet target operating current 110A, dimensioning for 150A
Conduction cooled magnet, with one stage cooling
Water cooled shell @350K max
Probe in a primary vacuum chamber
Cold box:

- Cryomech AL325 coldhead
- Absolut System's low speed circulation fan
- 15bar helium gas circulation loop

Heat losses source @30K	Estimated Value
Radiative	10W
Current leads	16W
Gas circulation	20W
Others	<1W
Total	**47W**





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Front Shell Water Cooling

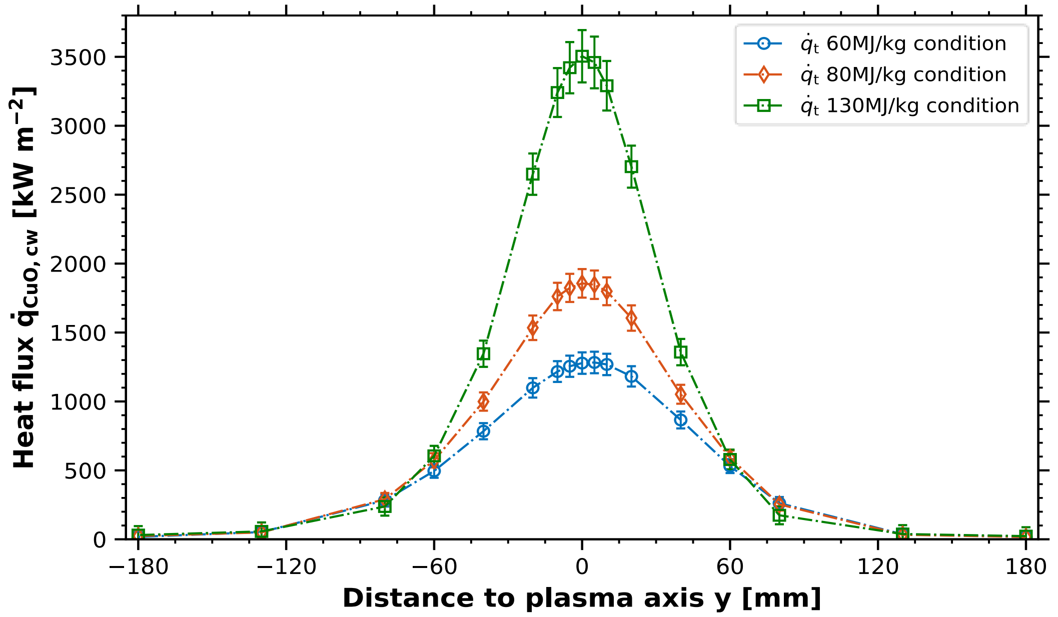
• Determination of the operational parameters

Water flow available

28bar maximum on the probe front, 350K max temperature

11bar on the side panels

Heat flux profile from the plasma jet

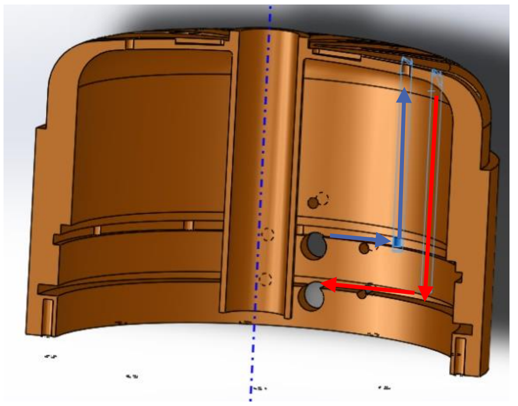


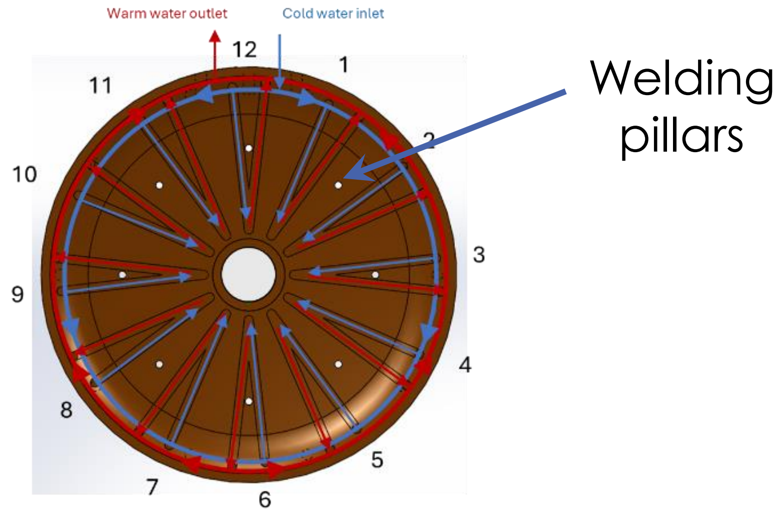
• Probe geometry

Multiple parallel U-channels

Laser welded assembly

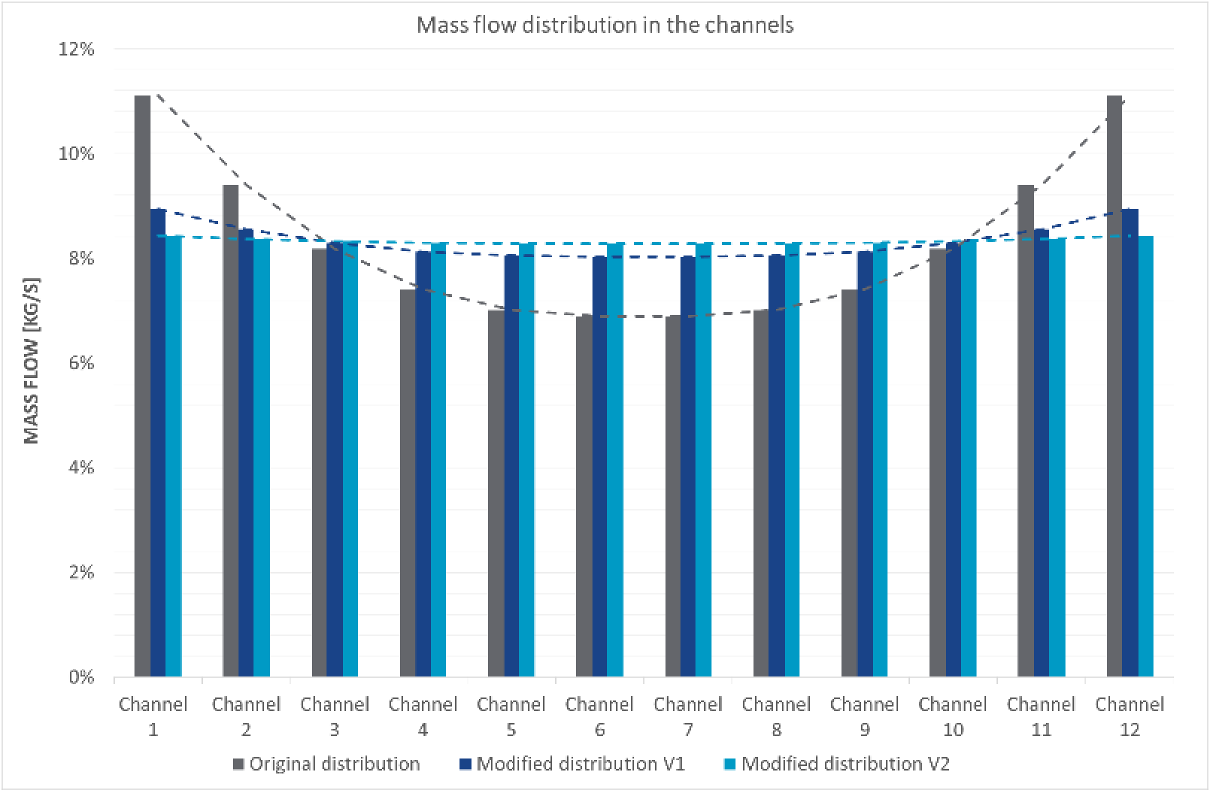
Mechanical validation and optimization of the pillars positioning





