

# Performance of conduction-cooled HTS Magnet in radio blackout mitigation experiment

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## Background

### Problem:

Radio blackout during hypersonic or reentry flight of space vehicles. Dense plasma layers lead to attenuation or reflection of radio waves → interruption of communication with ground stations or satellites.

### Solution:

Reduction of plasma density by magneto hydrodynamic effects caused by crossed electric and magnetic fields.

Placement of transmitter and antenna in regions with lower plasma density.

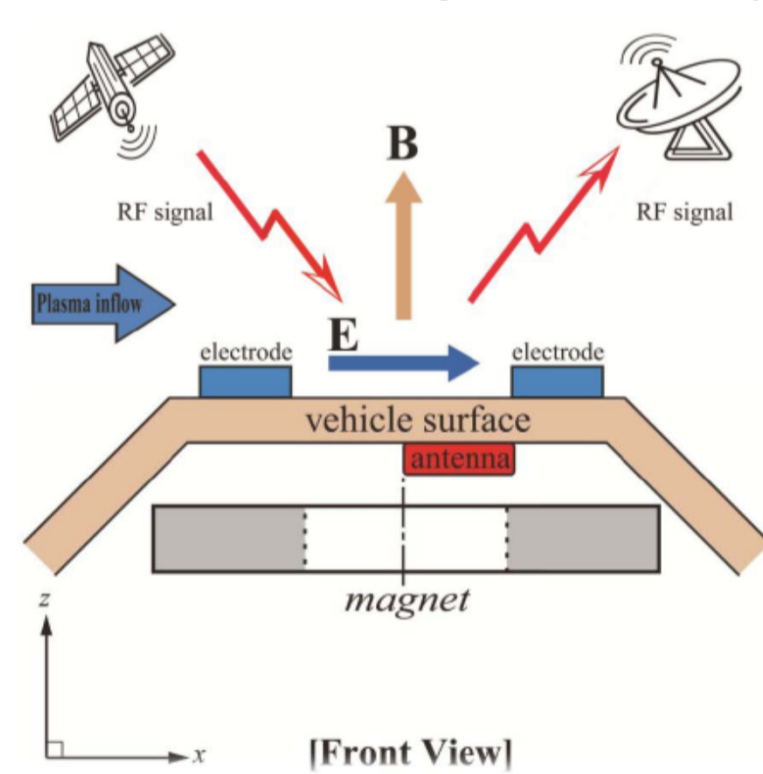
### Project COMBIT:



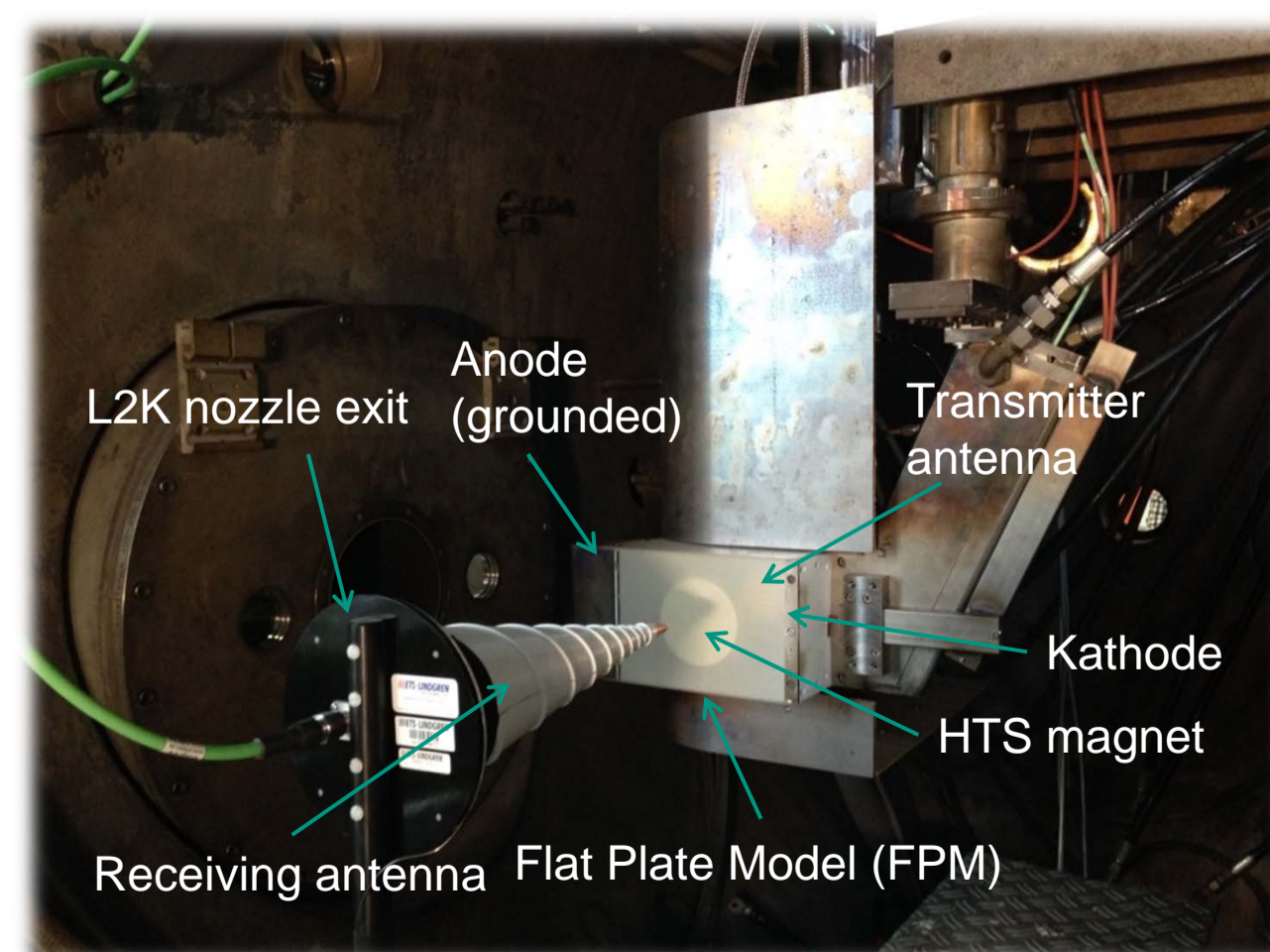
Ground experiment to demonstrate local reduction of plasma density with crossed electric and magnetic fields.

