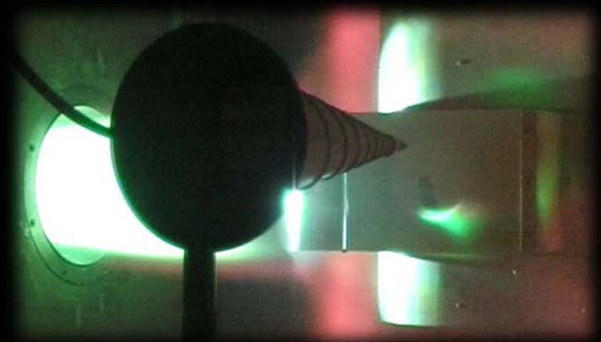
Karlsruhe Institute of Technology

Design and Performance of a Conduction-Cooled HTS Magnet in the Radio-Blackout-Experiment COMBIT

S. I. Schlachter, J. Brand, H. Fillinger, W. Goldacker, A. Kling, A. Kudymow, B. Ringsdorf, U. Walschburger, J. Willms, and H. Wu

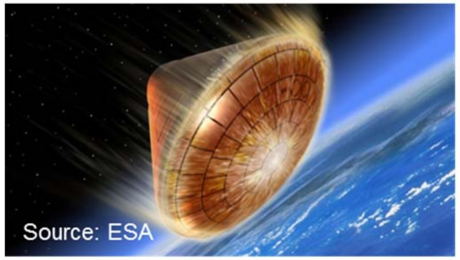
Karlsruher Institut für Technologie, ITEP, Eggenstein-Leopoldshafen, Germany

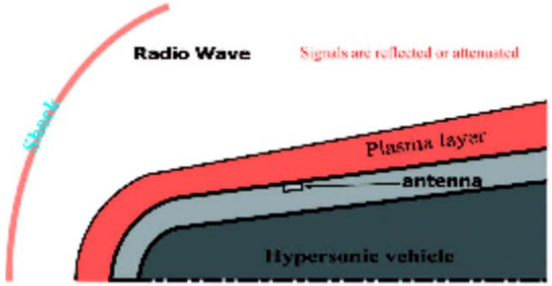
INSTITUTE FOR TECHNICAL PHYSICS (ITEP) - SUPERCONDUCTING MATERIALS AND ENERGY APPLICATIONS (SUPRA)



Background: Radio Blackout

- Communication interruption due to attenuation and/or reflection of radio waves by plasma layer that is created during hypersonic or re-entry flight



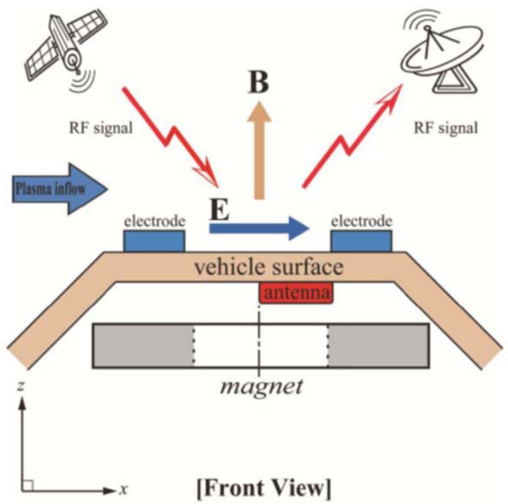


- **Problem:**
  - Hypersonic flow creates plasma layer around vehicle.
  - Dense plasma layer has high plasma frequency

$$f_e = \frac{\omega_e}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{e^2 n_e}{\varepsilon_0 m_e}} > f_{radio}$$

→ reflection of RF signals: 'Radio Blackout'

- **Solution** (*K.M. Lemmer et al. Journal of Spacecraft and Rockets **46** (2009) 1100*)**:**
  - Reduction of plasma frequency
    by reduction of plasma density n_e → ***E*x*B* drift:**



COMBIT: Communication Blackout Mitigation for Spacecrafts

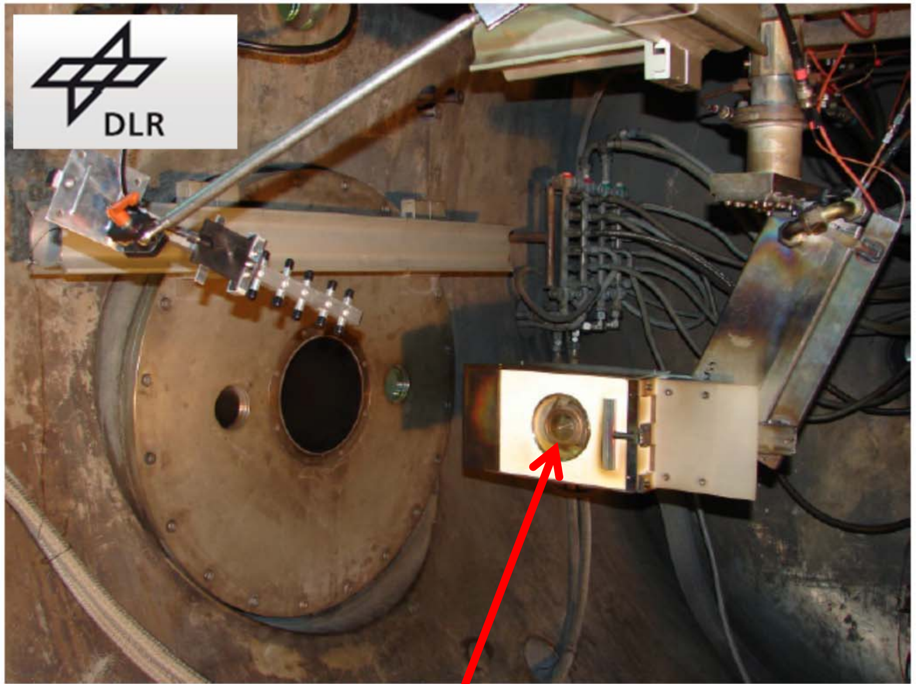
- **Project**: Helmholtz - Russia Joint Research Group

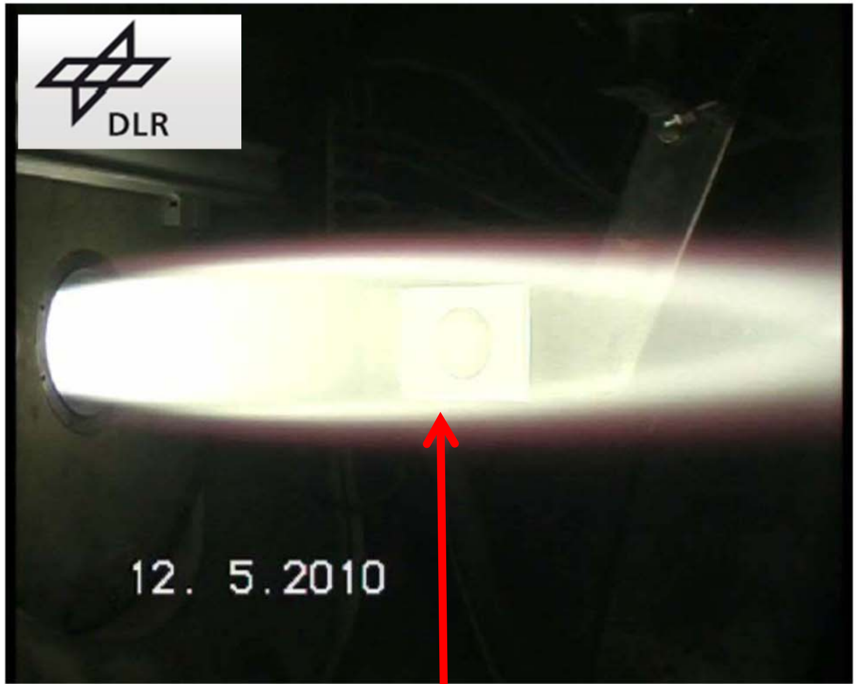
- **Project objective**
  - Study the ExB mitigation scheme for re-entry communication blackout both numerically and experimentally