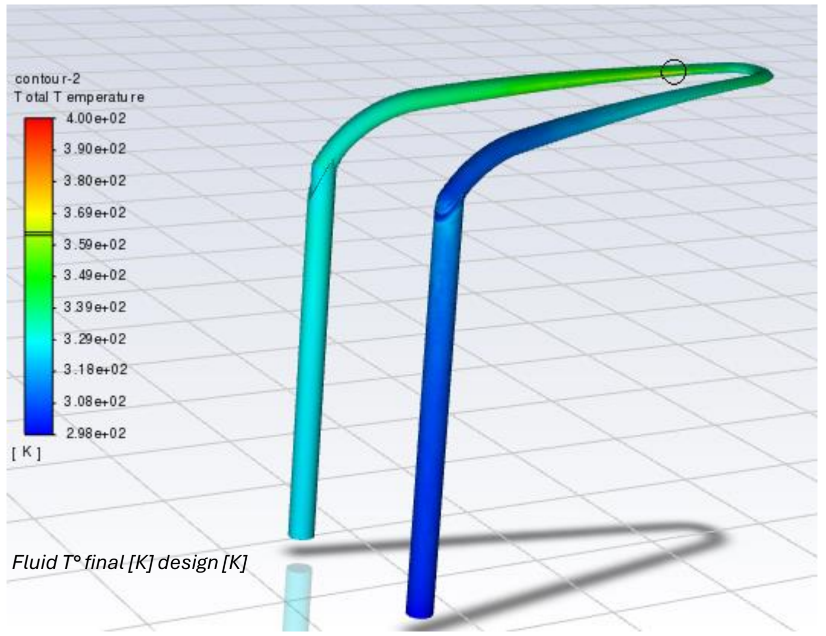
• Channel optimization

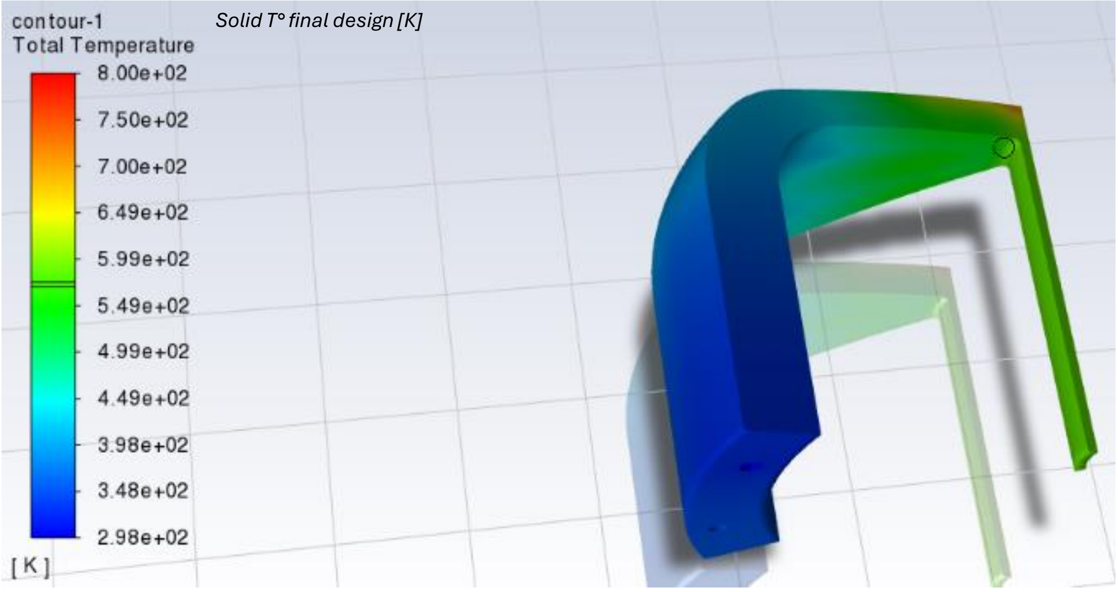
Pressure drop



Thermal optimization for homogenization and limitation of maximum temperature

Number and shape of channels => 8





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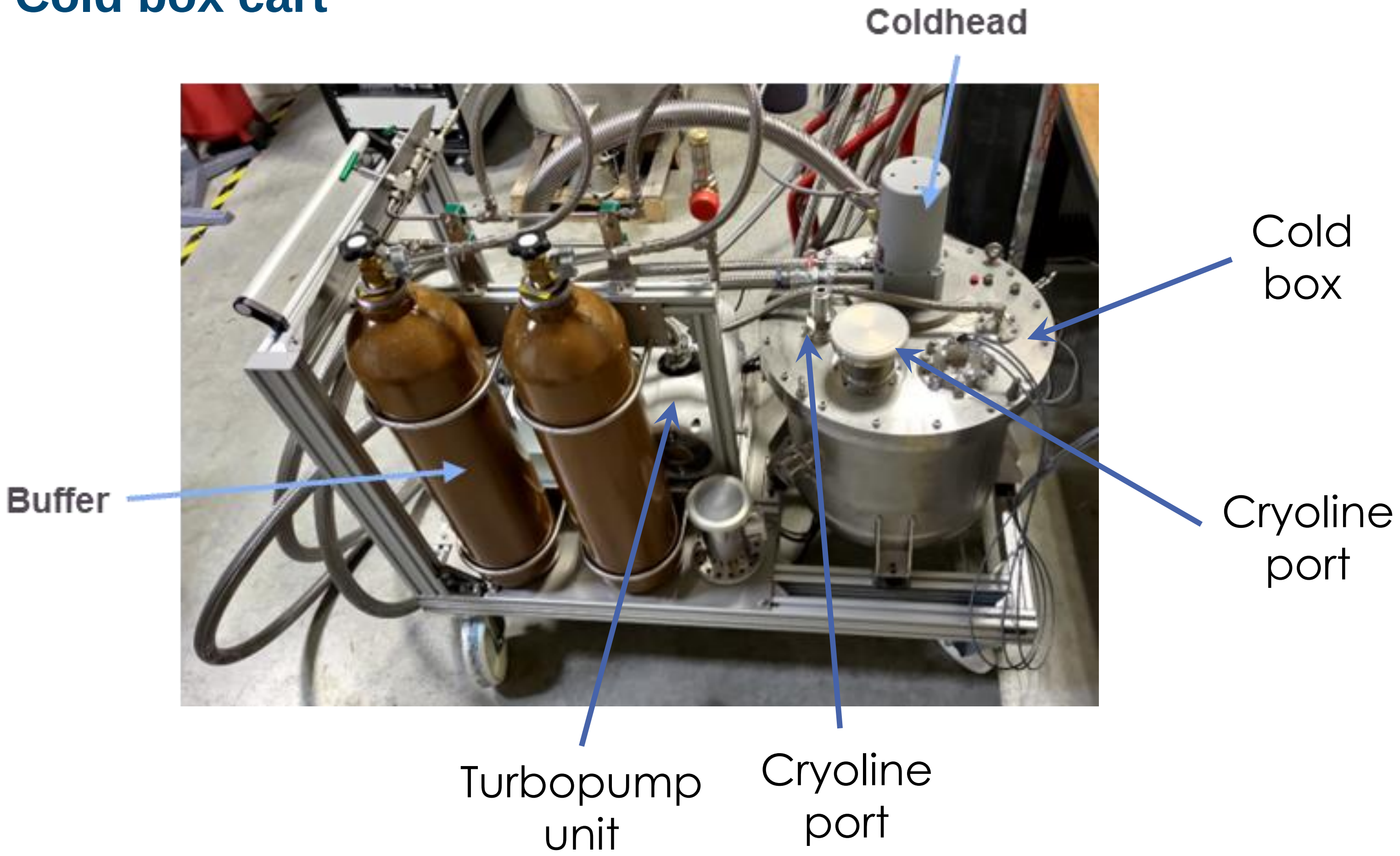
Manufacturing and Assembly

