



WP1: FE-FRT

Steering Committee Meeting
20.10.2026

Activities Update – Points of attention

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WP1: FE-FRT (Official overview)

HZB, CERN, CNRS, Uni.Lancaster

Convener: Axel Neumann (HZB), deputy Alick Macpherson (CERN)

Main contacts with other partners: Alick Macpherson (CERN), Walid Kaabi (CNRS), Graeme Burt (Uni.Lanc.), industry: Alexei Kanareykin (Euclid Techlabs)



Task 1.1: Coordination of R&D on FE-FRT – M1-M48 (HZB)

- General coordination by HZB.

Task 1.2: FE-FRT for **Transient Beam Loading** – M1-M40 (CERN)

- Design a full FE-FRT-based 400 MHz tuner, applicable to **LHC transient detuning** scenarios.
- Perform full RF, mechanical and cryogenic evaluation of the FE-FRT-equipped . LHC cryo-module.
- Use design lessons learned to design a tuner for transient detuning of FCC 800 MHz multi-cell cavities.

Task 1.3: FE-FRT for **Microphonics** – M1-M48 (HZB)

- Establish characteristics and performance of FE-FRT ferroelectric material at frequencies ≥ 1300 MHz.
- Design, fabricate and validate an FE-FRT **for microphonics suppression** on a single-cell 1.3 GHz cavity.
- Design, fabricate and validate an FE-FRT for **multi-cell cavity at 1300 MHz**, in a cryomodule-like setup.

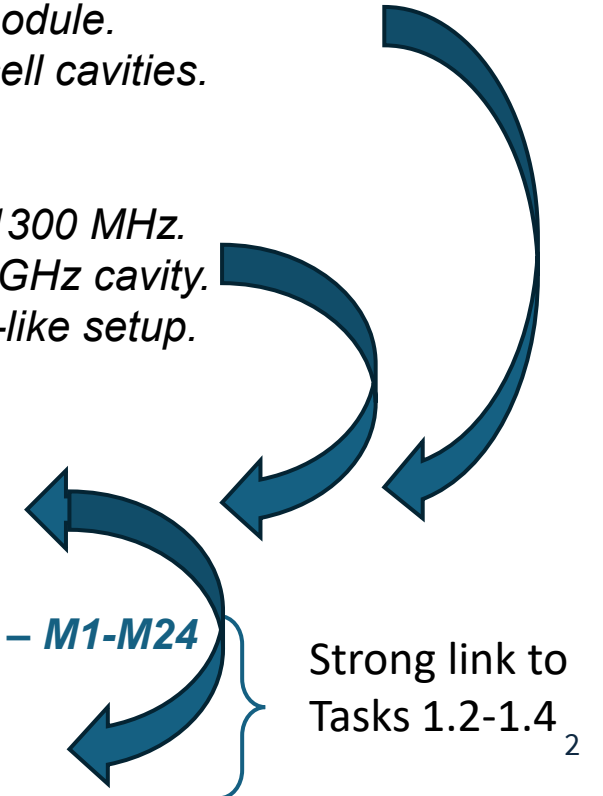
Task 1.4: FE-FRT in Energy-Recovery LINAC (ERL) mode – M1-M48 (CNRS)

- End-group design study for integration into ERL-type cavity, study **HOM+BBU** properties.
- FE-FRT design study for **RF and mechanical integration into upgraded ERL** cavity.

Task 6.2: Retrofitting Fast Reactive Tuners into existing cryomodules HL-LHC oriented – M1-M24

- Study of frequency domain multiplexor-based HOM coupler
- Study the effect of **HOMs on FE-FRT** operation to define max leakage
- Study the heating due to high fundamental power in the coupler

- Task 2.4 **Integrated LLRF control using FE-FRT**
- Task 3.3 **RF tunability**, FE-FRT for Nb3SN coated cavities?