Partners: DLR, KIT, IOFFE Institute

Role of KIT: Design and construction of superconducting magnet and cryogenic system



Courtesy of A. Gülhan, DLR Cologne, Joint Research Proposal Helmholtz Russia Joint Research Group



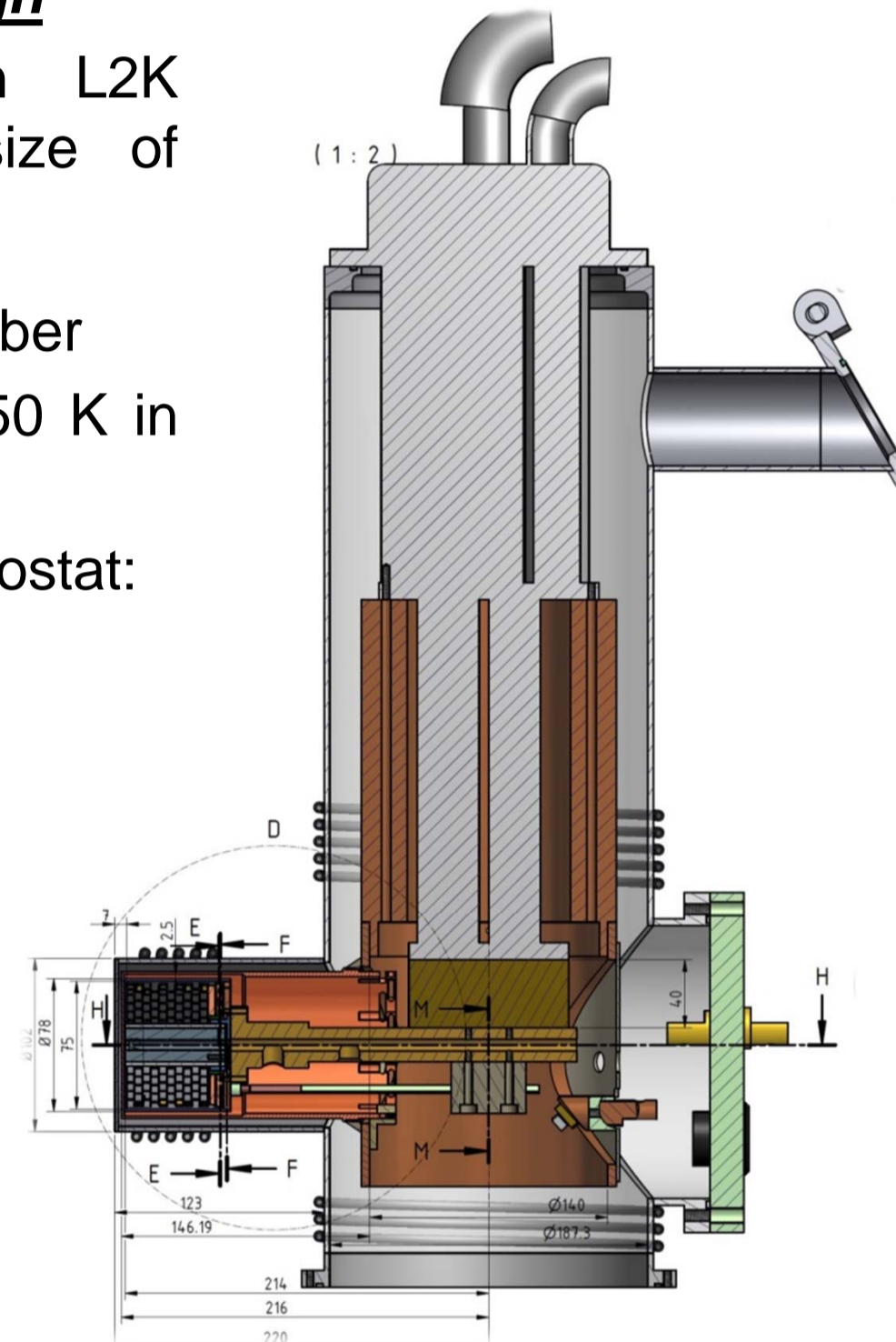
Experimental Setup with HTS magnet and cryogenic system installed in the L2K arc heated wind tunnel @ DLR.