- **Water-cooled shell**

Shell and cryostat

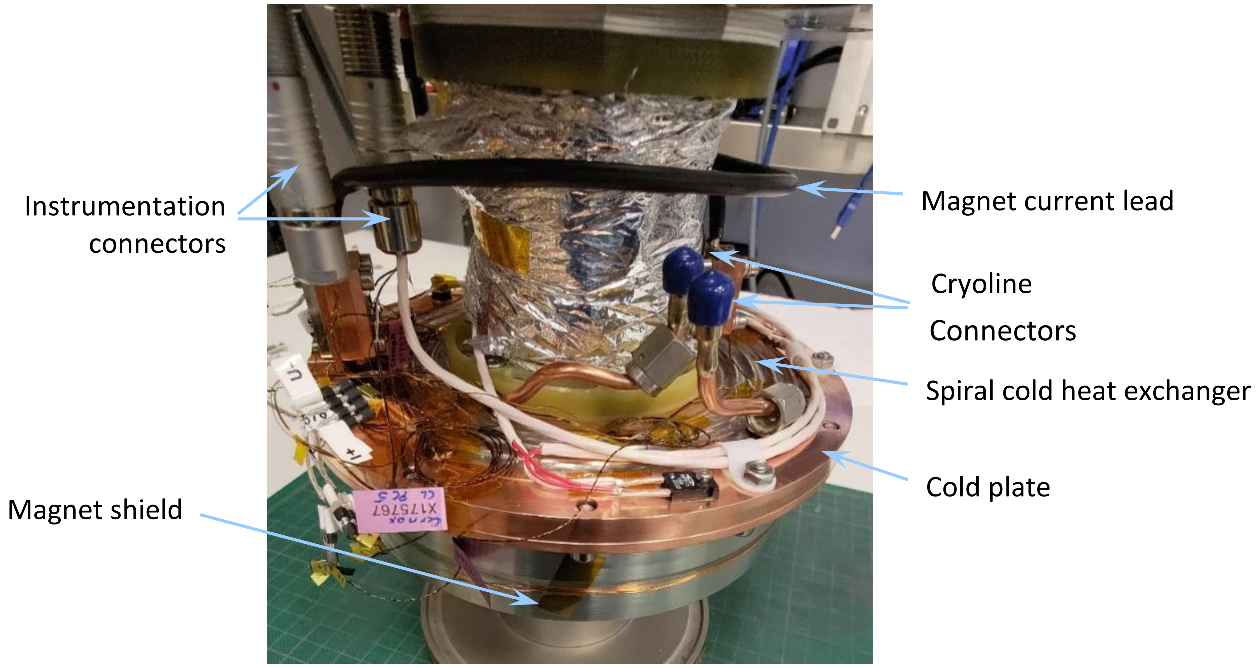
Welded shell

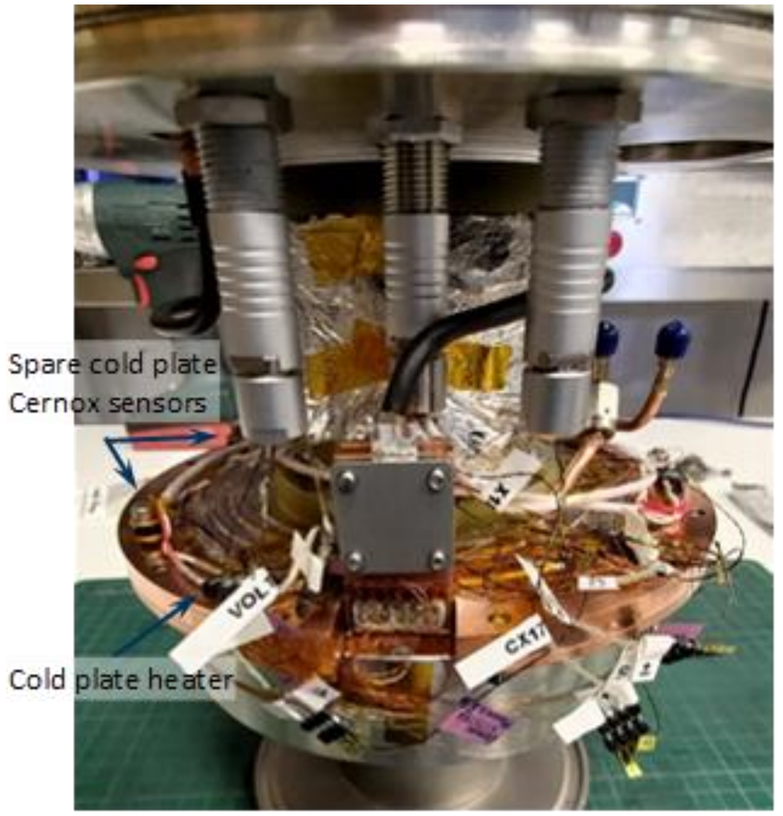
- **Cold box cart**



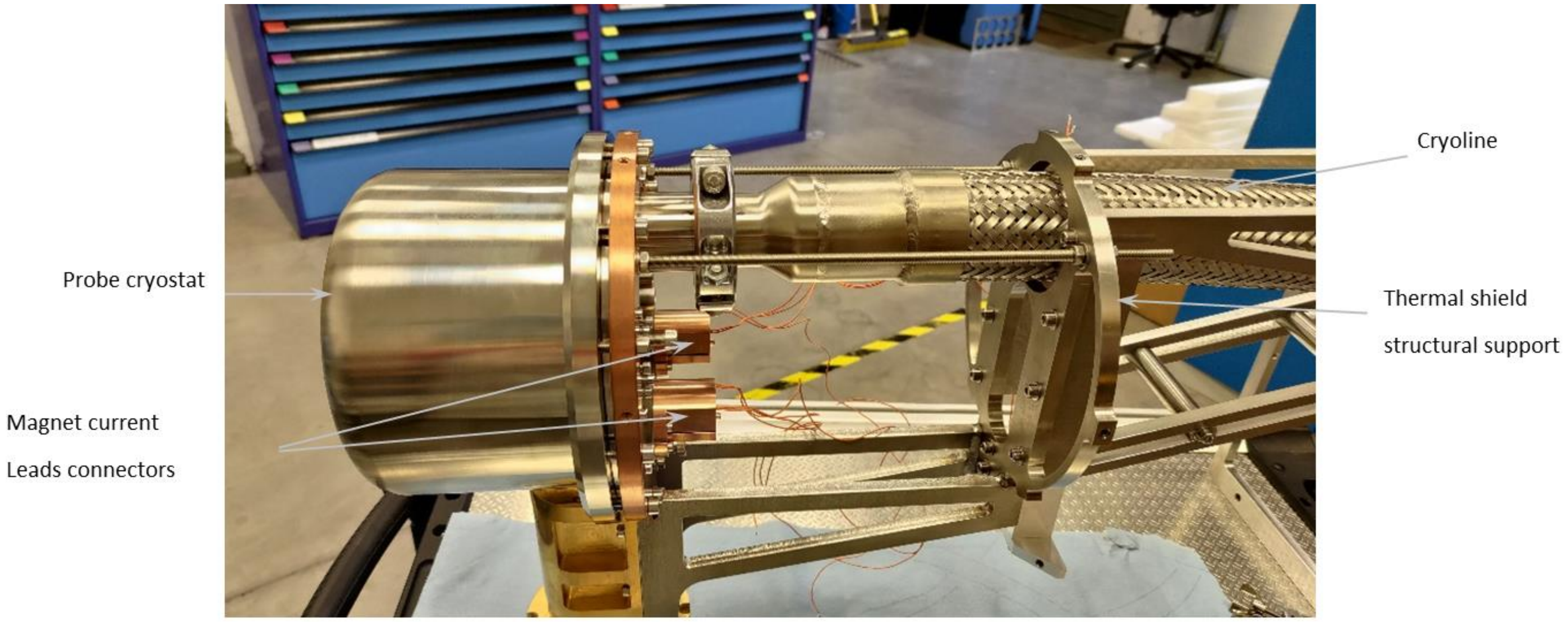
- **Magnet assembly**

Magnet characterization @KIT showed conductor defects, limiting maximum operating current to 50A => about 660mT in the front of the probe (about 1.5T initially planned)