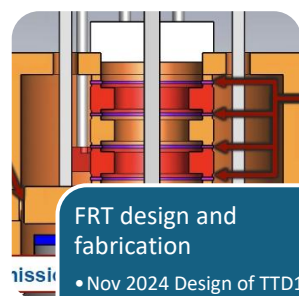


Strong link to
Tasks 1.2-1.4₂

iSAS timeline and milestones

Task 1.2: FE-FRT for *Transient Beam Loading* – M1-M40 (CERN)

iSAS funds:
0.44 M€



FRT design and fabrication

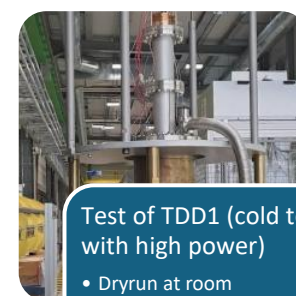
- Nov 2024 Design of TTD1
- June 2025 Fabrication of TTD1
- July 2024 Design and fabrication of teststand
- April 2025 LLRF control ready



Done

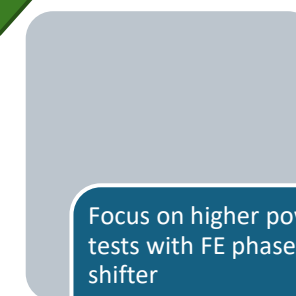
FE ceramics

- Material characterized at 400 MHz
- High voltage breakdown tests performed
- Sample preparation established



Test of TDD1 (cold test with high power)

- Dryrun at room temperature in Q3 2025
- Cold test (low power) performed
- High power test in Q3 2026



Focus on higher power tests with FE phase shifter

- Not started



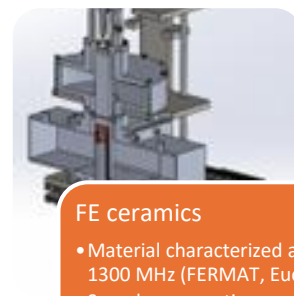
Task 1.3: FE-FRT for *Microphonics* – M1-M48 (HZB)

iSAS funds:
0.57 M€



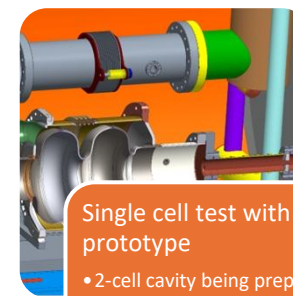
FRT design and fabrication

- May 2025 RF design ready
- June 2025 Mechanical design
- Preparation of LLRF system started (RFSoc)
- Tuner ready for Q1-2 2026



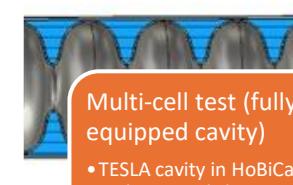
FE ceramics

- Material characterized at 1300 MHz (FERMAT, Euclid)
- Sample preparation: Cutting, grinding, lapping, polishing
- Sample analysis



Single cell test with prototype

- 2-cell cavity being prepared at RI
- Critically coupled, but with blade tuner +piezos
- Microphonics compensation proof of principle test



Multi-cell test (fully equipped cavity)

- TESLA cavity in HoBiCaT with FPC and classic tuner
- FE-FRT second version, e.g. optimized also for higher stored energy
- Final LLRF + FE-FRT test

On track



MS41/ Feb 26
Risk analysis

Done

Done

MS1/ Feb 26

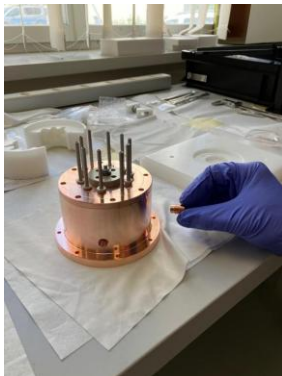
MS4/ Feb 27

On track

MS5/ Oct 27

Recent news from task 1.2

- Cold test for major MS3 and corresponding deliverable successfully performed at CERN!
- This has just ended one week ago with about 100 Gb of data to analyse
- 3.5 weeks of uninterrupted operation, anti-cryostat scheme worked out in VTS
- Very, very preliminary: FoM of about 10 (design 50), kHz range of tuning of a 400 MHz cavity (this is a record)
→ This test can be regarded as a success, it was also the only and last test available within iSAS (Just in time!)
- Issues were observed (of course), e.g. HV breakdown at the cooling pipes/HV supply inlet with RF filters → to be studied



- The systems worked, problems mostly arised due to the setup of an anti-cryostat in a VTS test environment
- Highest tuning ever observed with a FE-FRT
- Highest experimentally reached figure of merit so far