## Cryogenic System and HTS Magnet

### Magnet and cryostat design

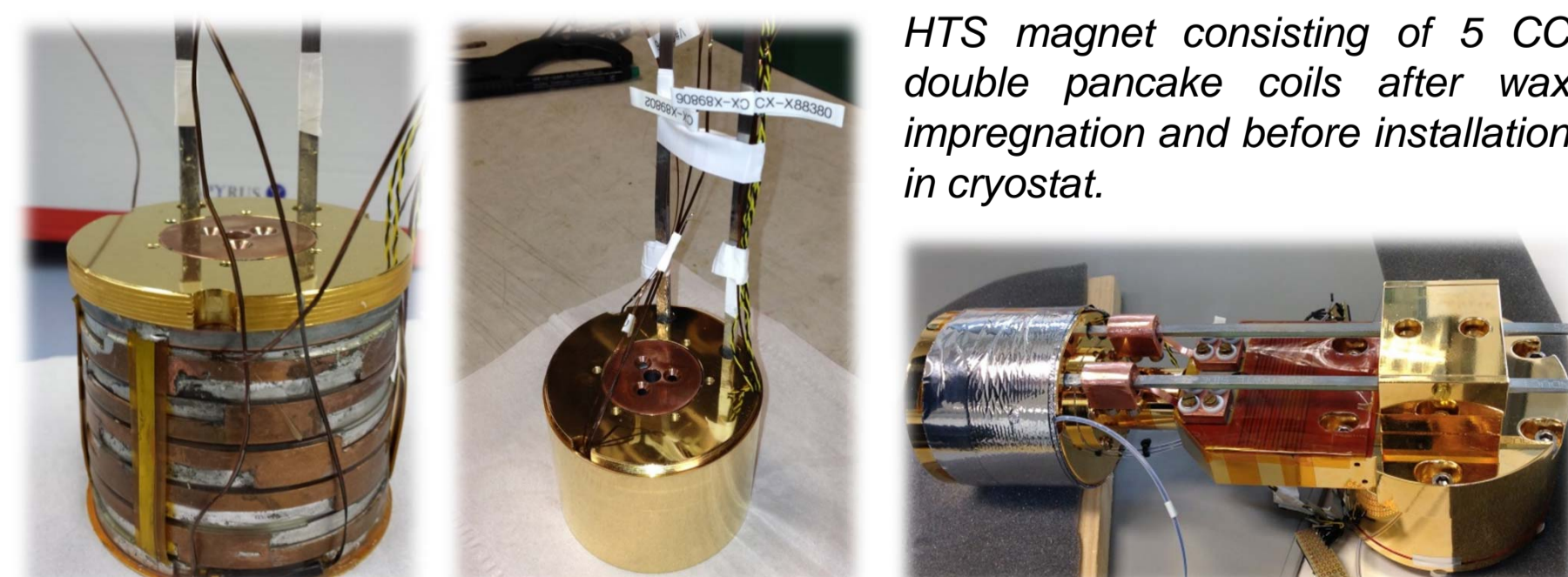
Experimental situation in L2K plasma chamber limits size of cryostat and magnet!

- Cryostat in vacuum chamber
- Temperatures up to ~ 450 K in plasma beam
- Maximum diameter of cryostat: ~100 mm around magnet



### Parameters of the COMBIT HTS magnet

- Coated Conductor: SCS4050-AP
- Number of double pancakes: 5
- Outer winding diameter: 70 mm
- Inner winding diameter: 25 mm
- Length of winding pack: 49 mm
- Turns per pancake: ~ 186
- Conductor length per double pancake: ~ 55 m
- Self-inductance  $L$  [mH]: 73 mH
- Coil constant (central field)  $B/I$ : 34.08 mT/A

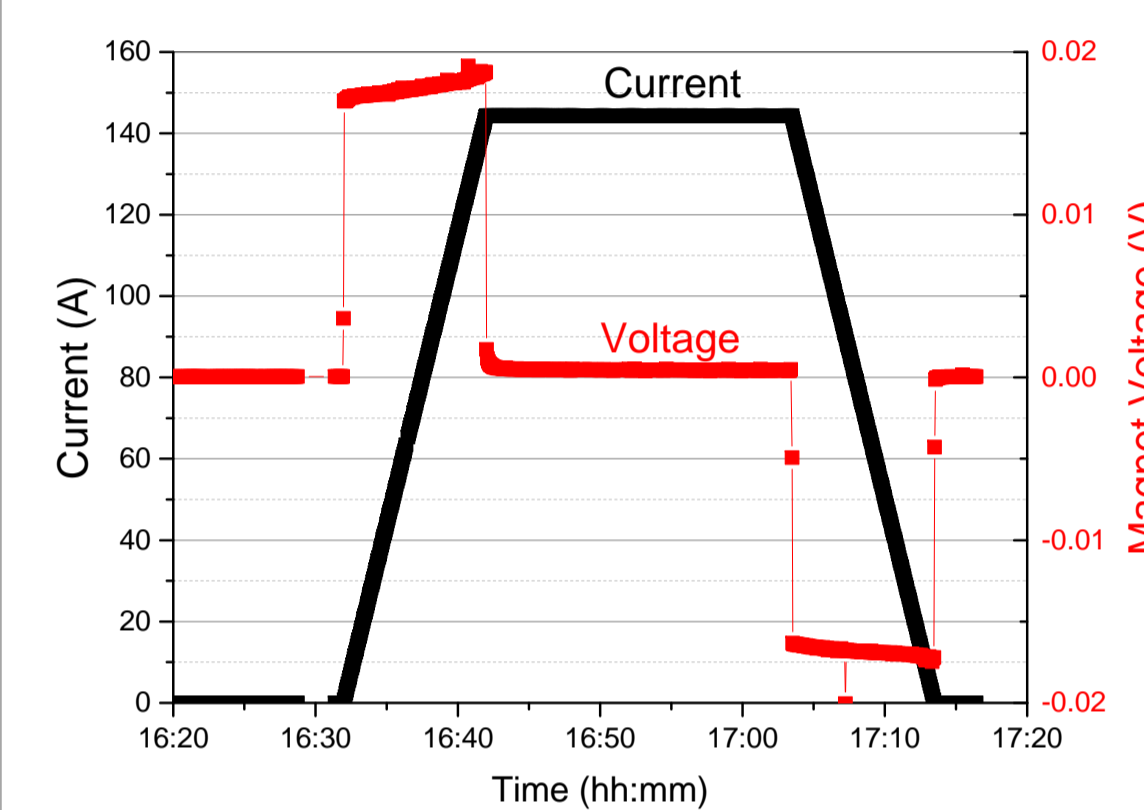


HTS magnet consisting of 5 CC double pancake coils after wax impregnation and before installation in cryostat.