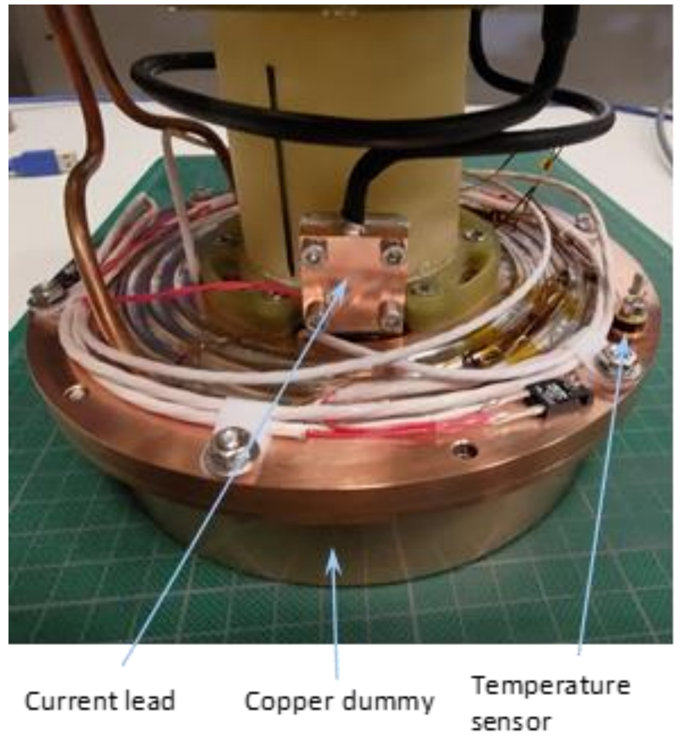
- **Probe assembly**

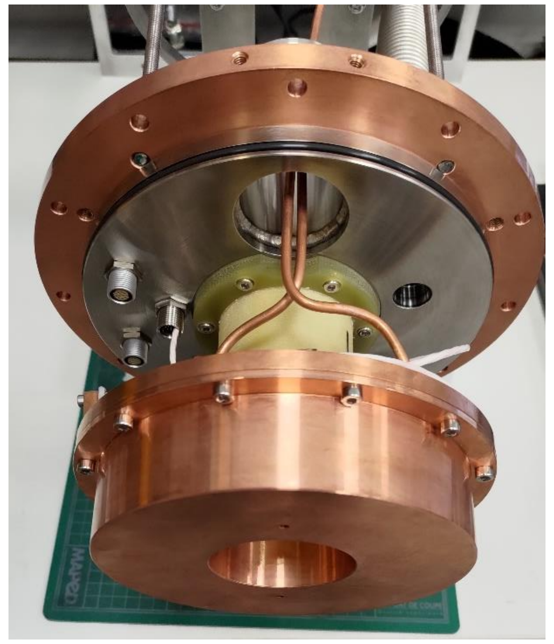


Preliminary Tests

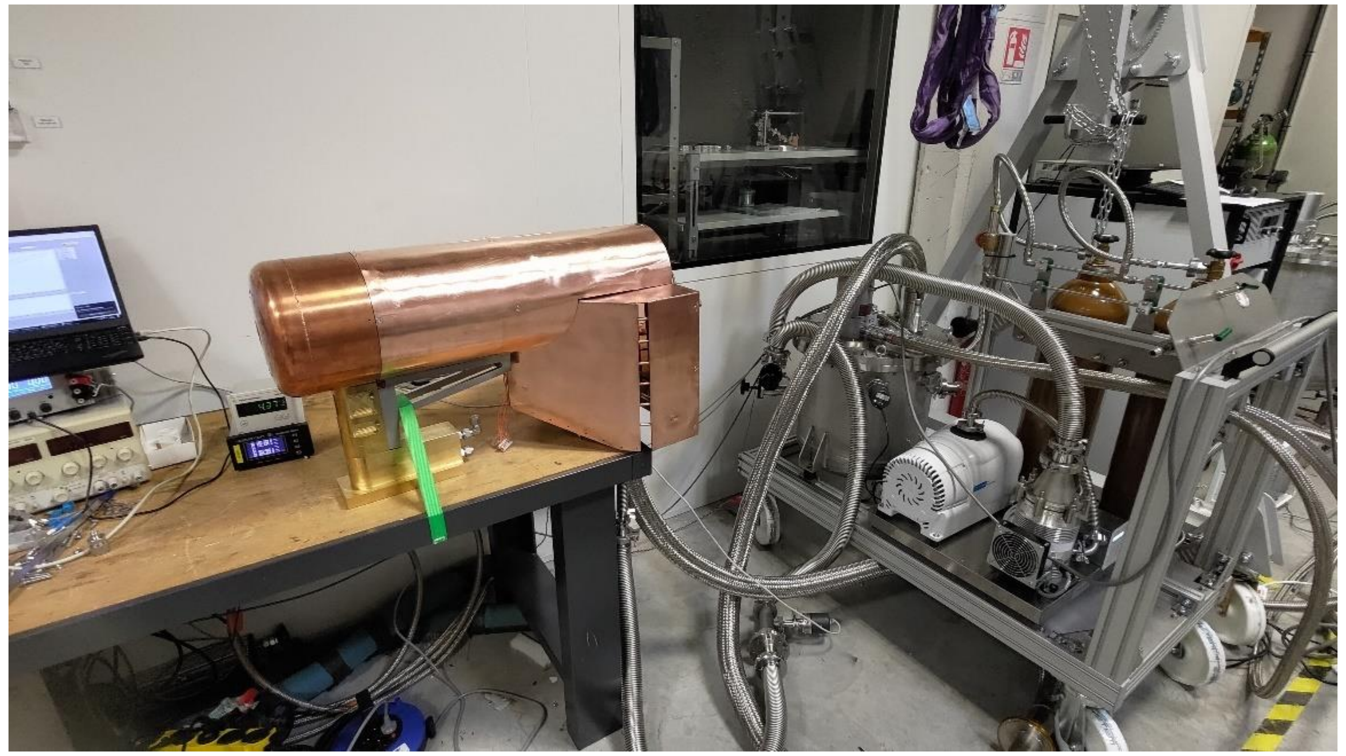
- **In-house Validation tests**

Use of a dummy coil
Same shape and mass as the HTS coil
Instrumented with a heater to mimic the heat load from the current leads

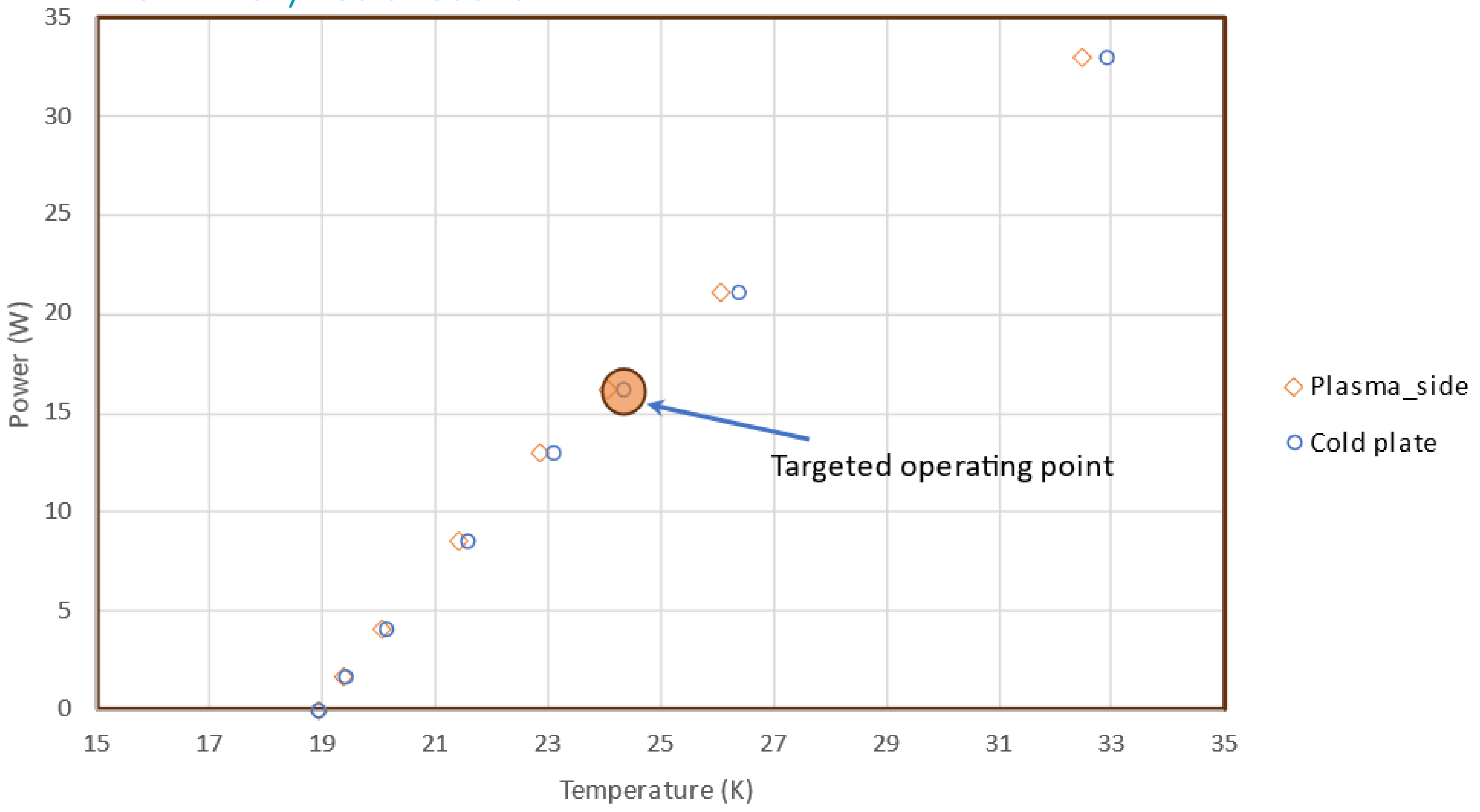




Probe during preliminary tests



Preliminary tests results



Test successful with margin: initial target of 30K

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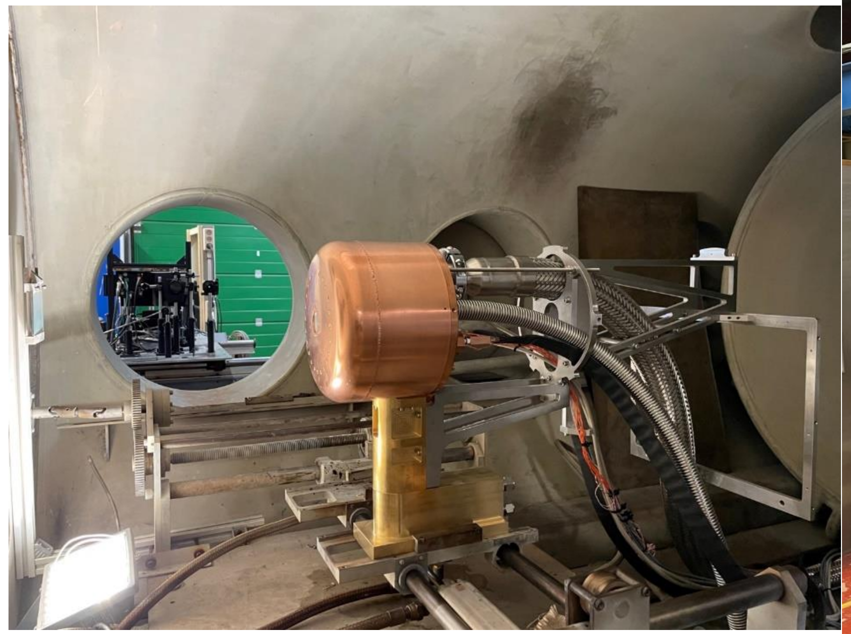
Installation at IRS/VKI