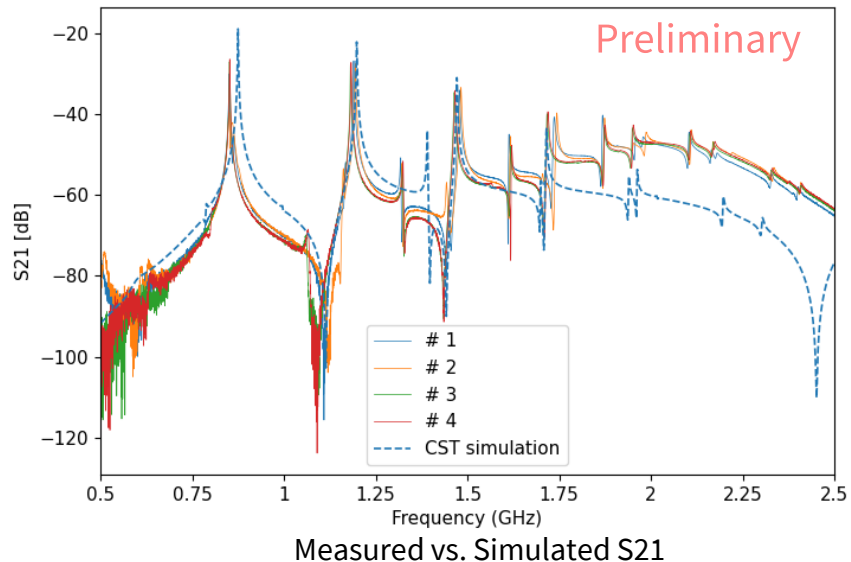
Task 1.3 updates

Thanks to N. Shipman, A. Frahm, A. Ushakov and others for their work and material

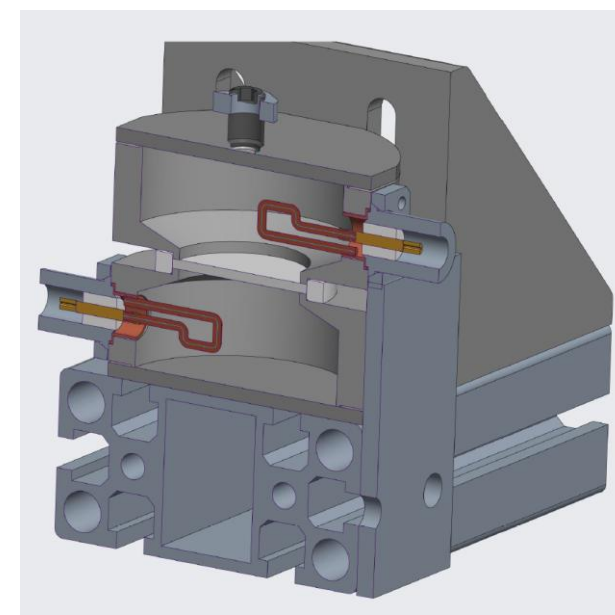
SPARC

(SPlit-cAavity Resonator for Ceramic Characterisation)

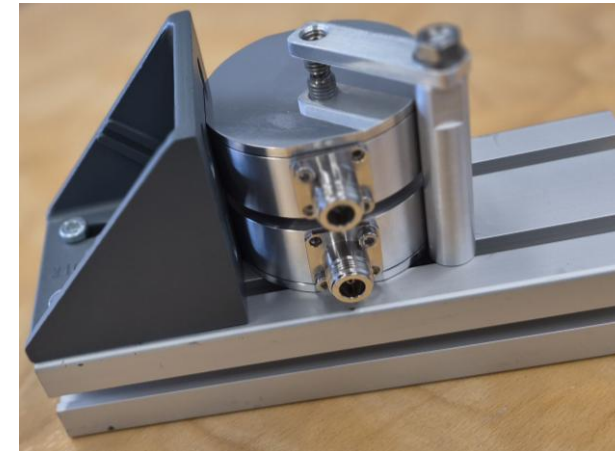
- Aim: quick, simple reliable permittivity measurements of FE samples
- Use: cross check FERMAT, study effect of heat treatments, radiation, water absorption etc.
- Features: quick (dis)assembly, easy alignment, smaller contact area, rotatable antennas
- Limitations: cannot test with HV bias or metalised samples