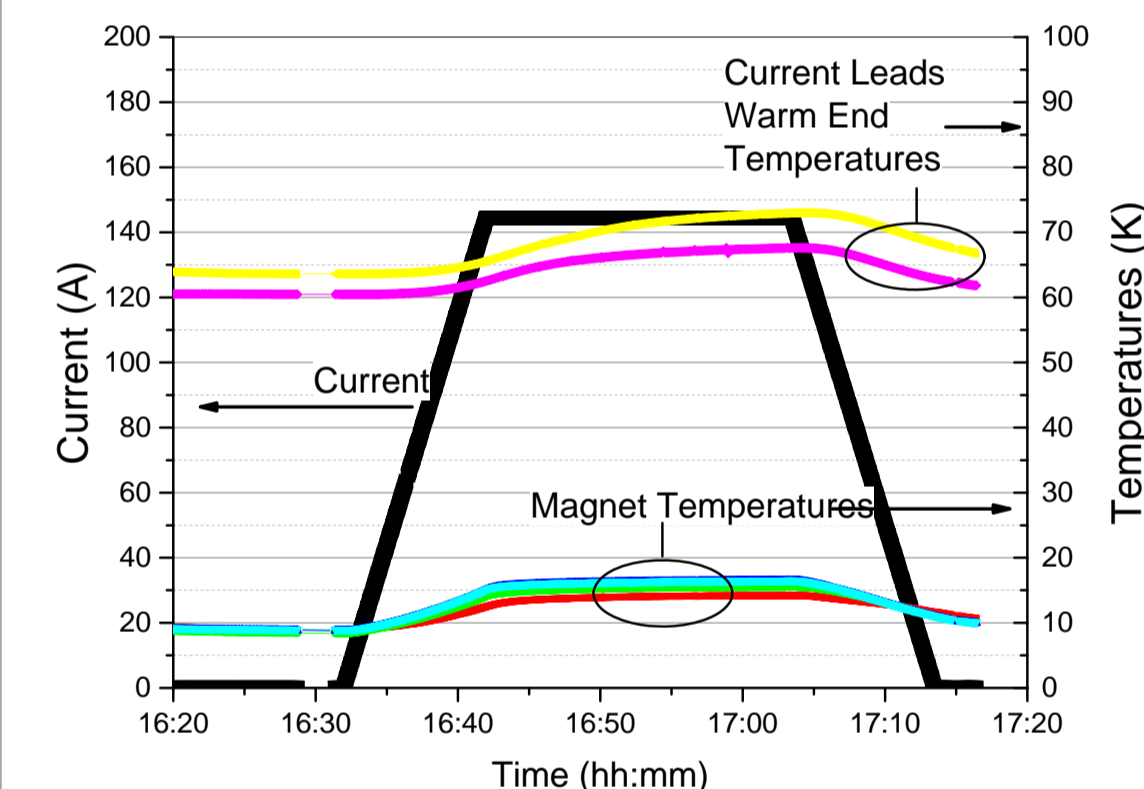
## Performance of Magnet in Plasma Experiments

### Magnet Voltages and Temperatures

Currents up to 144 A applied →  $B = 2$  T outside FPM



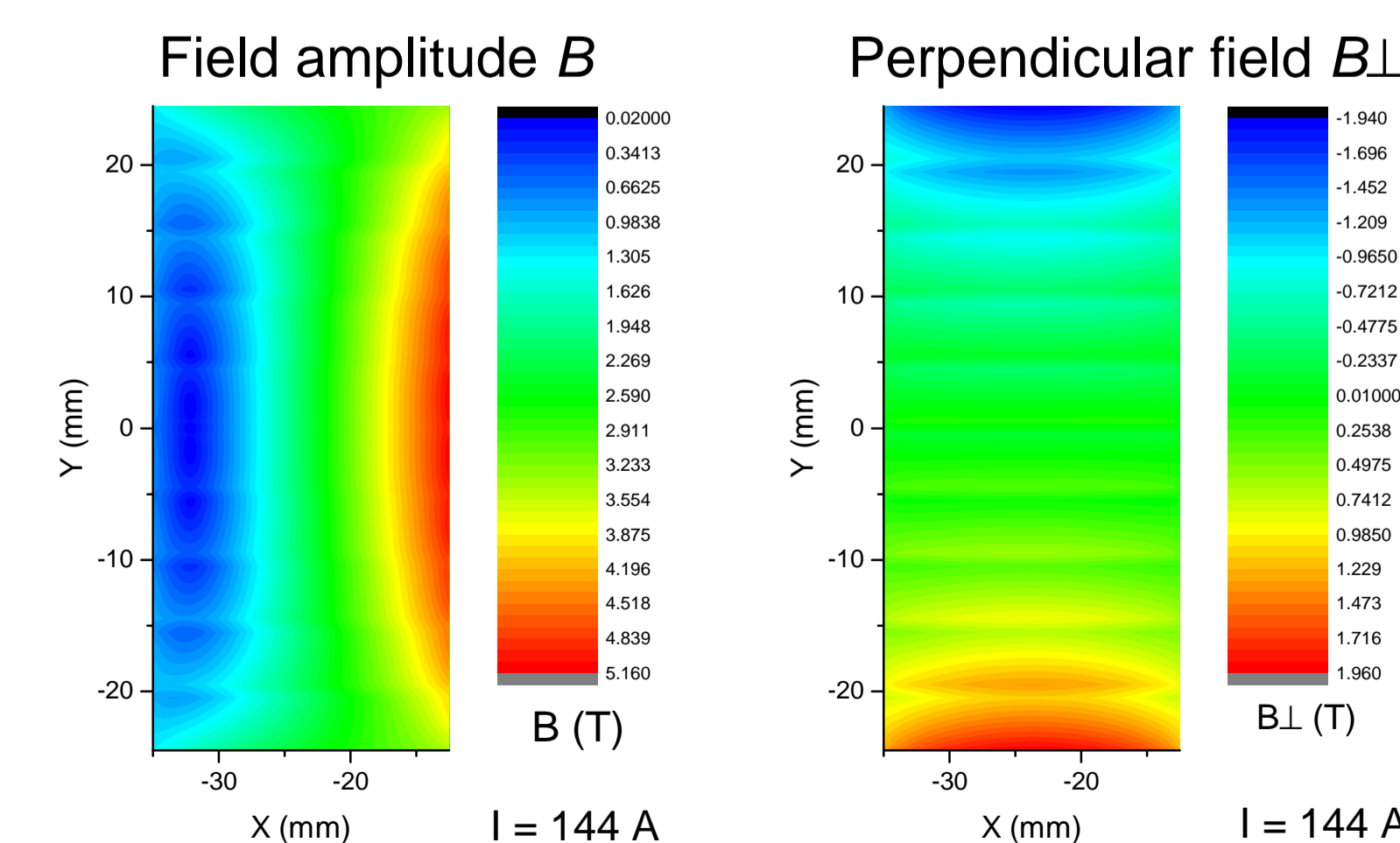
Magnet voltage and current during field ramp to  $B = 2$  T and during plasma experiments at this field amplitude.