- **Partners and their role in project:**
  - ***German Aerospace Center (DLR), Cologne***
    - Project management and technical coordination (together with IOFFE)
    - Ground experiments
  - ***Karlsruhe Institute of Technology***
    - Design, fabrication and test of superconducting magnet and cryogenic system
  - ***IOFFE (Physical-Technical Institute, Russian Academy of Sciences, Saint Petersburg)***
    - Physical modelling and numerical simulations

Experiment @ DLR Cologne in L2K arc heated wind tunnel

State-of-the-art: flat plate model with normal conducting magnet





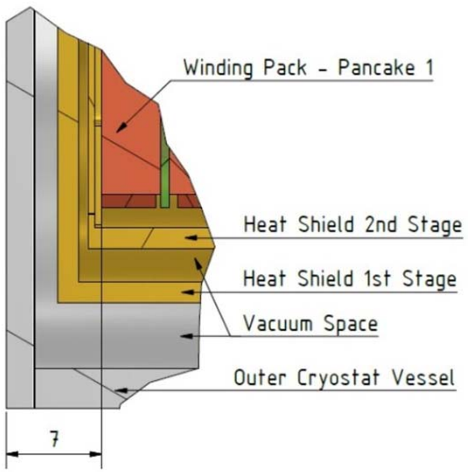
Cu magnet

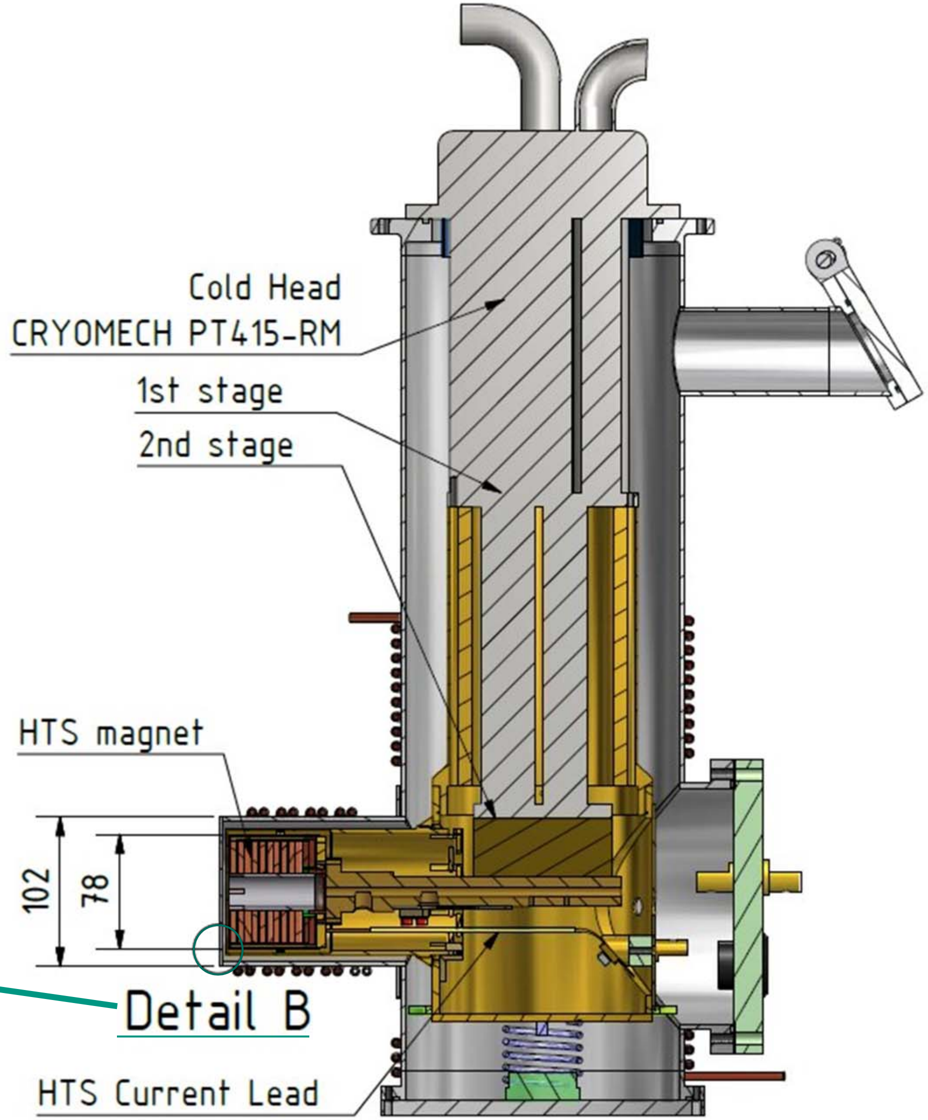
Plasma beam

COMBIT HTS Magnet and Cryostat

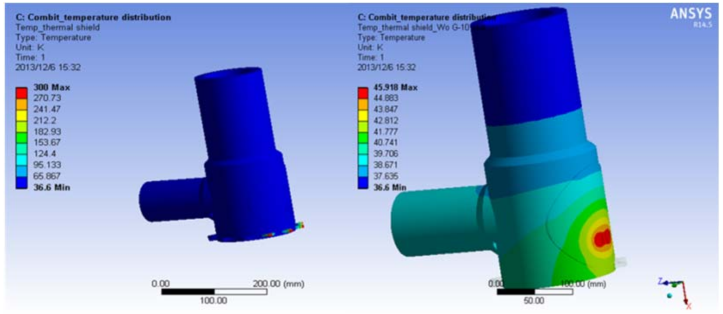
Restrictions and Requirements:

- Pressure in plasma chamber: ~1 mbar
- Temperature in plasma beam: ~ 450 K
- Outer diameter of cryostat around magnet coil **~100 mm**
- Magnetic field as high as possible
  - ➢ Distance from winding end to outer cryostat wall as small as possible (~ **7 mm**)