Antennas for preliminary test



Cutaway of SPARC



SPARC

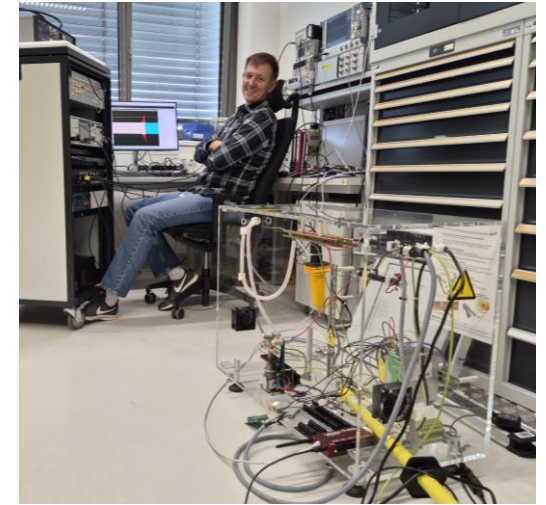
Transfer function measurements: Input to WP2

- We have measured the 10kV amplifiers characteristics and transfer function
 - Used a 330pF capacitive dummy load
 - Will test with FE-FRT next
- **First step for feedback algorithm design**
- Preliminary results as expected:
 - ~30kHz 3dB bandwidth at 2kV peak-to-peak
 - Amplifier trips at ≈ 6.5 kHz at 10kV peak-to-peak