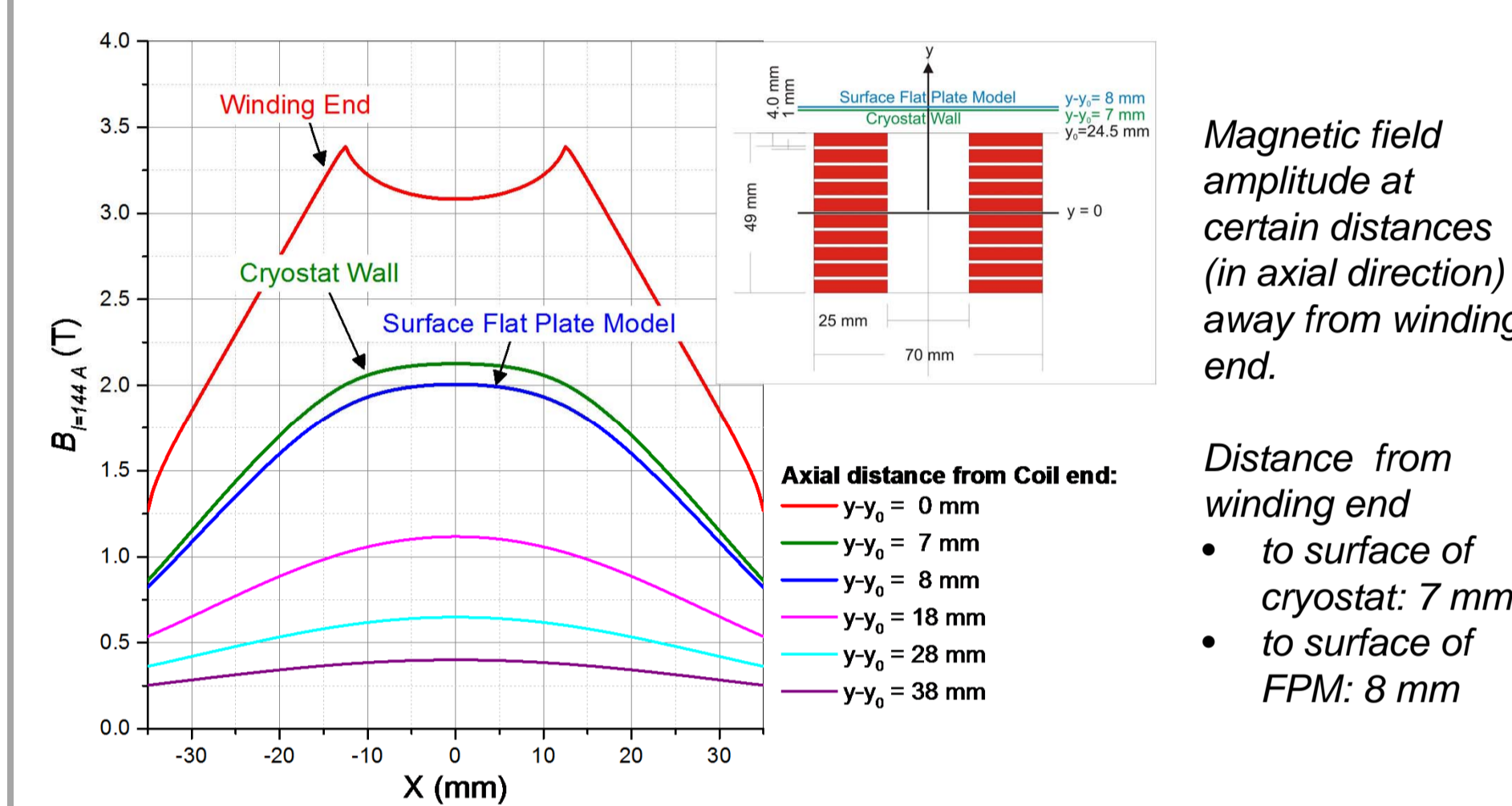
Magnet temperatures and current during field ramp to  $B = 2$  T and during plasma experiments at this field amplitude.