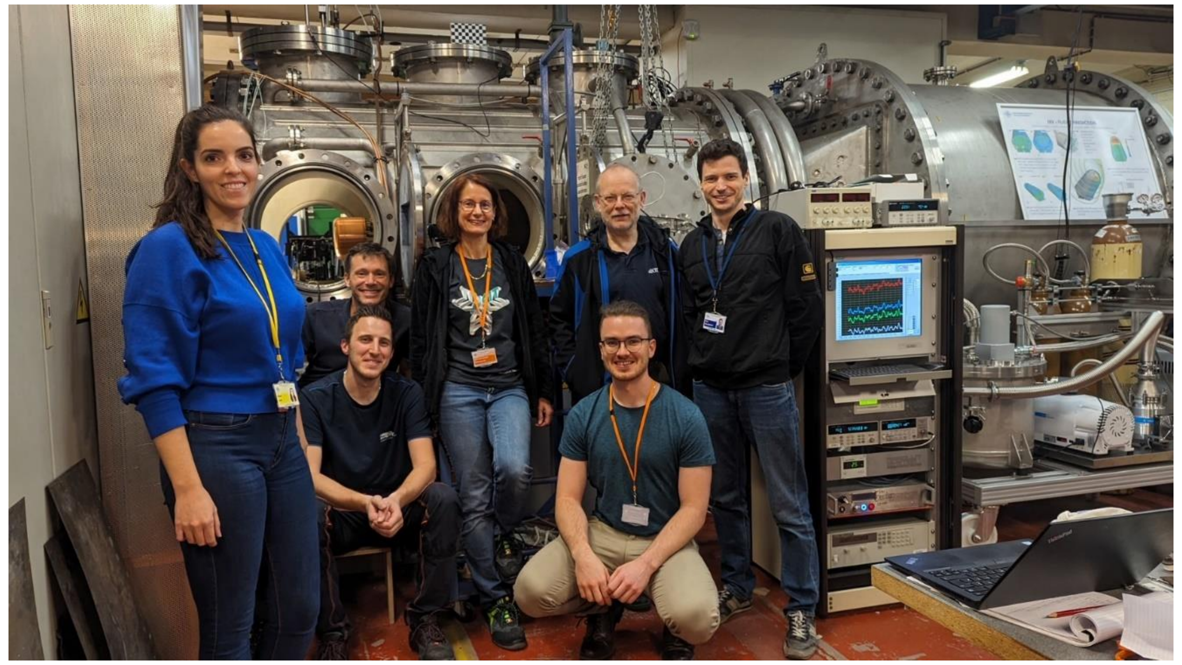
- **VKI Installation, October 2023**

Probe being installed in the chamber



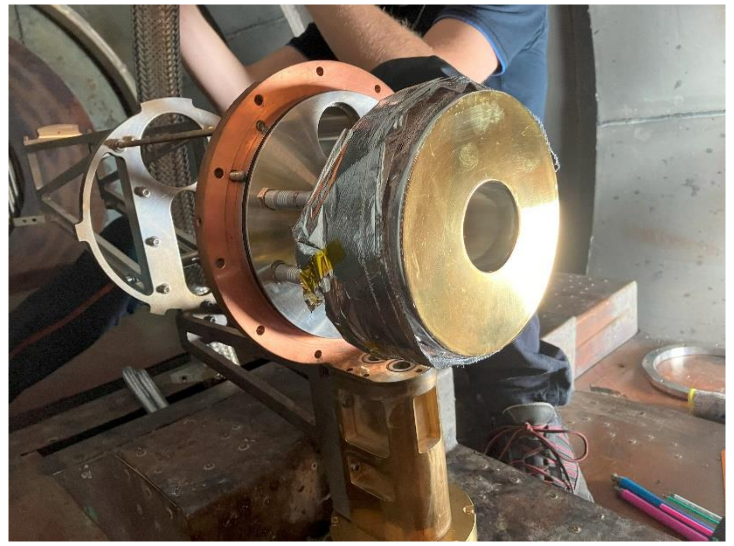
Overall Setup

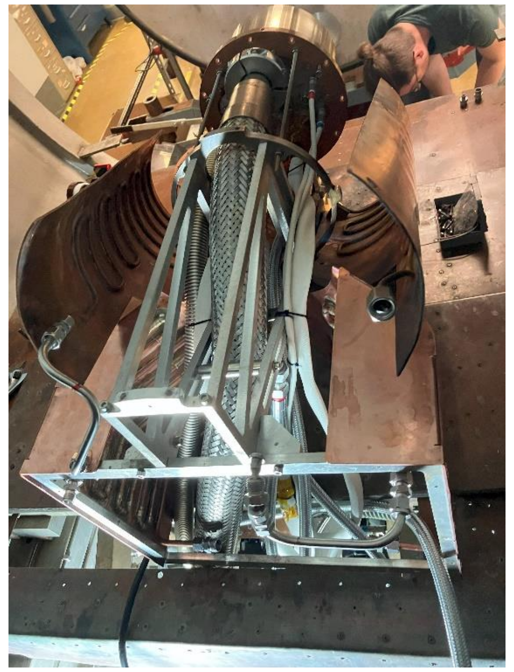
Team work (incomplete MEESST team)



- **IRS Installation, March 2024**

Probe Chamber assembly





Chamber Interface plate

Coldbox

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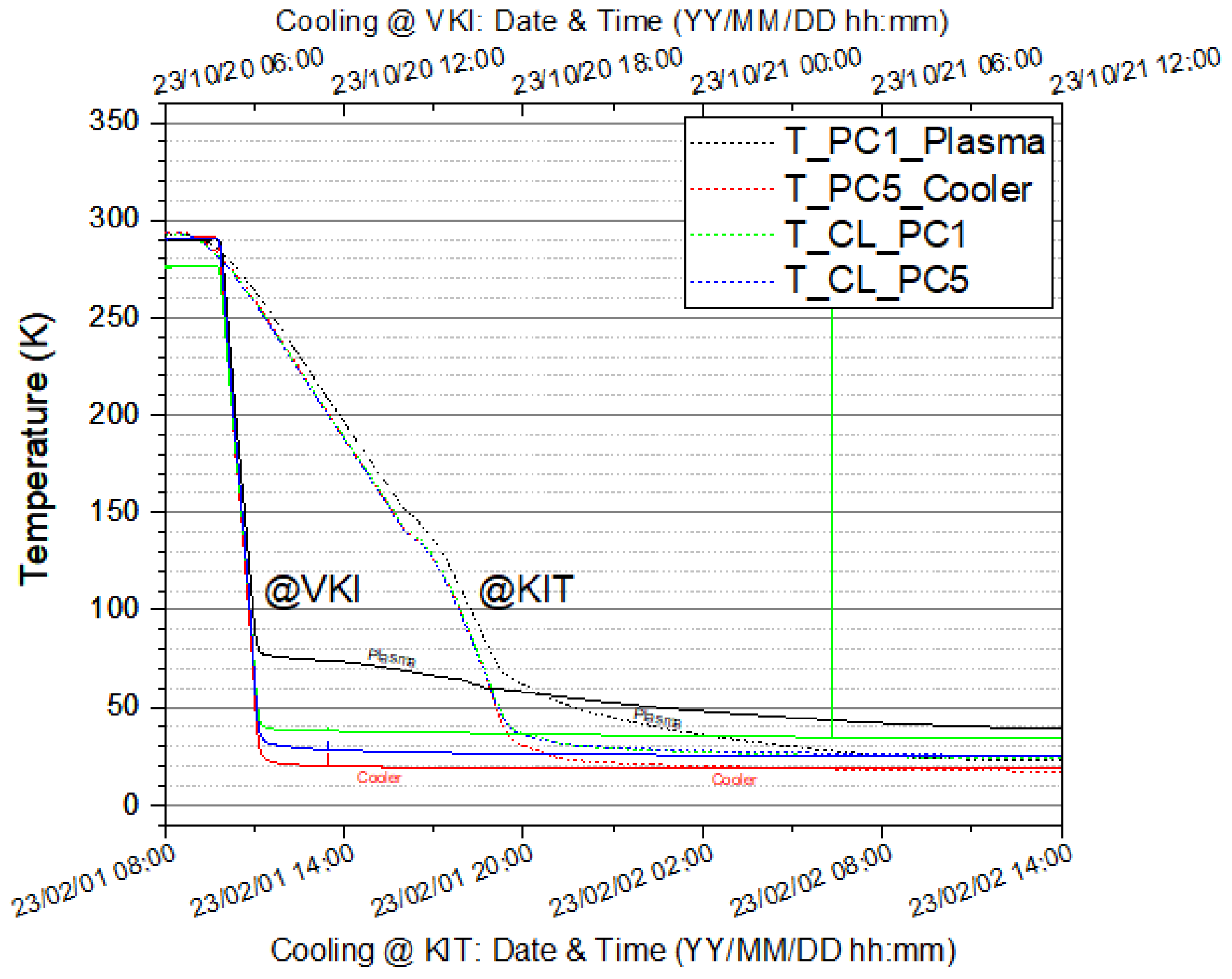
Results