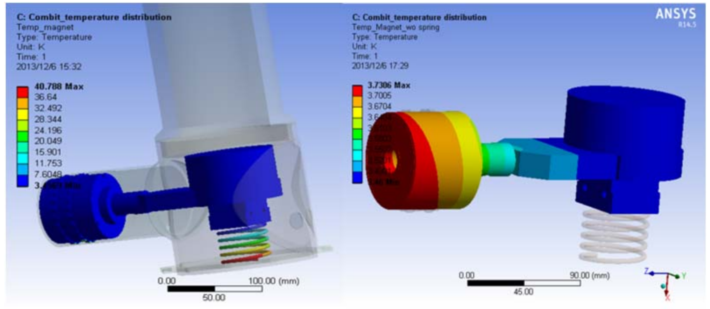


Calculation of Heat Loads



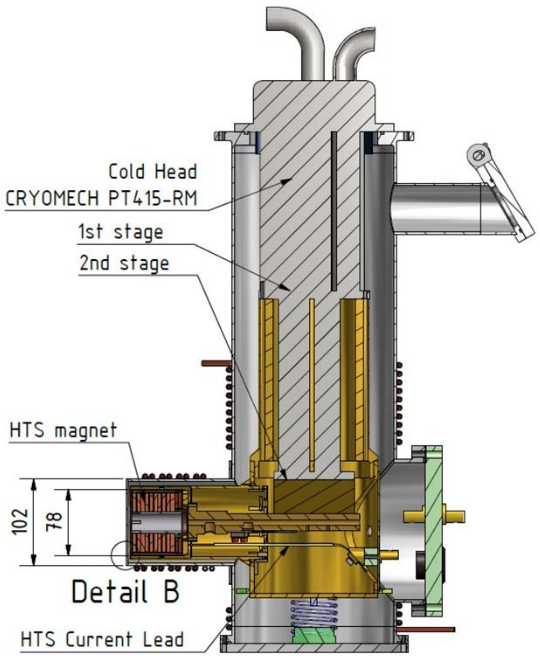
40K region of Combit magnet

40K region without G-10 star_150



4K region of Combit magnet

4K region without support spring and G-10 stars

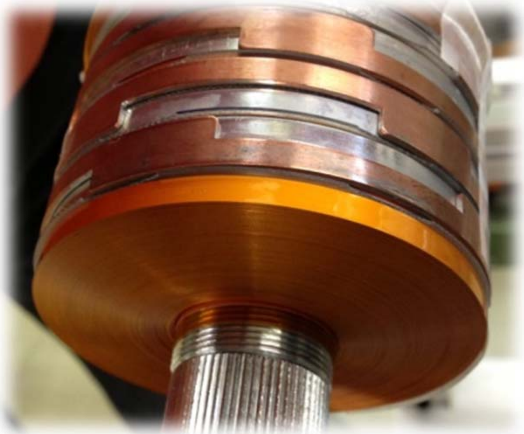


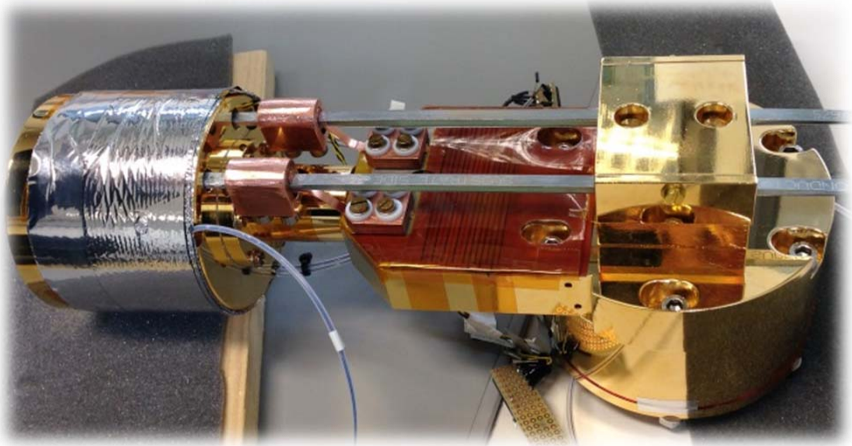
	40 K region (W)	4 K region (W)	
		0 A	135 A
Radiation	0.93	0.007	
Support spring	---	0.001	
G-10 star_150	1.24	---	
G-10 stars	---	0.12	
Instrument wiring	0.01	0.032	
Soldering joints	---	0	0.287
Current leads	22.67	0.06	0.06
Total	**24.85**	**0.22**	**0.51**

Winding of Insulated HTS Magnet with REBCO Coated Conductor

KIT Karlsruher Institut für Technologie

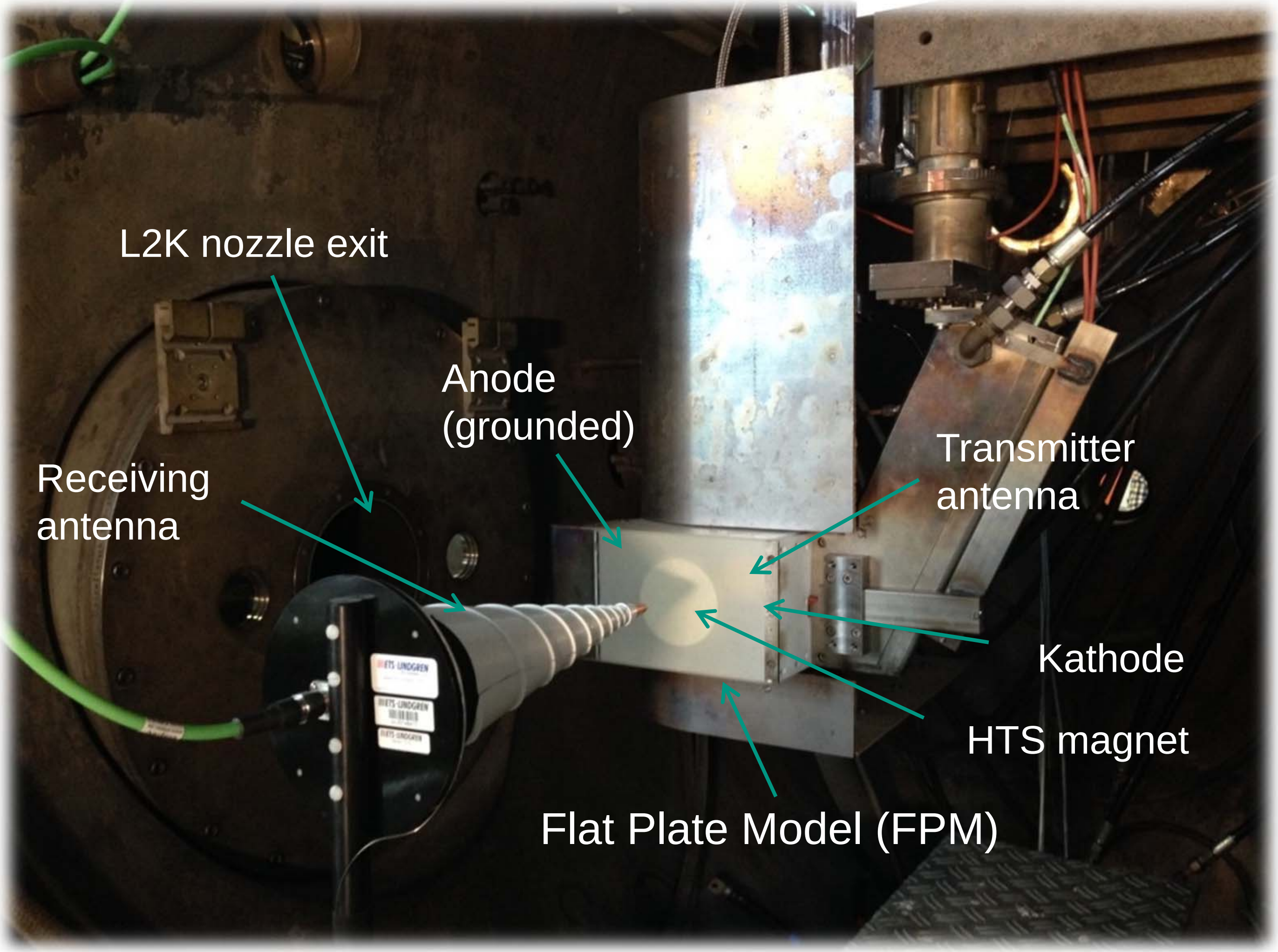
- SuperPower SCS4050-AP + 25 µm Kapton Foil