- No influence of plasma on magnet voltages and temperatures observed
- Central field @  $I = 144$  A:  $B_{\text{central}} = 4.9$  T
- Max. field at winding @  $I = 144$  A:  $B_{\text{max, Wdg}} = 5.16$  T

### Magnetic Field in Coil Winding @ $I = 144$ A:



### Magnetic Field outside Coil @ $I = 144$ A:

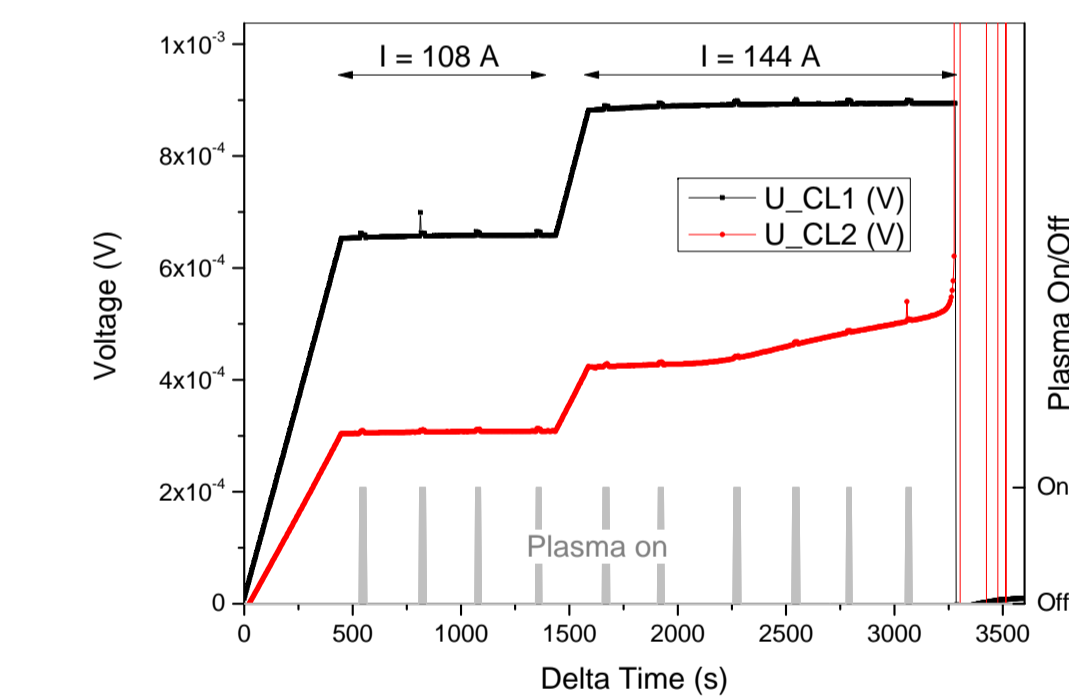
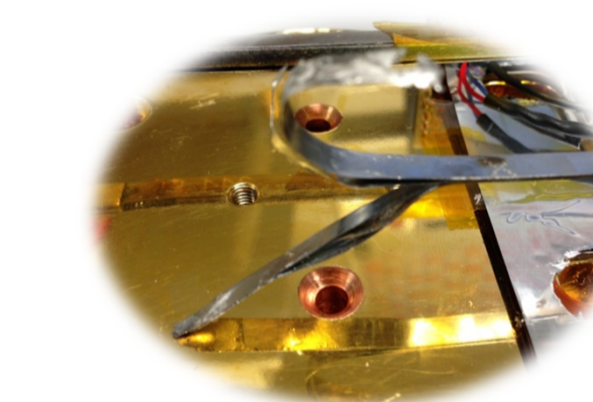


Magnetic field amplitude at certain distances (in axial direction) away from winding end.

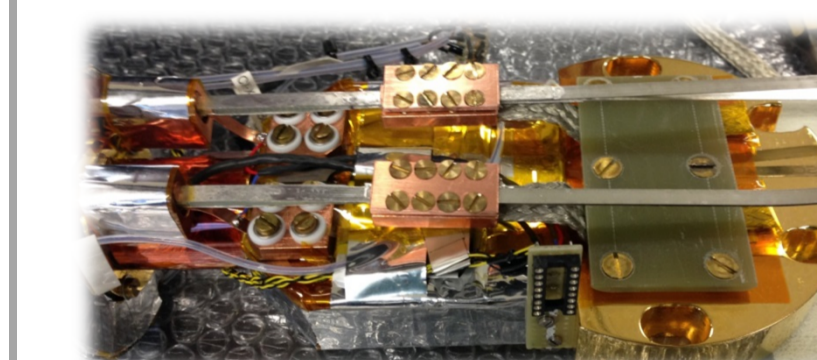
- Distance from winding end
- to surface of cryostat: 7 mm
- to surface of FPM: 8 mm