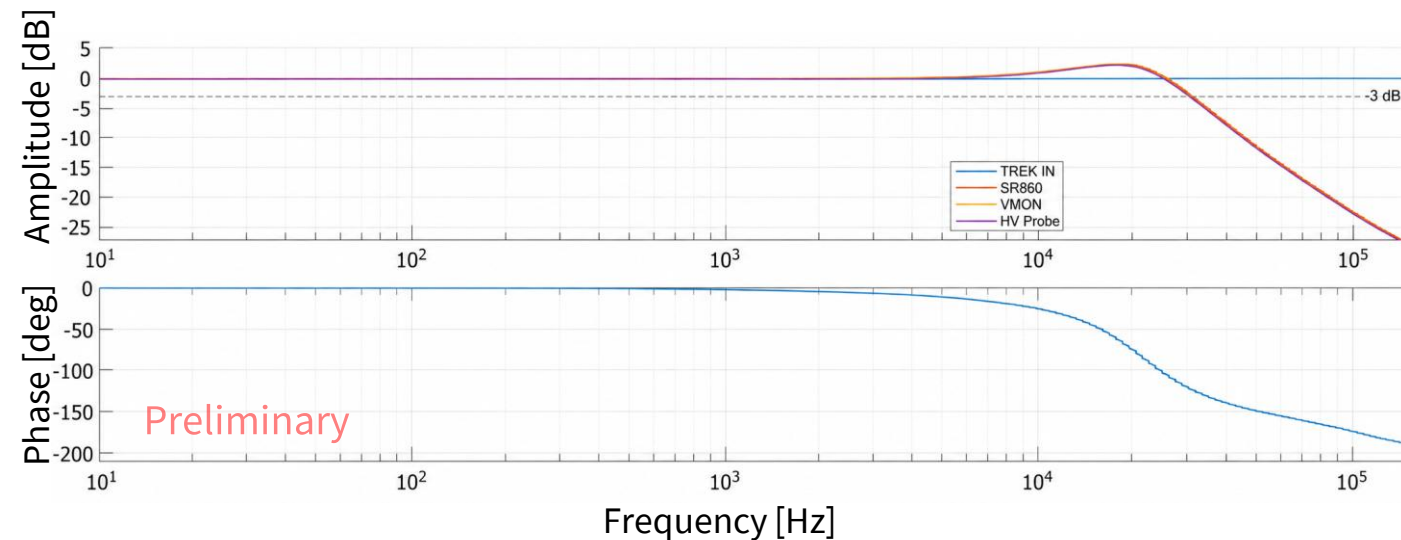


TREK 10/40A-HS high-voltage amplifier

Input for C. Joly and
F. Bouly of WP2



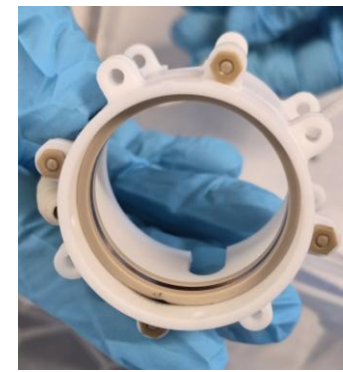
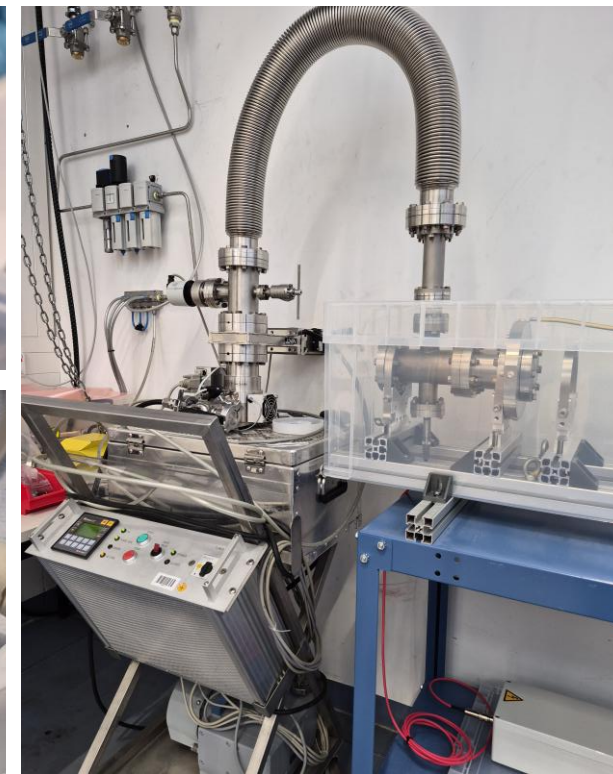
Andriy happy he hasn't electrocuted himself.



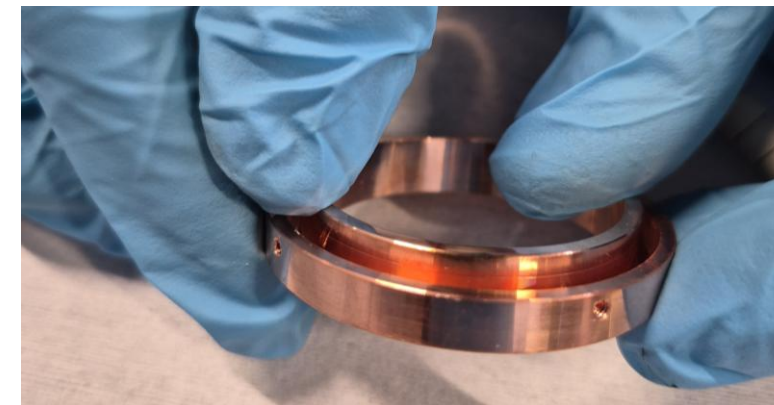
Amplitude and phase vs frequency for 2kV peak-to-peak sinusoidal signals.

High voltage bench testing – without FE

- Prior to cold test must verify FE-FRTs voltage handling. Target: 10kV
- For the first test we replaced the FE rings with PEEK
 - Avoid risk to FE as far as possible
- Vacuum $\approx 8.10^{-7}$ mbar, compression force 3kN
- During a slow ramp the FE-FRT achieved 10kV
- During fast turn on tests the FE-FRT broke down at 9kV
 - Suspected overshoot
 - Subsequently the FE-FRT could only withstand ≈ 300 V
- Signs from breakdown visible along outer edge of a PEEK ring
- FE-FRT successfully validated upto 10kV without ferro-electric but:
 - All components must now be carefully cleaned
 - Clear hint FE rings may not withstand 10kV at the first try

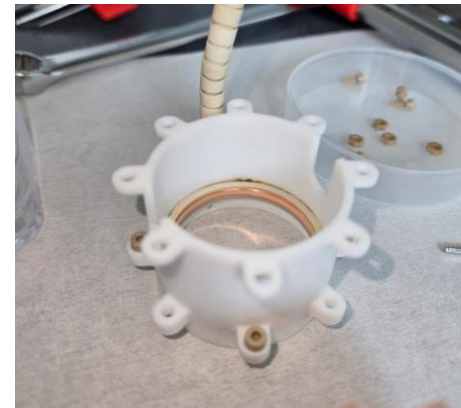


High voltage applied to BE-FRT main body under vacuum, with FE replaced by PEEK.