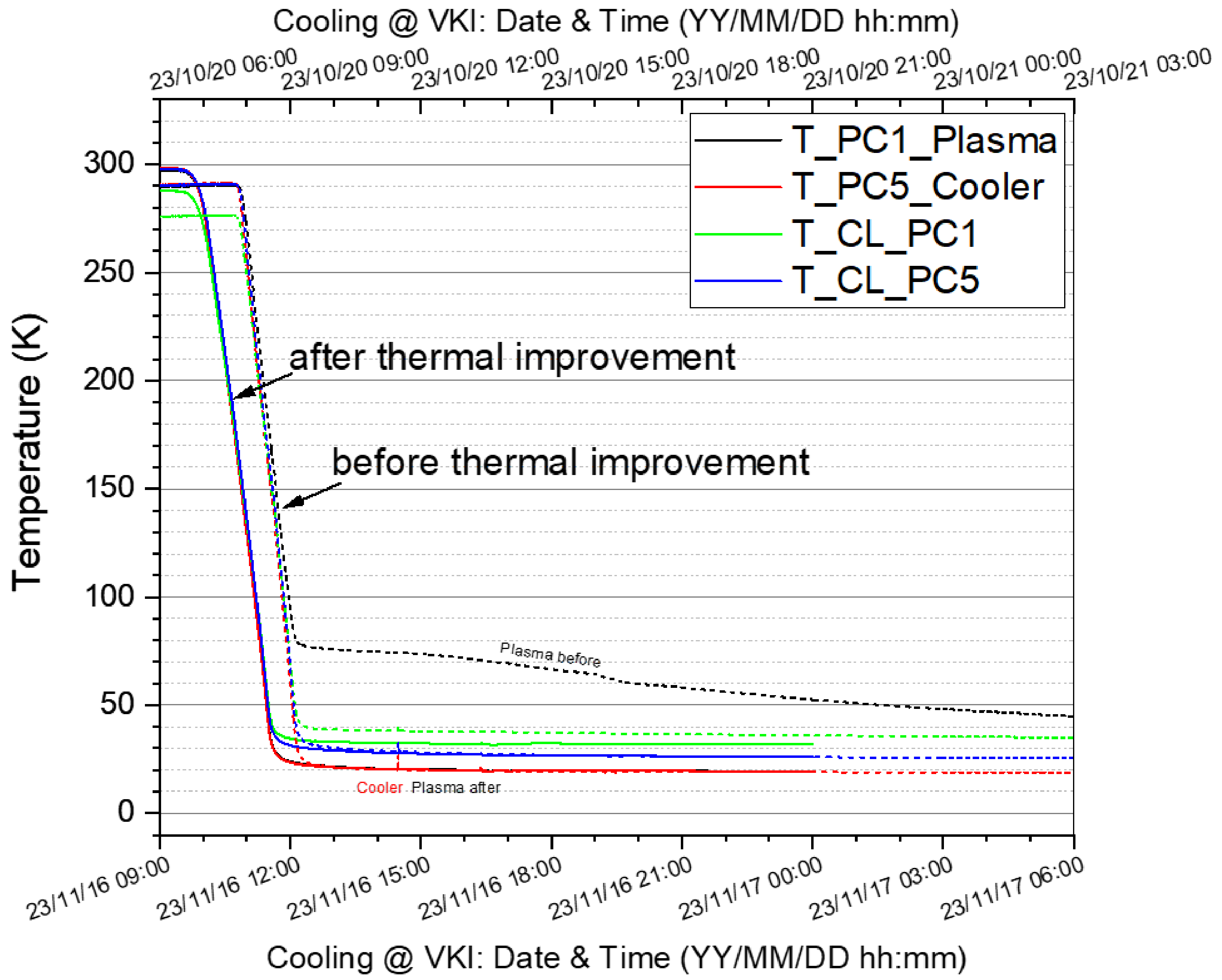
Initial cooldown with the magnet

Large temperature difference with validation test @KIT
Issue with thermal contact resistance not enough contact
Radiative shield lack of efficiency



Correction of the thermal issue

Increase of the thermal contact
Improved thermal shield



Cooling largely improved, showing similar behavior as @KIT

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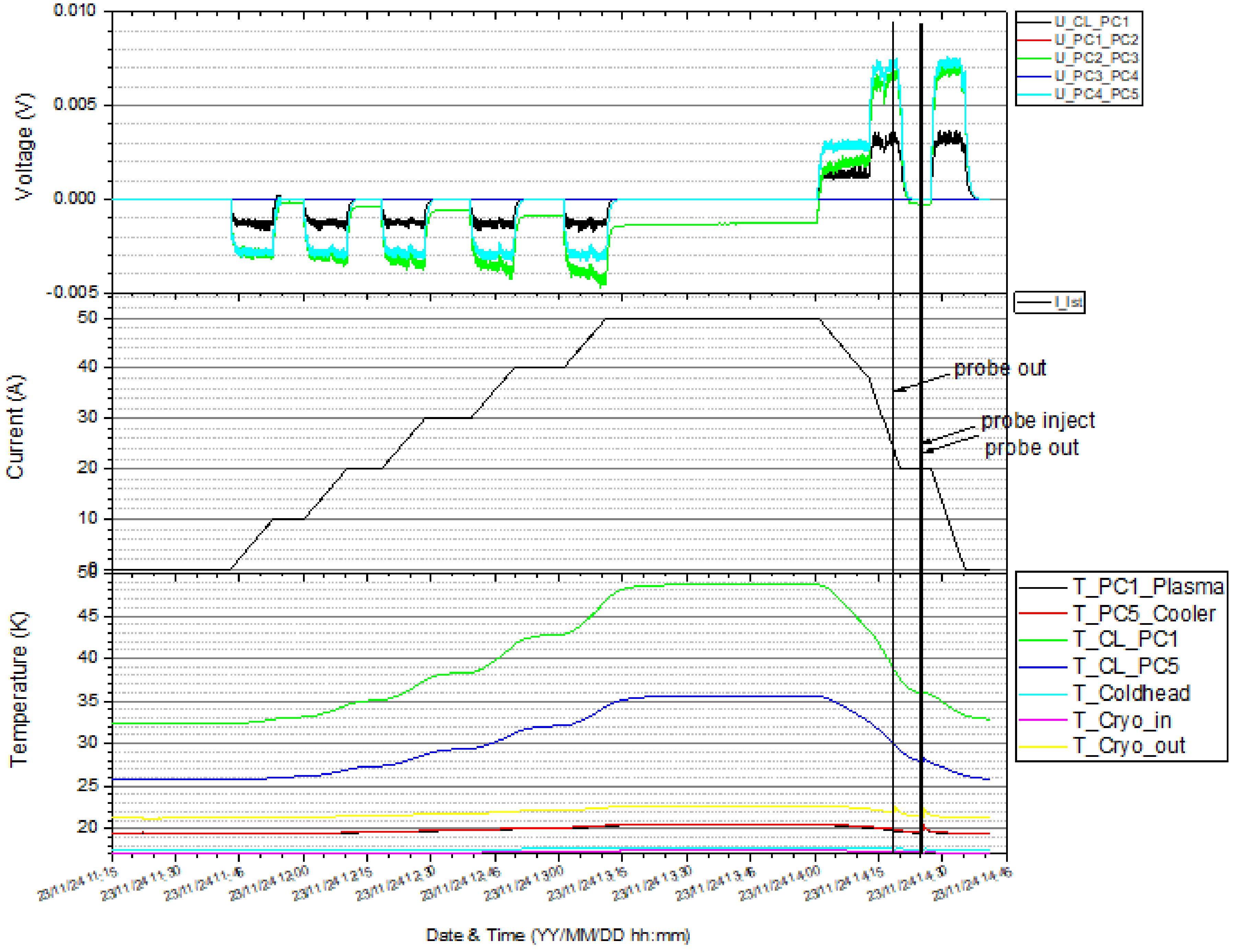
Results

Magnet on without plasma

Large temperature incursion on current leads, rather normal since we rely on conduction cooling and limited thermal contact => not impacting operation