### Quench of Current Lead (CL)

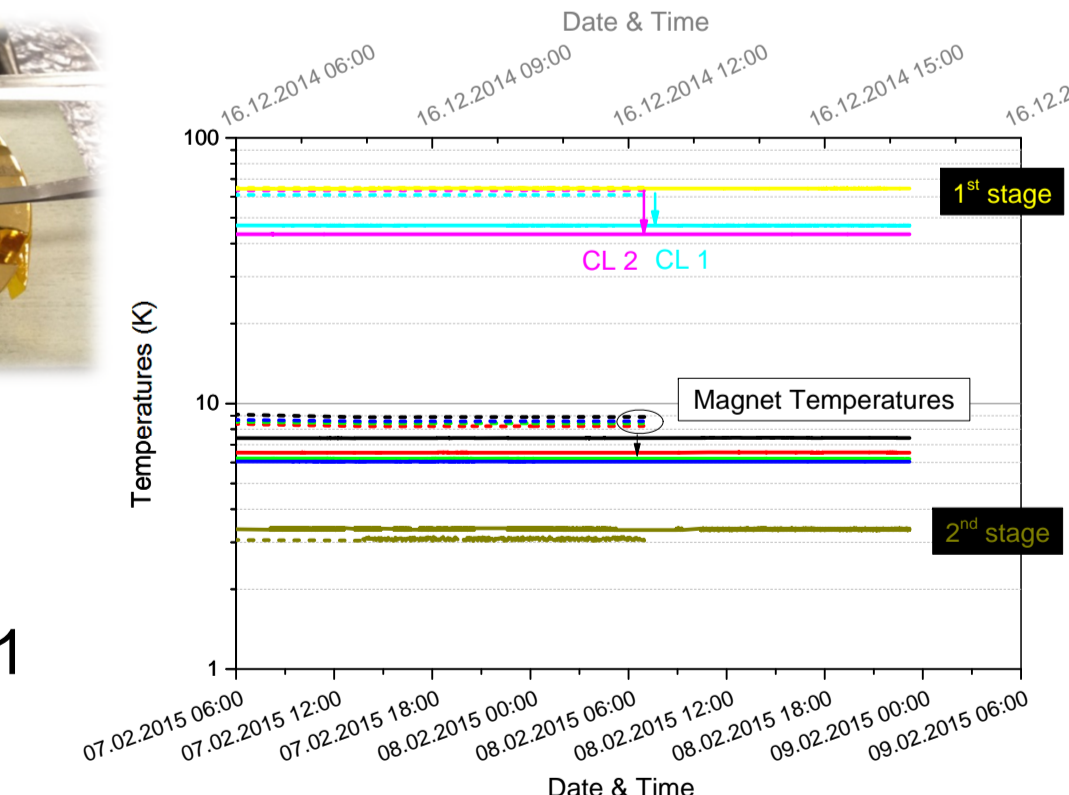
- CL2 quenched in experiment @  $I = 144$  A



- CL repaired and thermal anchoring improved



- CL warm end temperatures decreased by 14 K and 20 K for CL1 and CL2, respectively

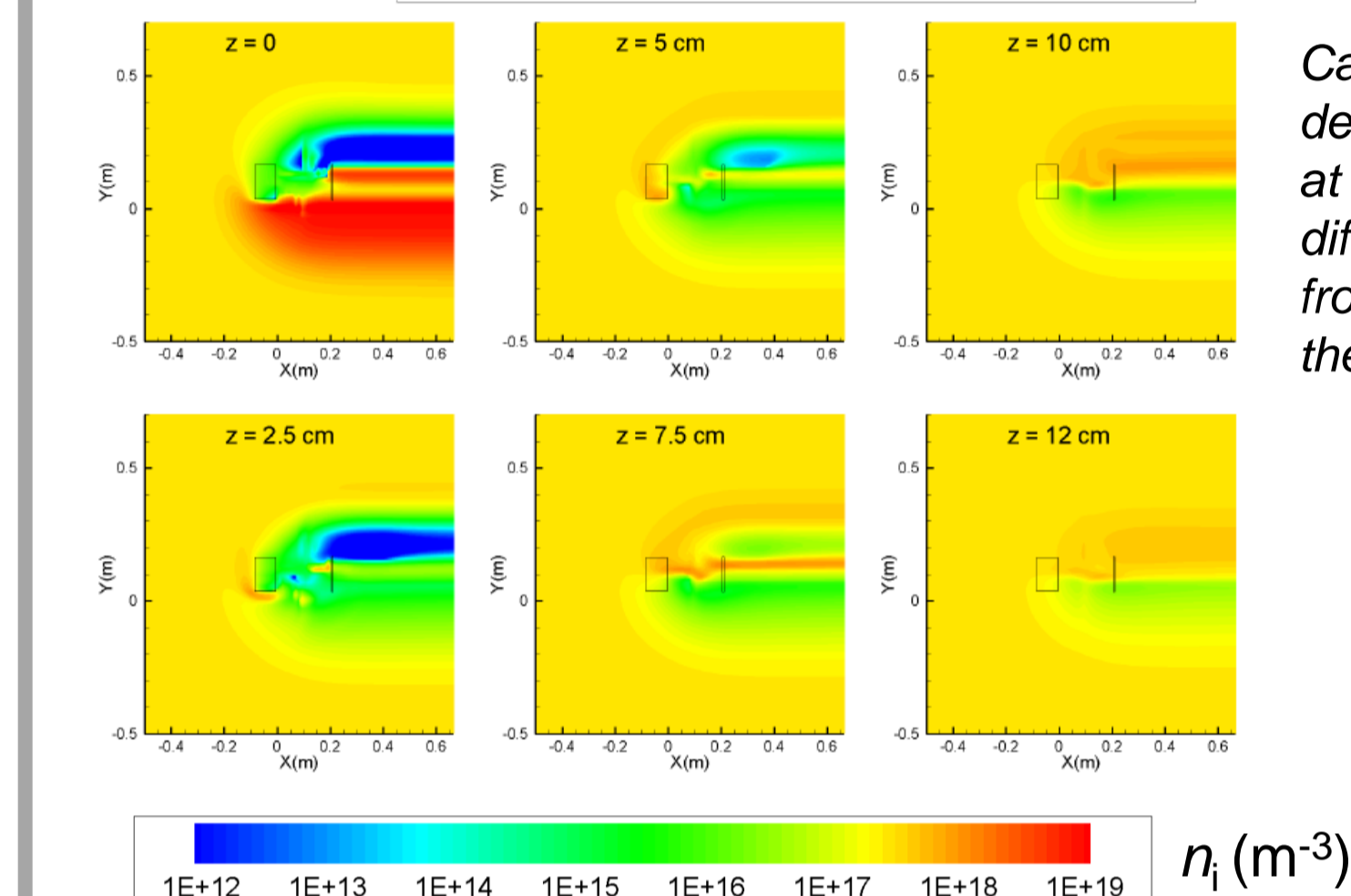


### Conclusions: Magnet Operation

- Successful operation of HTS magnet in plasma experiments.
- No influence of plasma on magnet voltages and temperatures.
- Improved thermal properties after repair of current lead.