High voltage bench testing – with FE 1st attempt

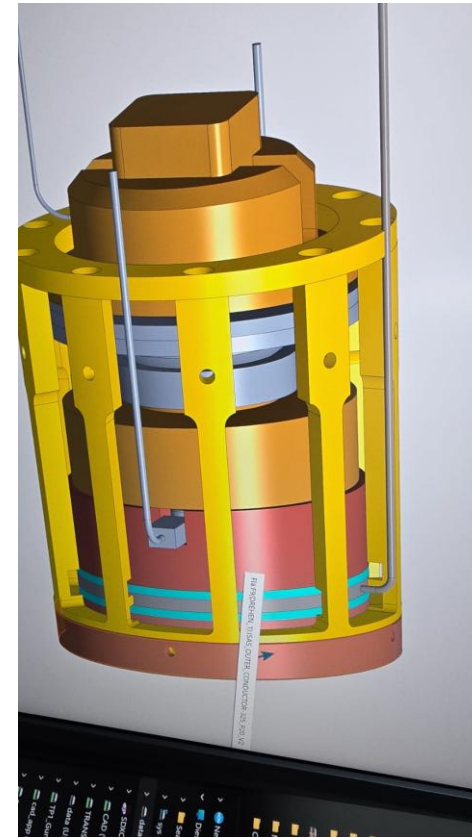
- With FE voltage of 5kV was achieved
- BD occurred along outer edge
 - Like with PEEK rings
- Suspect the alignment sleeve is trapping gas
- Redesign alignment sleeve for better pumping
- Retest in ~4 weeks
 - Once voltage has been obtained:
 - Transfer function measurements
 - RF bench characterization
 - If voltage still insufficient reduce electrode diameter