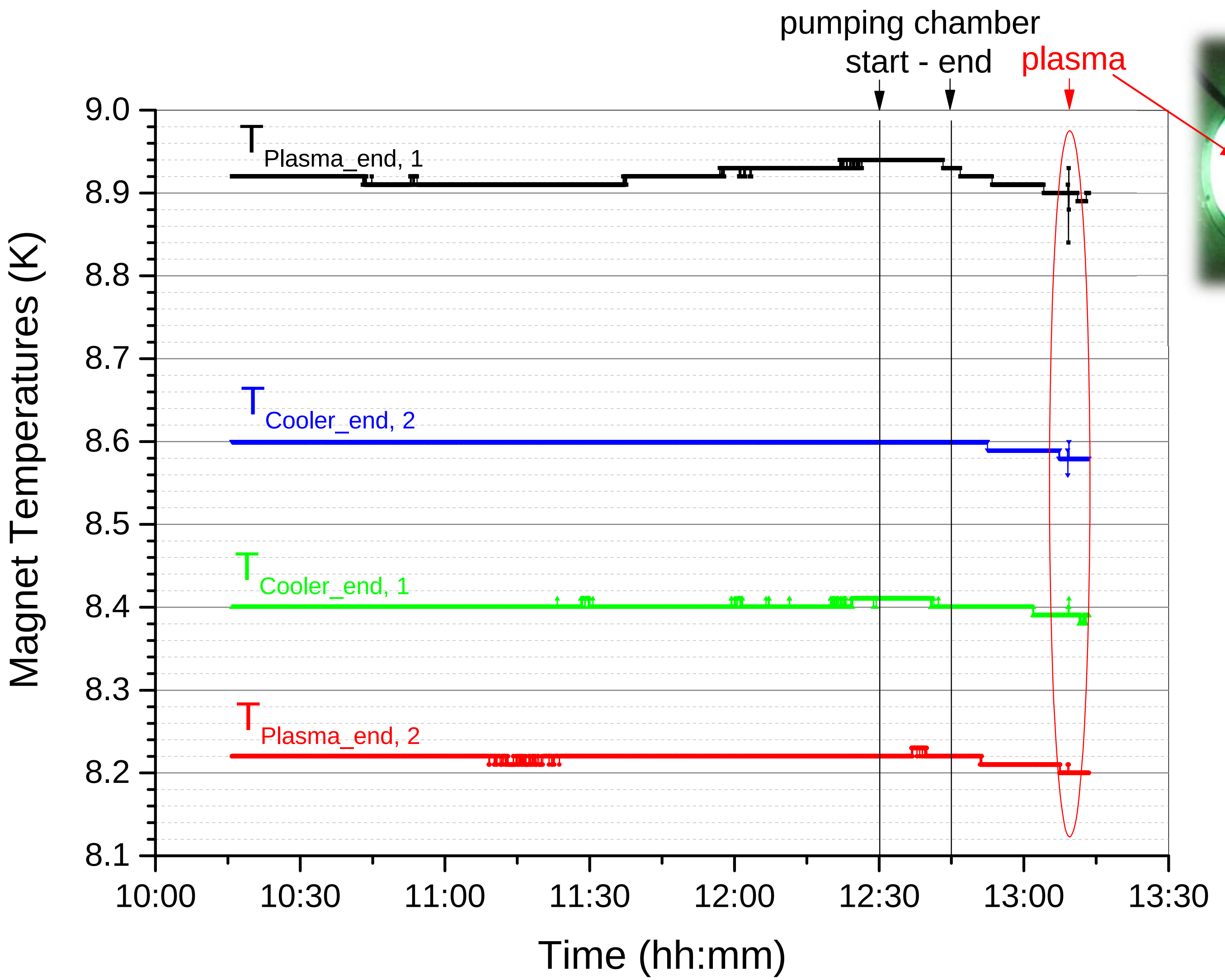


Parameter	Value
Number of double pancakes (DP)	5
Outer winding diameter [mm]	70
Inner winding diameter [mm]	25
Length of winding pack [mm]	49
Turns per pancakce	~ 186
Conductor length per DP [m]	~ 55
Self-inductance *L* [mH]	73
Coil contant (central field) *B*/*I* [mT/A]	34.08
Mass of coil [kg]	1.75