## Mitigation of Radio Blackout

### Calculated ion density – $B = 0.5$ T

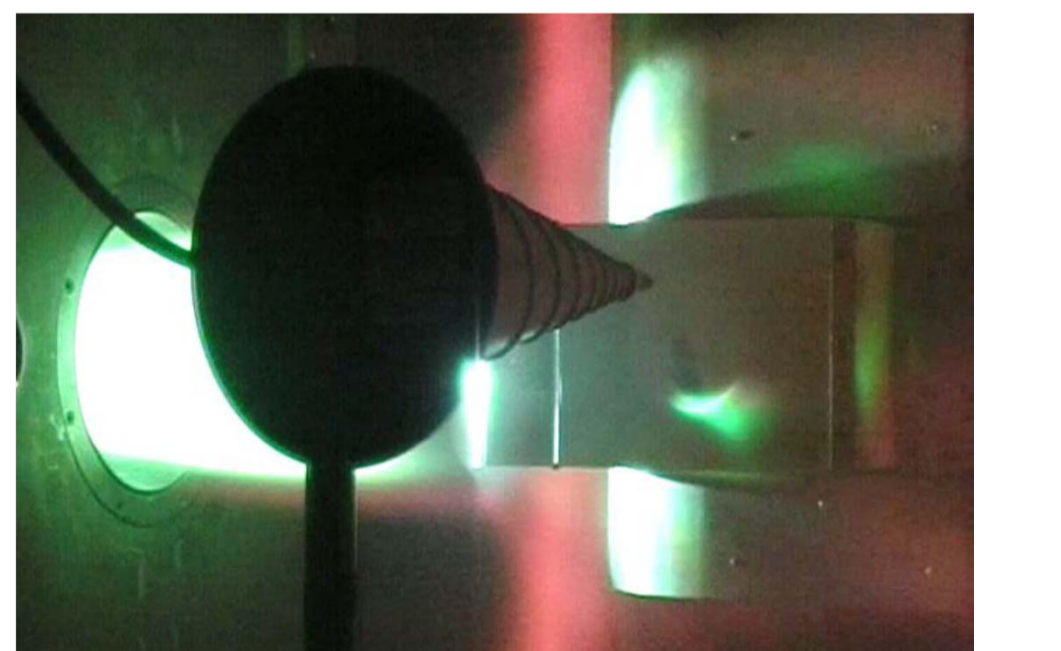


Calculated ion density distribution at  $B = 0.5$  T at different distances  $z$  from the surface of the FPM.

### Transmission Spectra

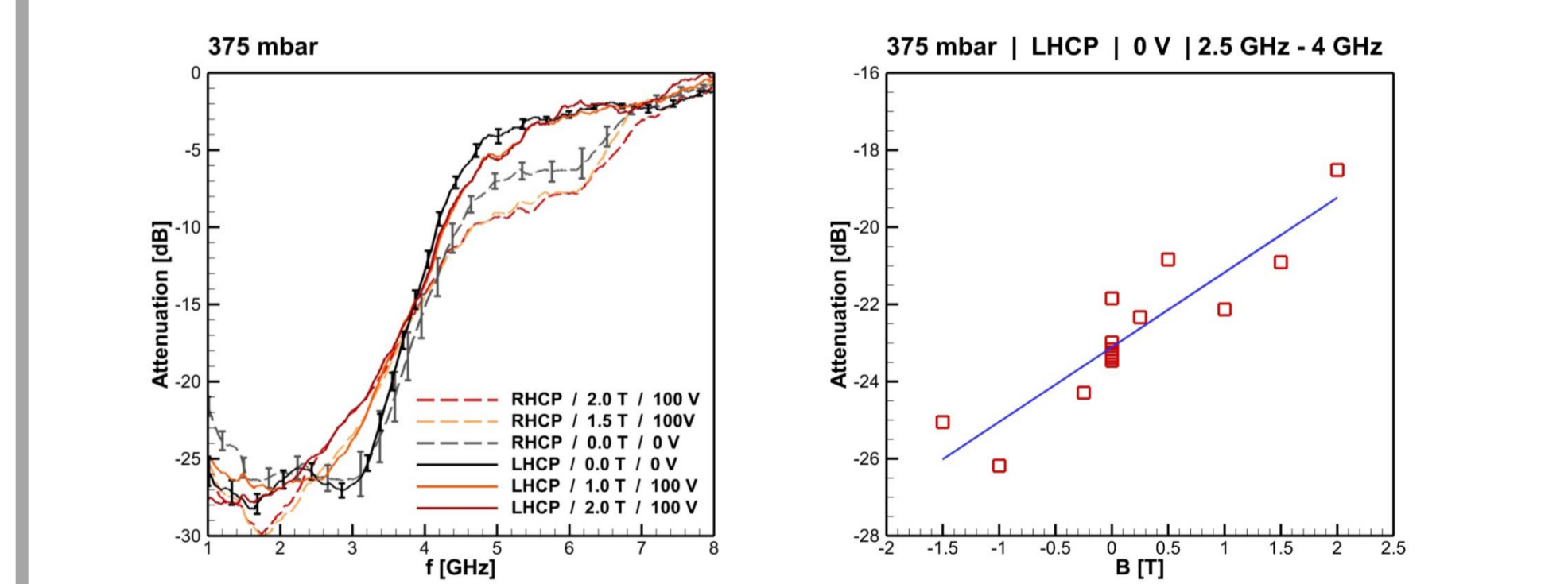
Measurements:

- 325 mbar and 375 mbar states
- Magnetic fields up to 2 T
- Voltages up to 200 V
- LHCP and RHCP



View on FPM containing the HTS magnet during plasma experiment @ DLR.

### Transmission spectra: signal attenuation – $B$ dependence



### Conclusions: Blackout Mitigation

- Ion densities calculated for various E and B fields.
- Small influence of magnetic field on electron density.
- No influence of electric field on electron density.