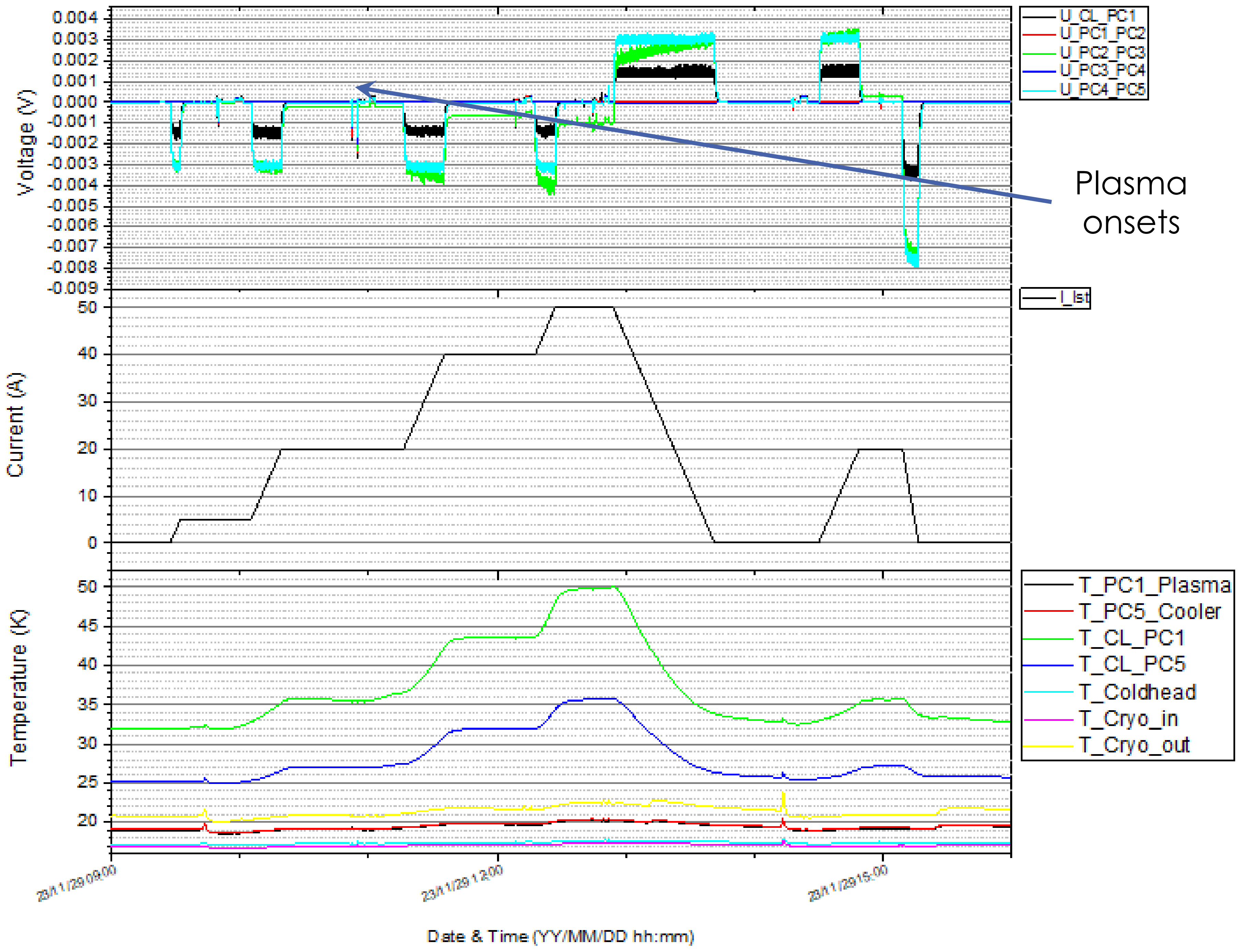
All over measurements stables



Magnet on with plasma

No visual impact of the plasma onset on temperatures

⇒ Both the cryo system and the front water cooling system are operating nominally !



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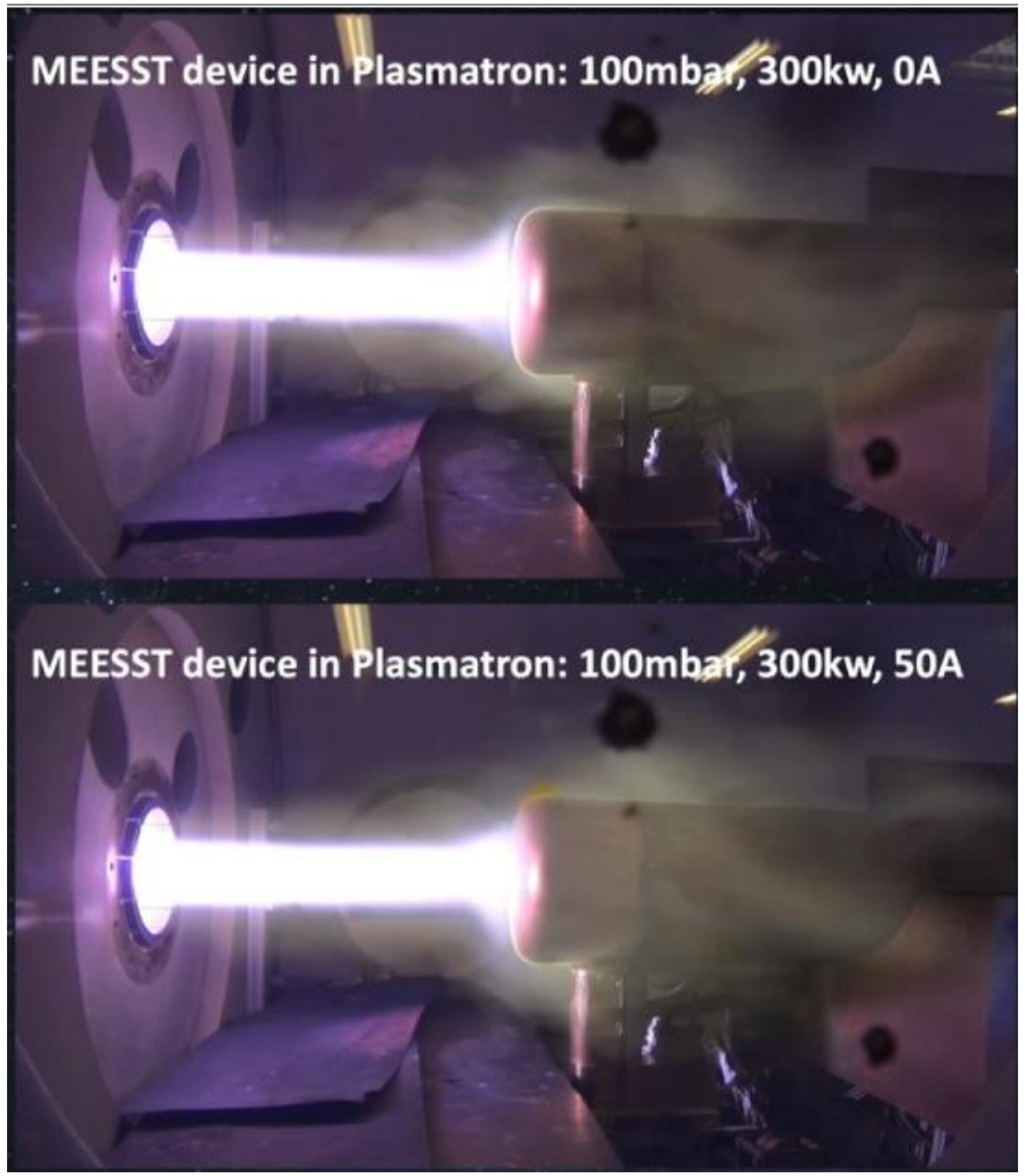
Results @VKI

Operation in the plasma

⇒ It's really hot

The front shell does not budge



Various issues

Water cooling not quite perfect

Issues with water flow on the side panels => large pressure drops linked to small inner piping diameter => low flow and cooling