Experiment @ DLR Cologne in L2K test chamber



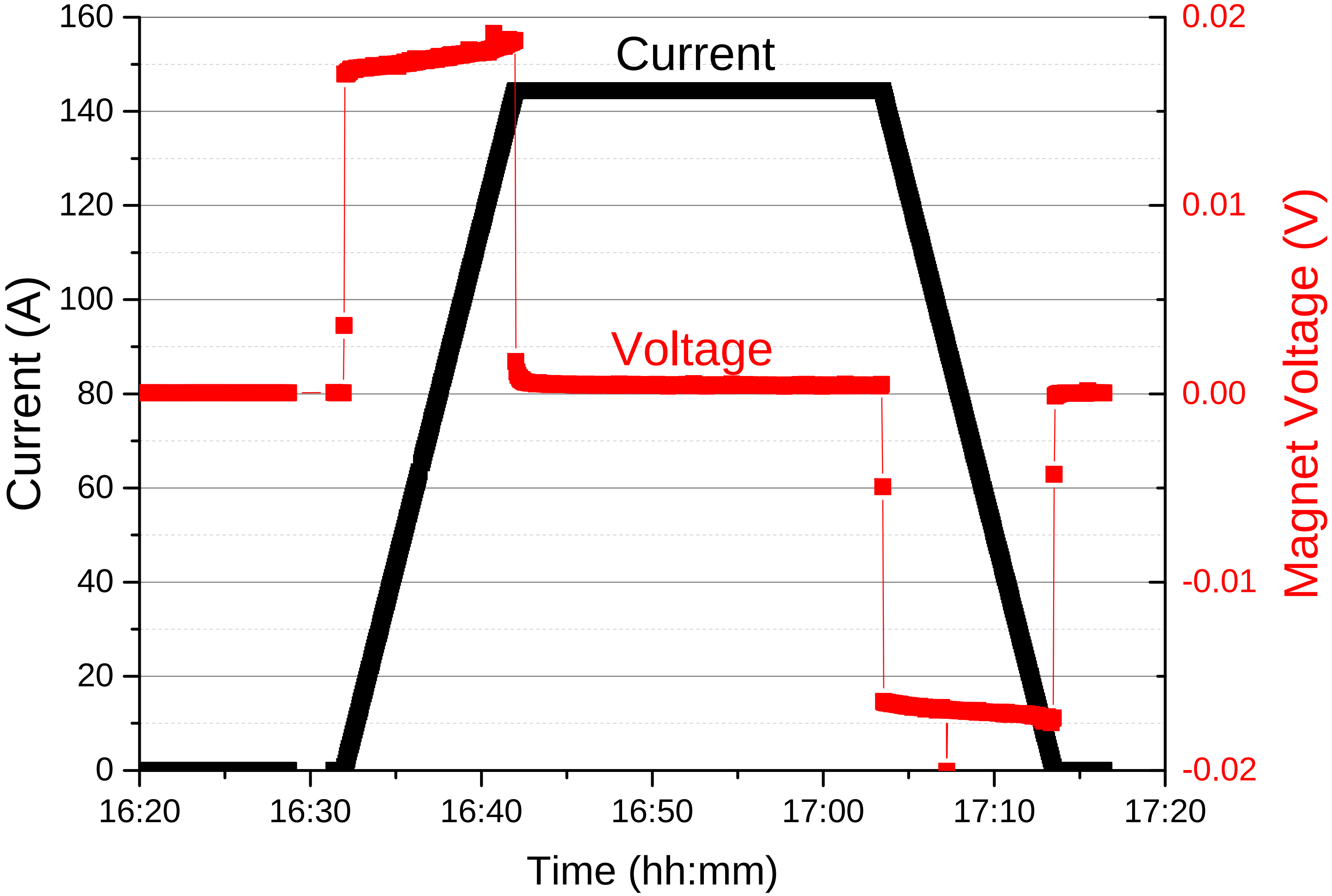
Magnet Test: Influence of Plasma



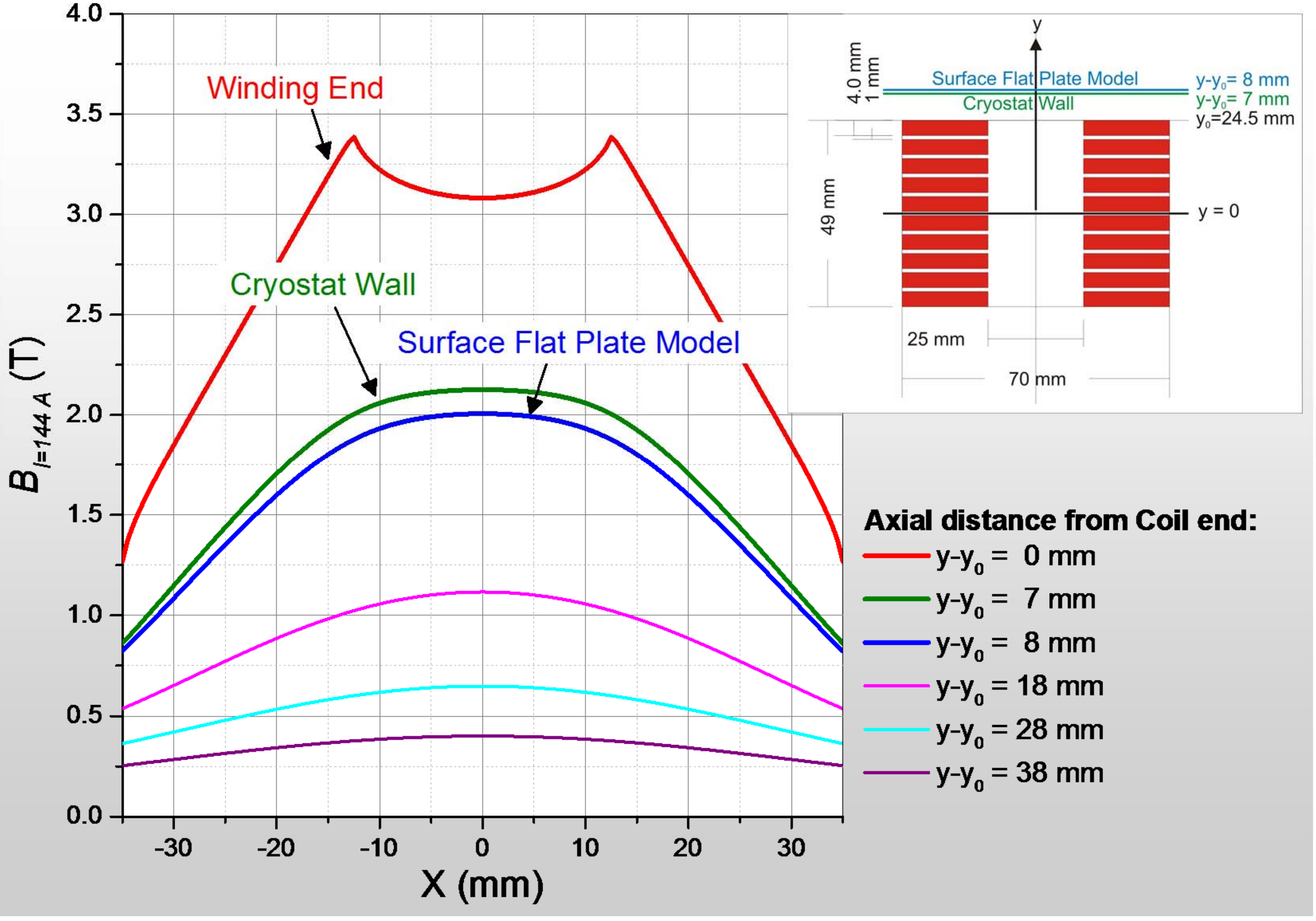
Plasma visible in voltage signals of T-sensors

- Electric disturbance !!
- No heating observed !!

Plasma Experiments: Ramp to I = 144 A

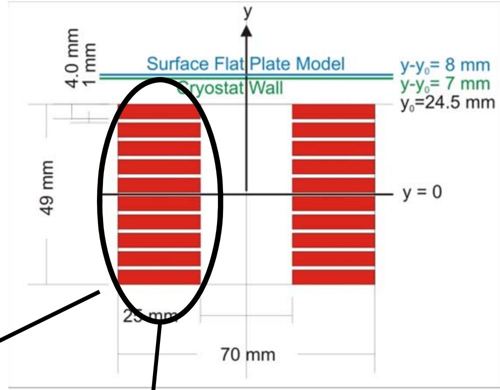


Magnetic field at I = 144 A

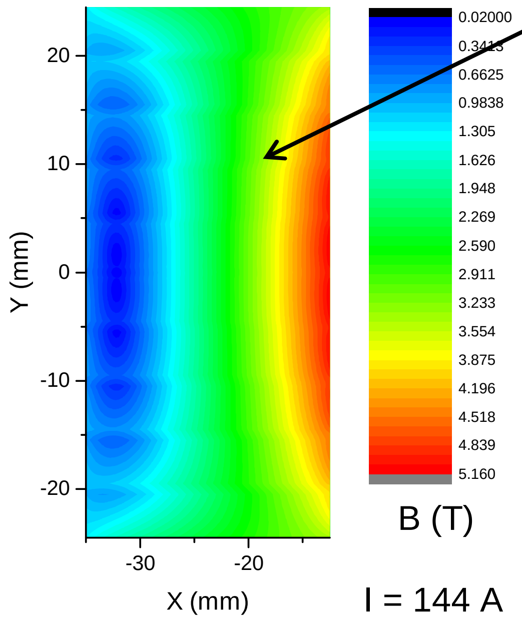


Field on surface of FPM: ***B* = 2 T**

Magnetic field in Winding pack

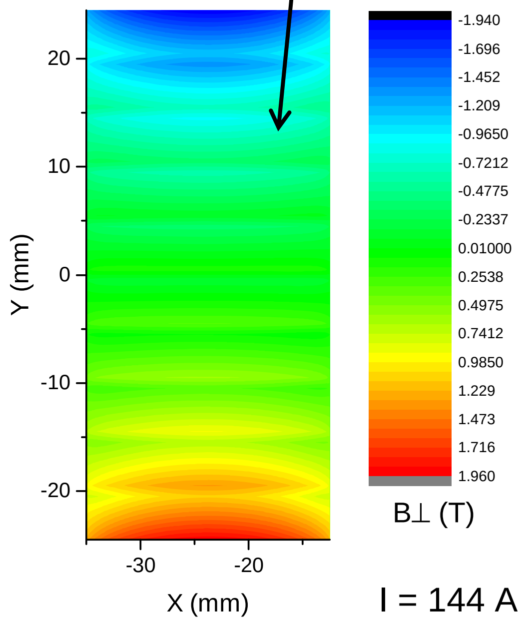


Magnetic field amplitude: B



I = 144 A

Perendicular field: $B_\perp$

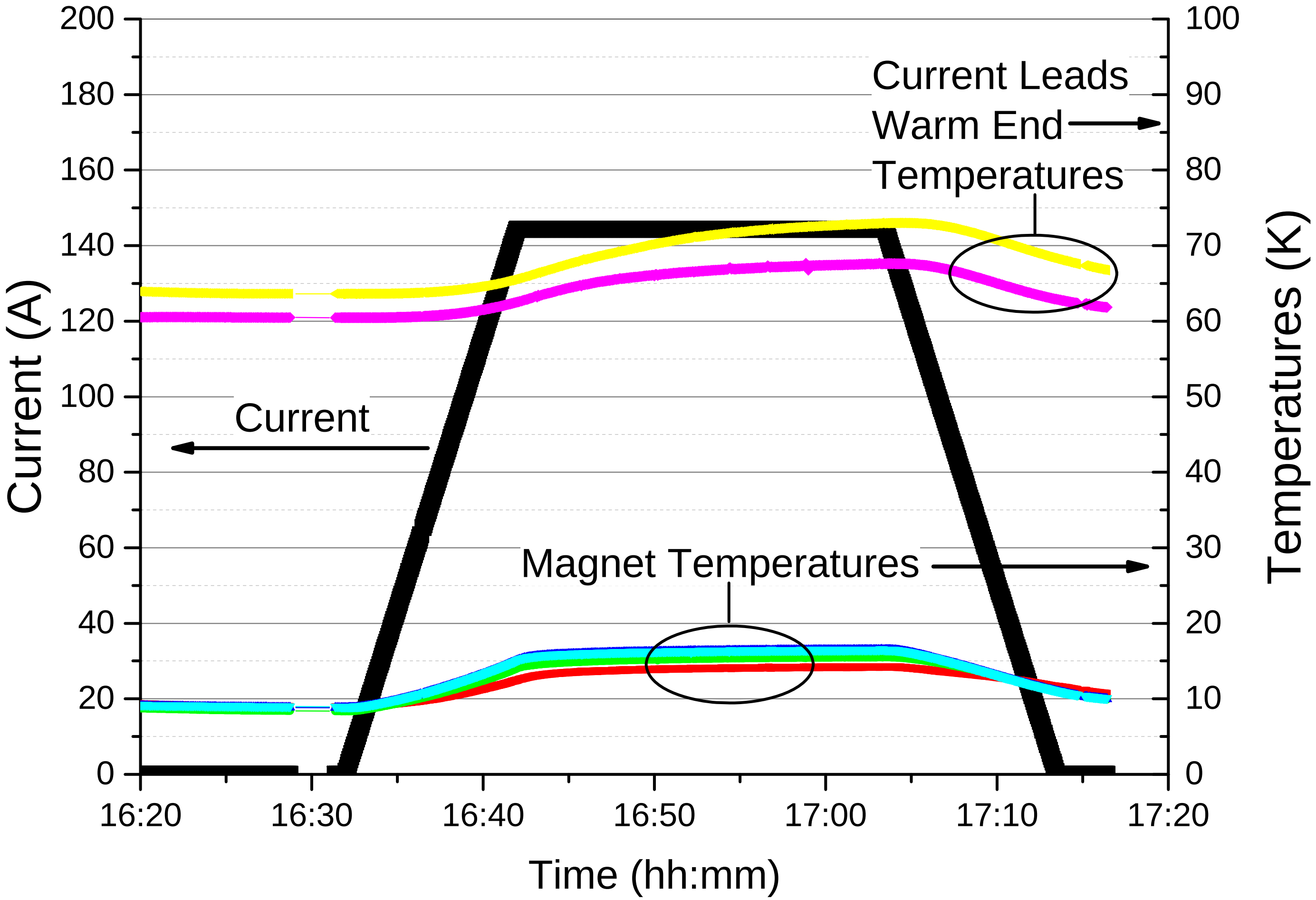


I = 144 A

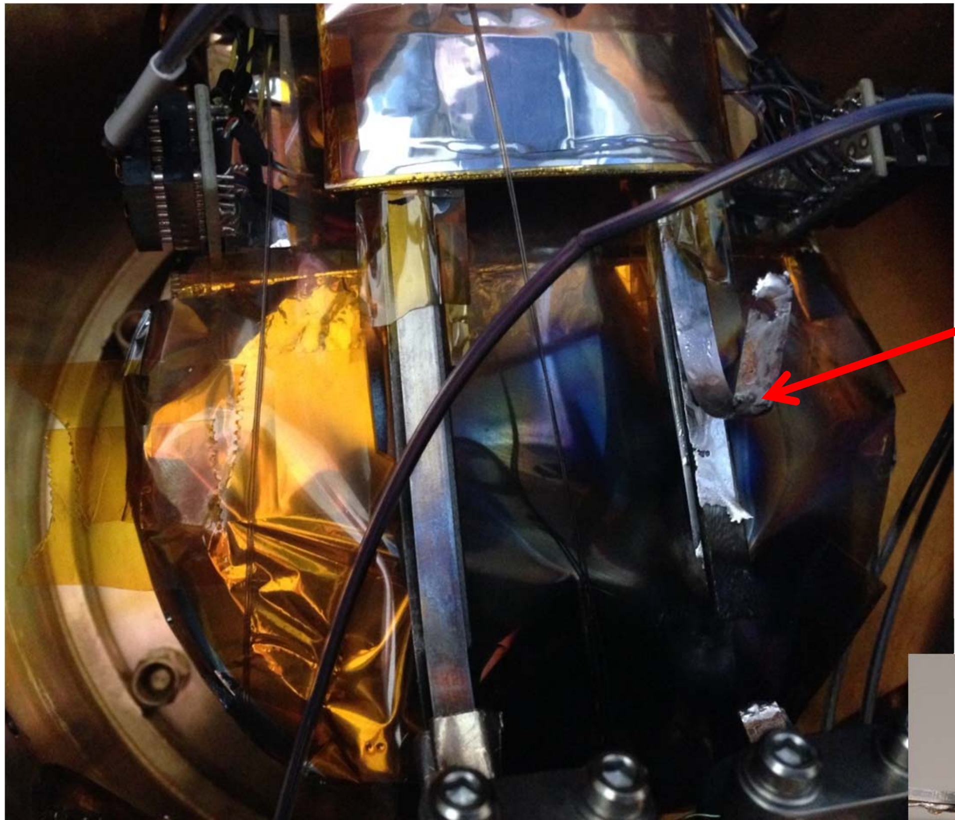
Maximum Field at Winding: ***B* = 5.16 T**; Maximum perpendicular Field: **$B_\perp$= 1.9 T**

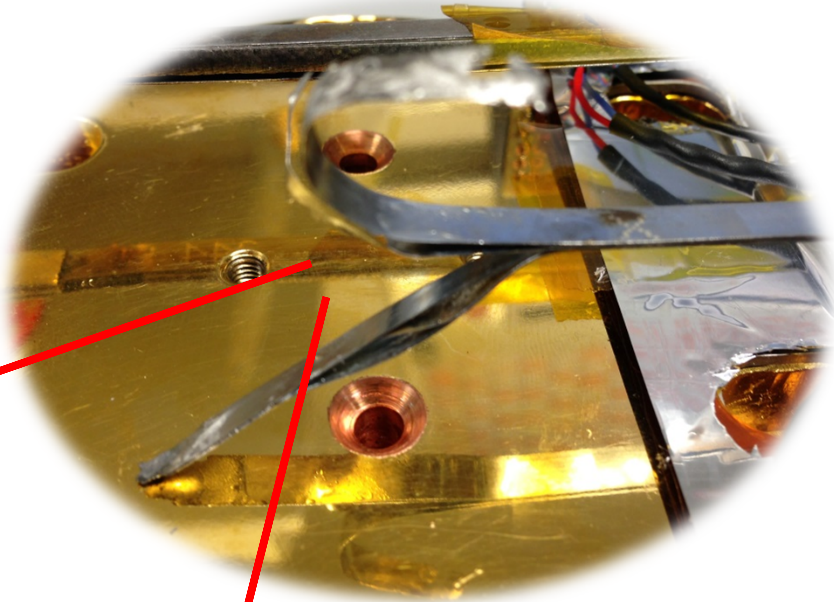
Central Field: **$B_{central}$ = 4.9 T**

Plasma Experiments:
Temperatures at maximum current (I = 144 A)