Addition of sacrificial materials for the runs

Various issues with shorts linked to materials not resilient to hot environment

Promising results and conclusions to be published soon

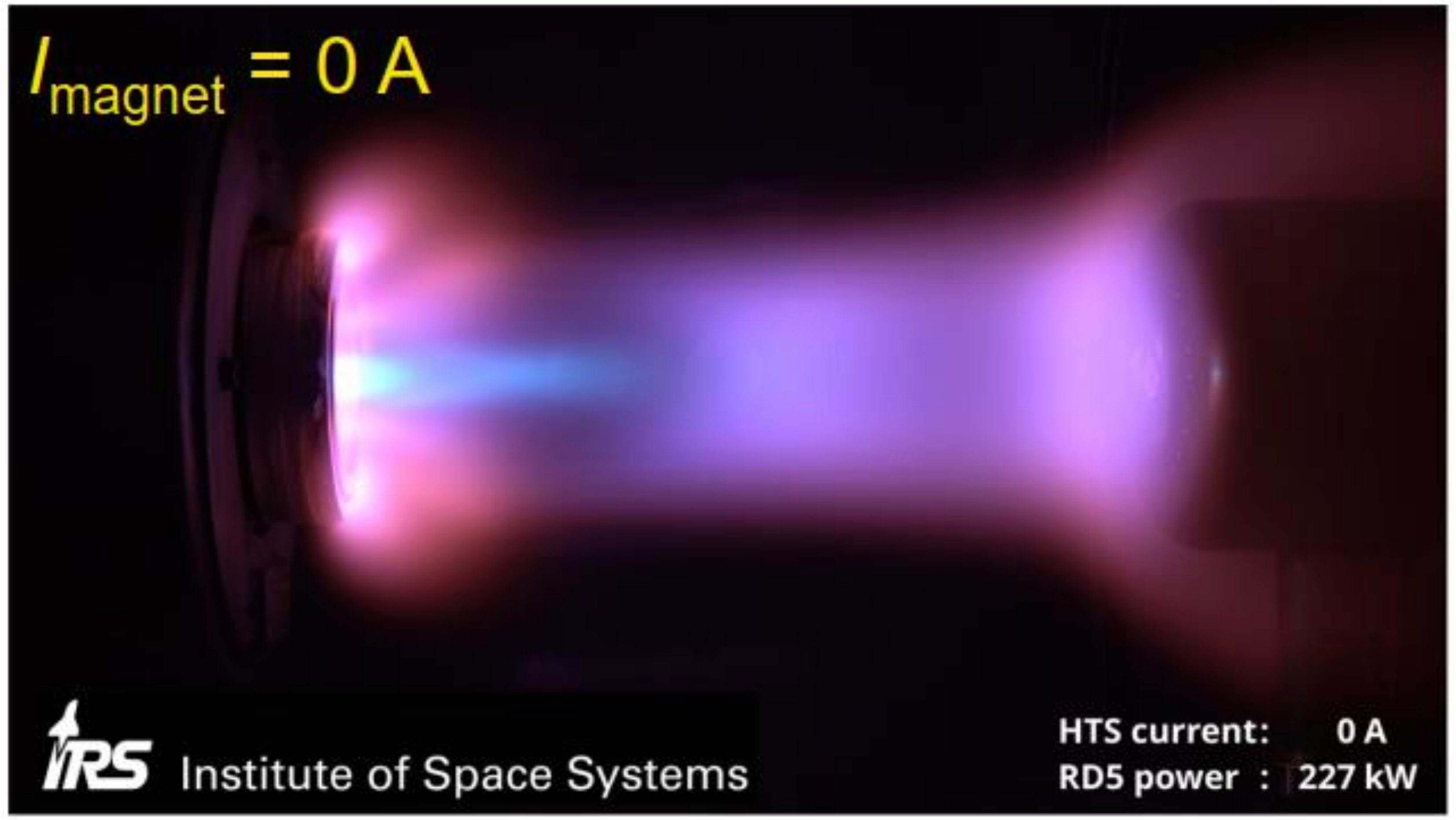
Results @IRS

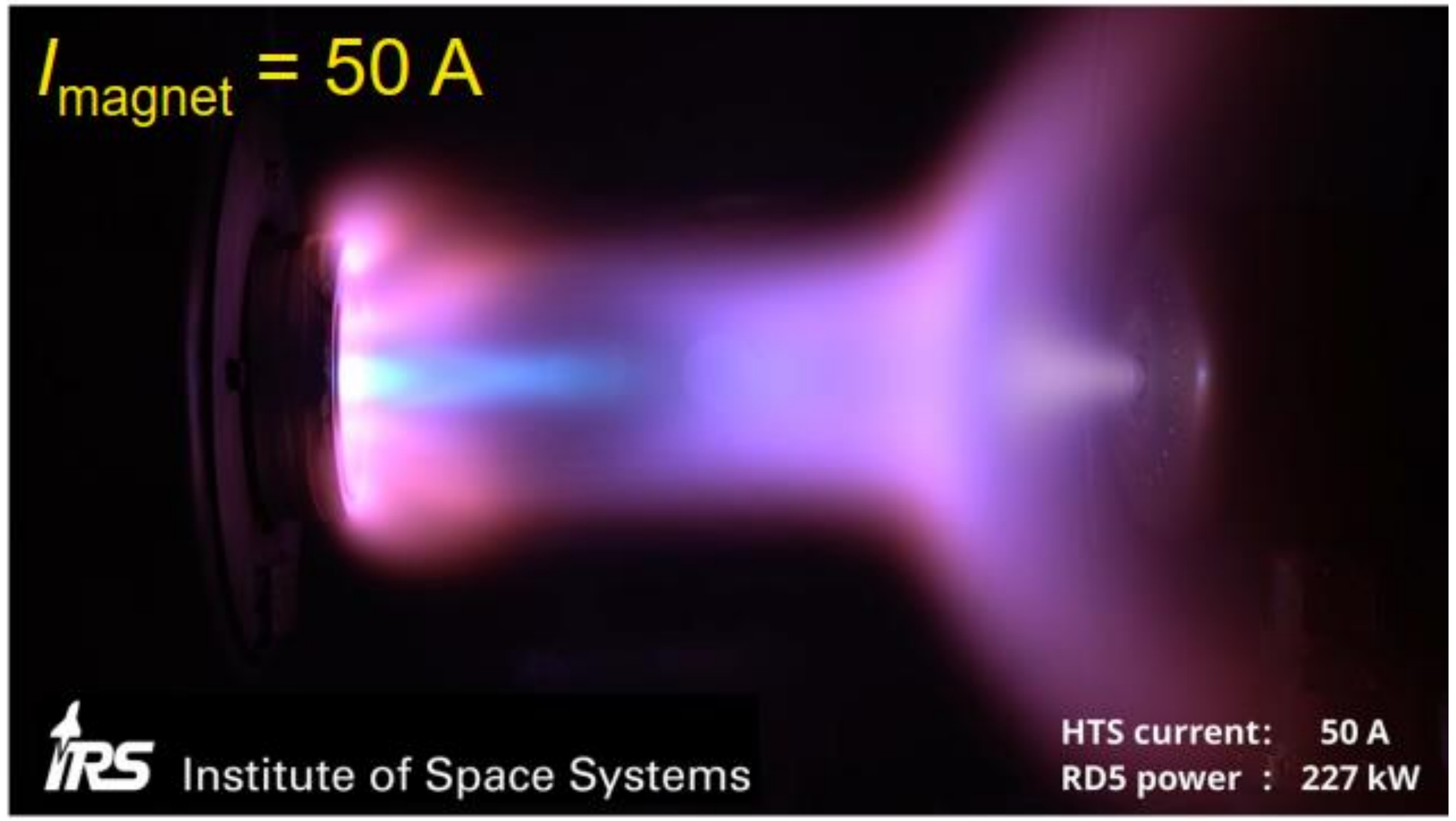
Probe subsequently moved and successfully installed @IRS

Initial magnet and cryosystem operated nominally both without and with plasma

Preliminary results

Visualization shows a net increased shock stand-off distance
A funelling mechanism (linked to the flux lines) locally increases the heat flux at the stagnation point
The overall heat flux deposited on the probe, however, is very noticeably impacted by the magnetic field





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Conclusions and Remarks

A Magnetohydrodynamic Enhanced Entry System for Space Transportation (MEESST) prototype has been successfully designed, fabricated and tested

The system has been **tested** in two plasma chambers @VKI and IRS successfully, for about **2 months+ at each institution**

The **results** are still under analysis but are showing **very promising** results **both for black-out and heat mitigations**

Within the MEESST project, **modeling efforts** have been **consistently ongoing** since the beginning of the project and are currently culminating with data validation and model adjustments

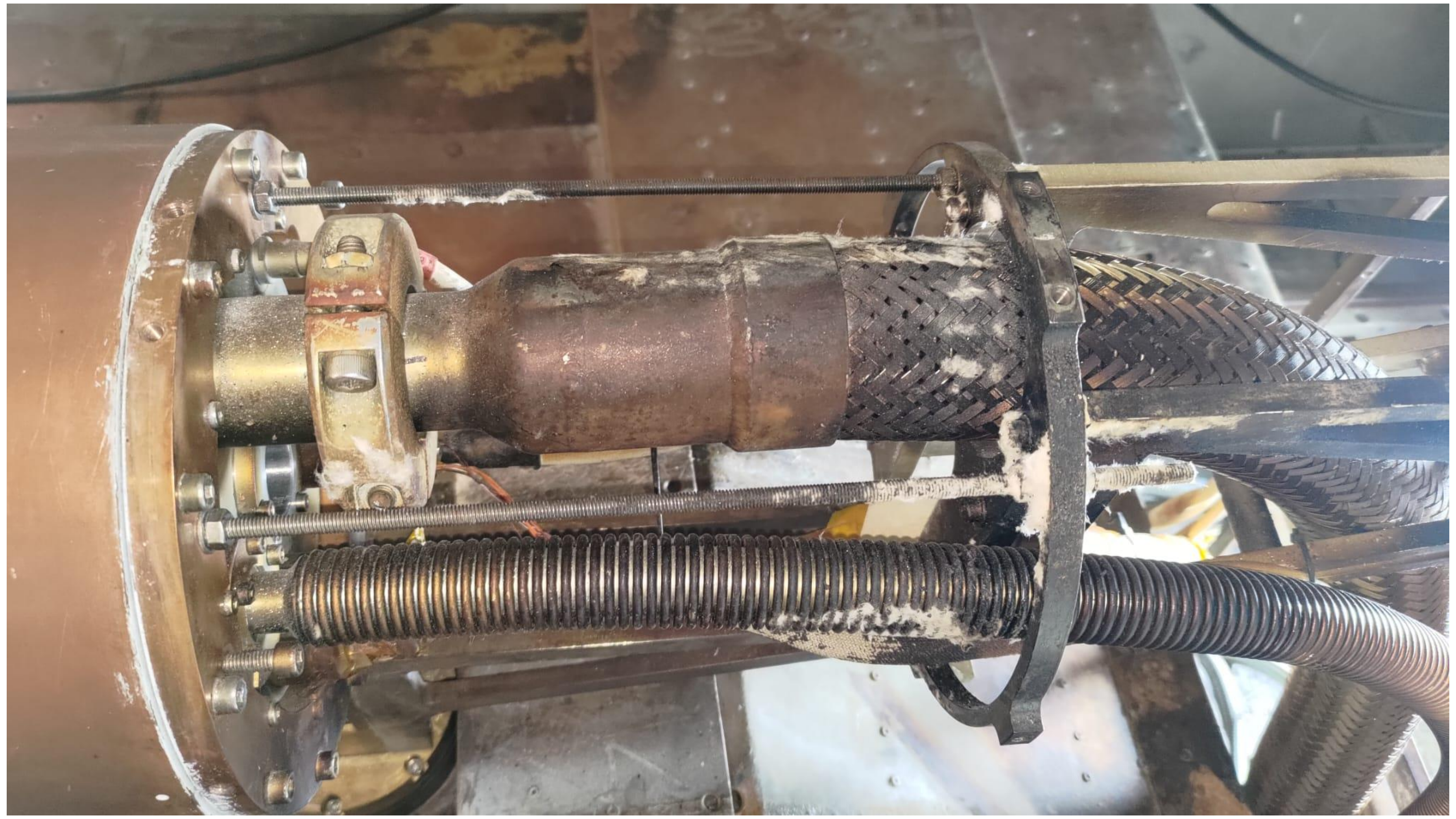
While defects in the YBCO conductor have limited the maximum operating magnetic field of the magnet, the reason for these defects have been identified resolved for future endeavors

Current leads cooling should probably be improved for larger operating current, depending on the target operating temperature

Though both the magnet and the cryogenic system have operated nominally until the last experimental campaign, the probe materials have been significantly stressed

Project end in september 2024

Onto real size systems ???



Thank you for your attention !

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