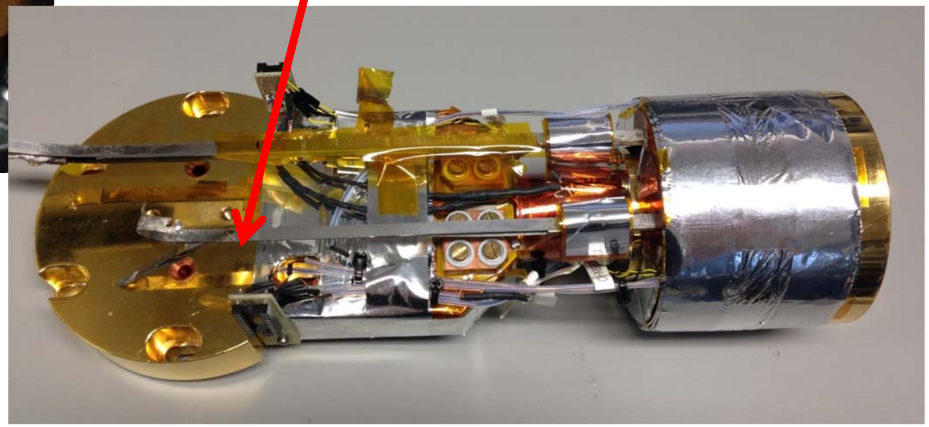


Repairing of Current Leads @ KIT after Failure in Plasma Experiment

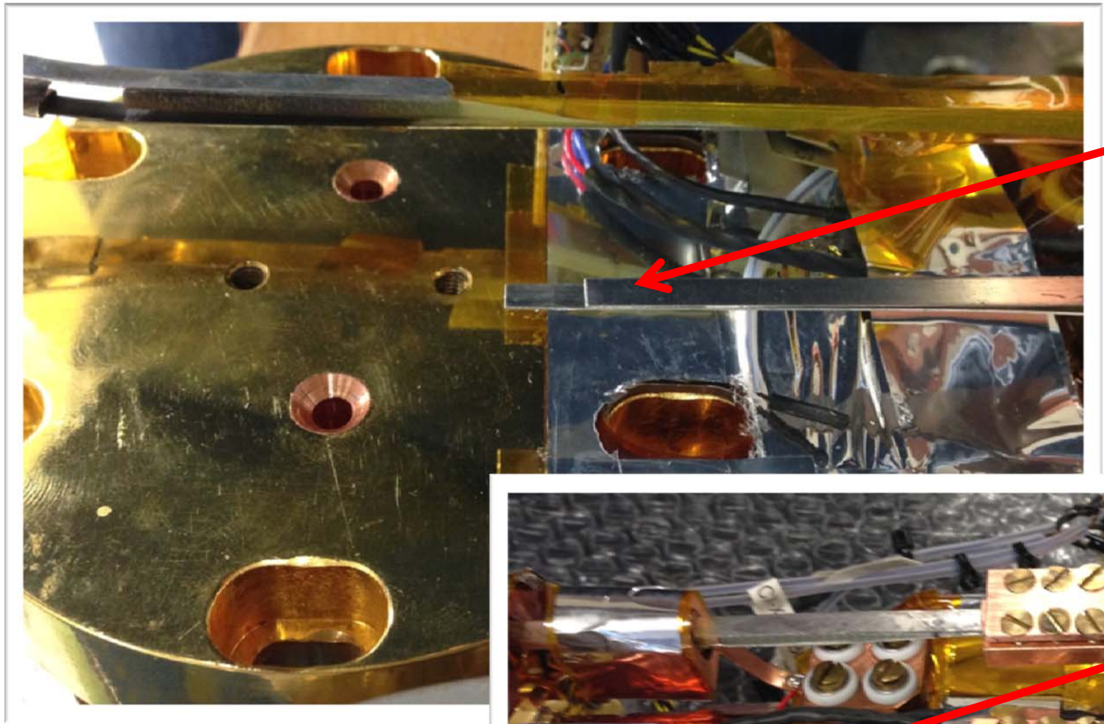




Current Lead #2 burned at warm end !



Jan. 2015: Repairing of Current Leads @ KIT

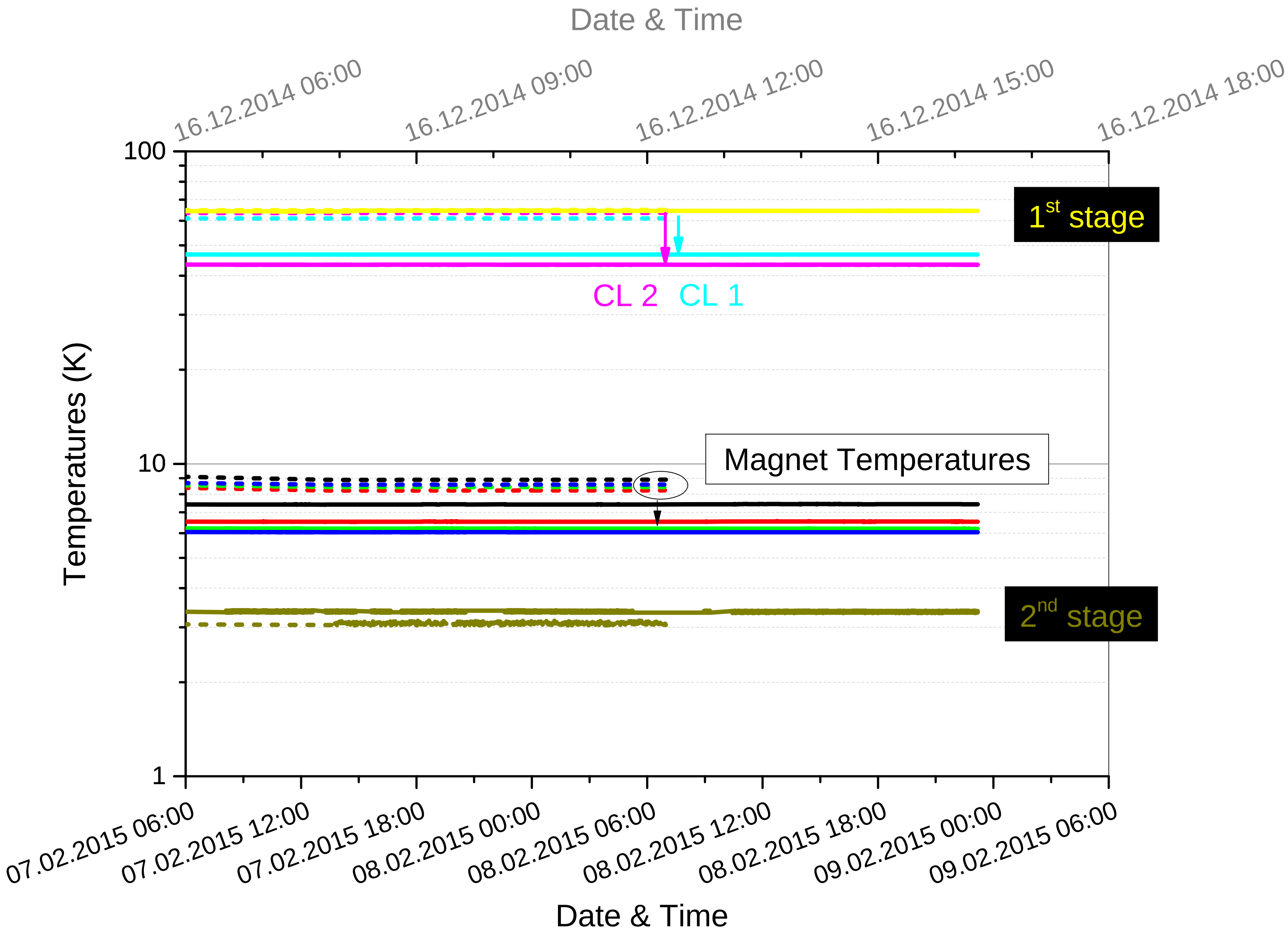


- burned parts cut away from current lead tapes
- new CL tapes soldered to remaining part

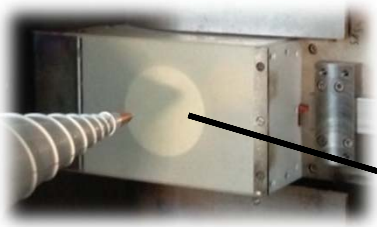
Heat sink for solder joints and in center of other current lead

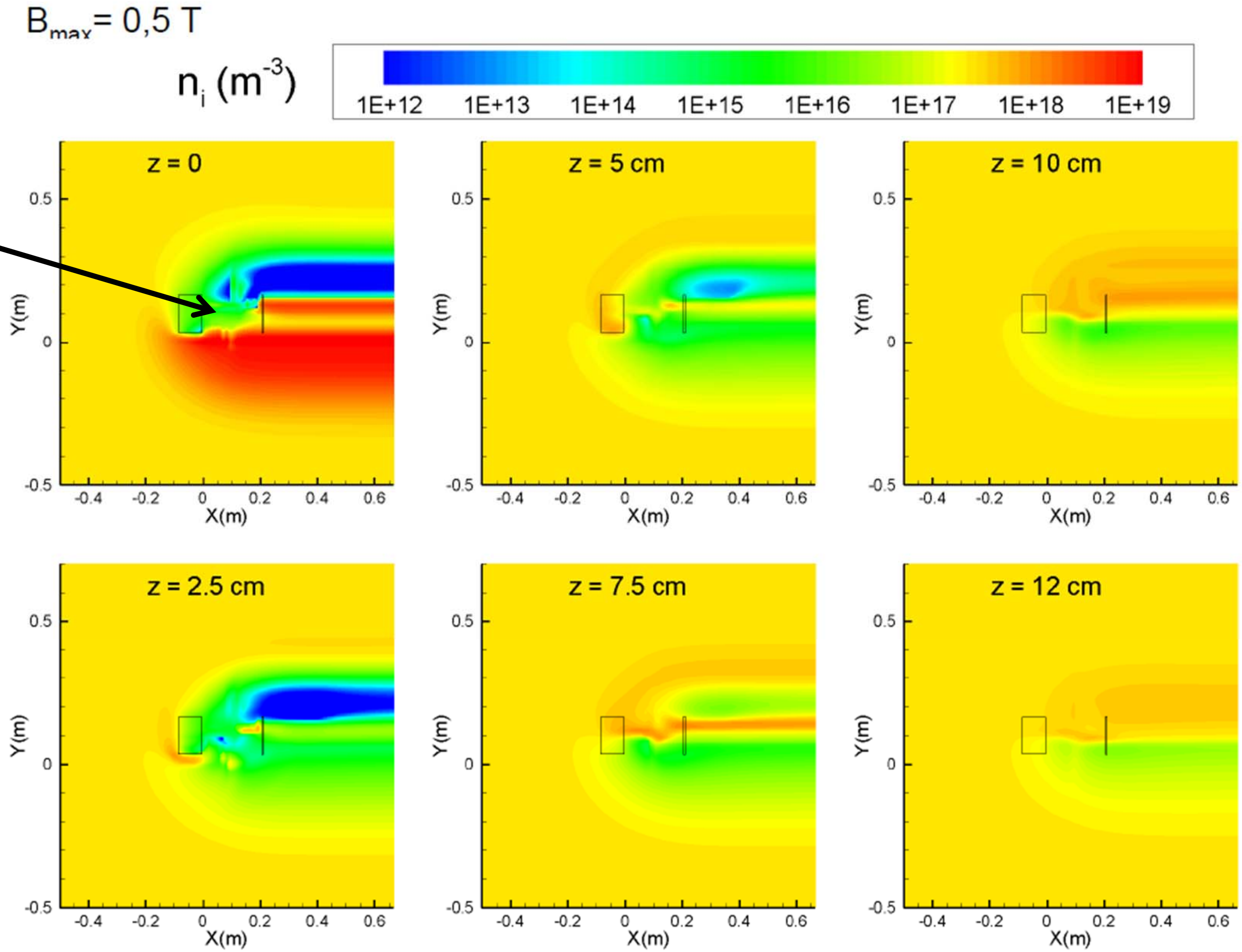
Cool Down after Repairing Current Leads

End Temperatures @ B = 0



Calculation of Ion Density Distribution





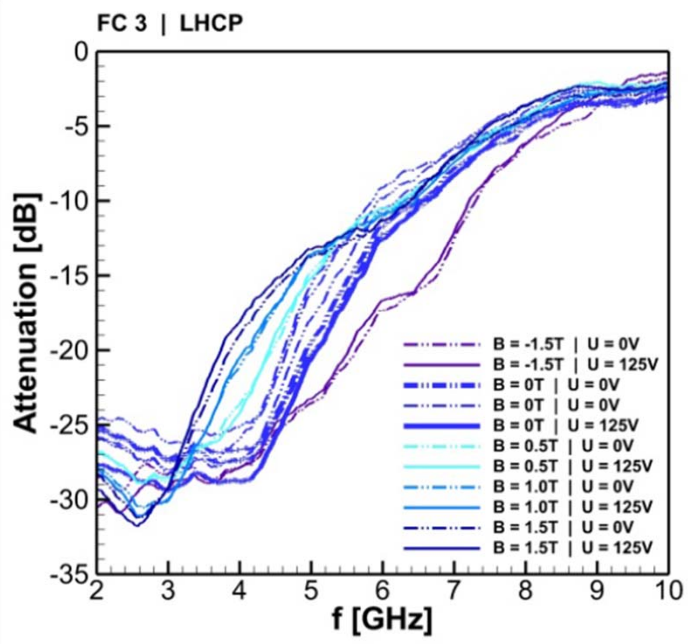
Courtesy of
Y.A. Kurakin,
S.A. Poniaev

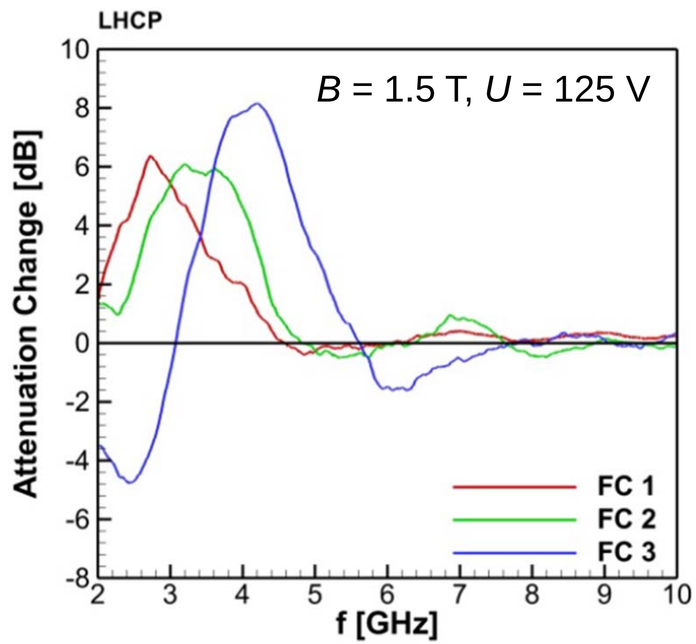
Ioffe Physical Technical Institute

ExB–Drift for Radio Blackout Mitigation
Signal attenuation @ different plasma flow conditions

Courtesy of A. Gülhan, L. Steffens

	FC1	FC2	FC3
Argon density (m^{-3})	2.28×10^{21}	2.14×10^{21}	1.89×10^{21}
Electron density (m^{-3})	1.6×10^{17}	2.7×10^{17}	6.1×10^{17}
Velocity(m/s)	1723	1850	2150
Plasma frequency f_p (Hz)	3.6	4.7	7.0





- ➢ No influence of Voltage visible
- ➢ Influence of *B*-Field clearly visible – depends on plasma flow conditions

Summary and Outlook

Summary

- COMBIT: Ground experiment for communication blackout mitigation using ***E***x***B*** drift
- Successful design, manufacturing and operation of sc magnet and cryogenic system:
  - Magnetic fields up to 2 T achieved on surface of FPM
  - No influence of plasma on magnet voltages and temperature
- Calculation of Ion density distributions
- Mitigation of radioblackout demonstrated
  - Influence of magnetic field shown
  - No influence of voltage observed

Outlook

- Can experiments be transferred to hypersonic / reentry flight ???
  → larger magnet (→ larger stray field), lower weight, less power

Acknowledgement

- This work was supported by the Helmholtz - Russia Joint Research Group “COMBIT” (HRJRG-304)

Thank you for your attention !