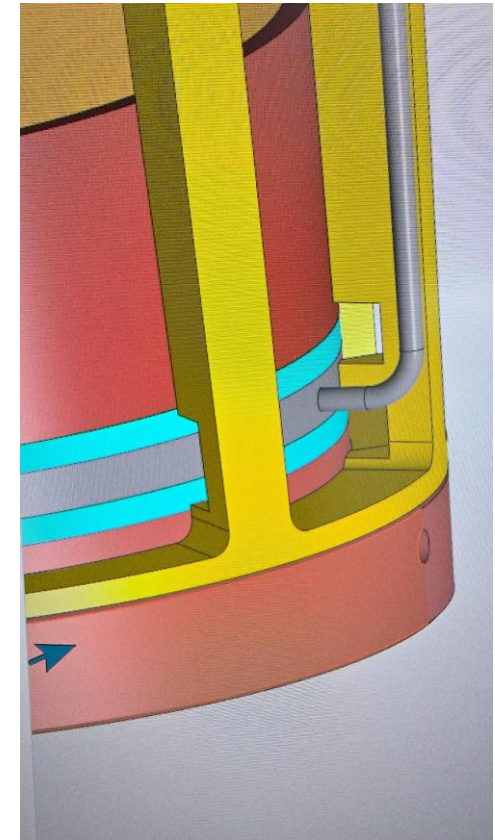
Old alignment sleeve



BD damage on outer edge of FE

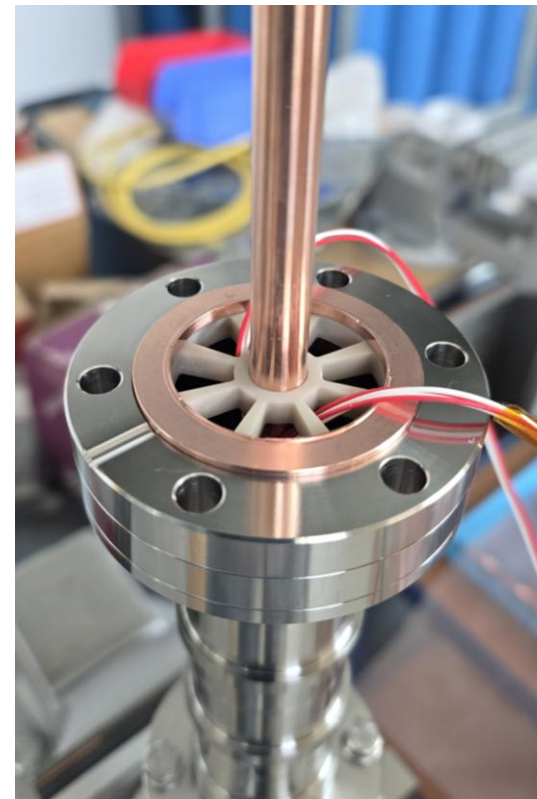


New alignment sleeve

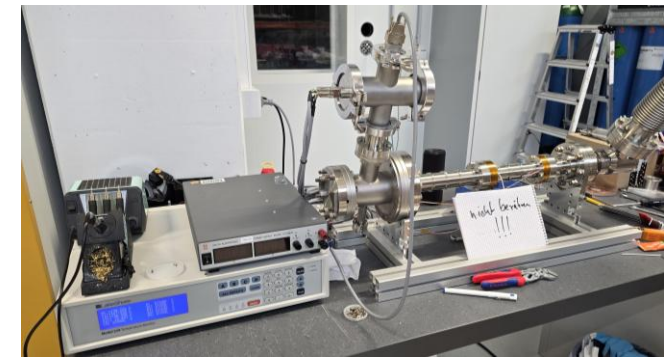


Thermal stress test of transmission line

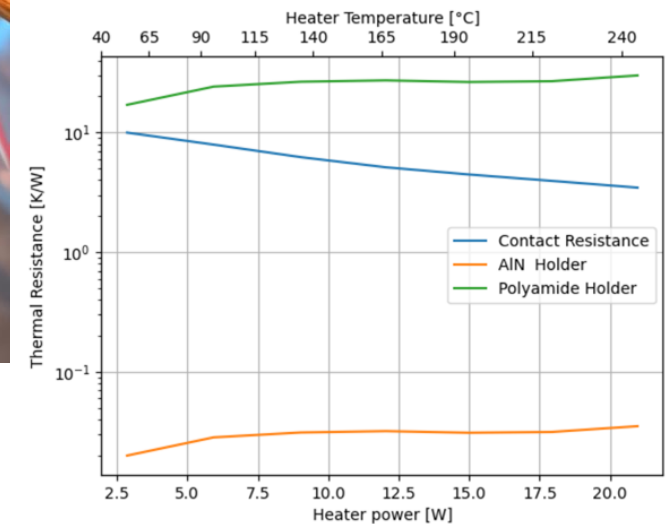
- FE-FRTs transmission line assembled with:
 - Temperature sensors placed along inner and outer conductor
 - Heater connected to inner conductor
- Placed under vacuum
- Heater power increased until temp of 250°C
- Tried first with 1 Polyamide and 1 AlN holder
 - Polyamide acts as spring, fear is ALN cracks
 - No breakage
- Tried next with 2x AlN holders
 - No breakage!



Transmission line assembly



Thermal bench test



Rough estimate of thermal contact resistance.



Attaching thermal sensors to inner conductor.

	2-cell cavity	9-cell cavity
Zero contact resistance	~0.1K	~1.6K
Estimated contact resistance	~10K	~160K

Rough estimate of inner conductor temp rise.

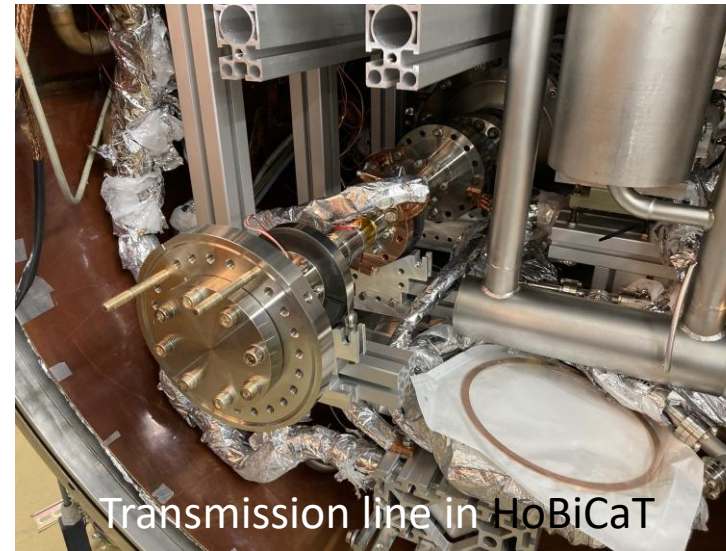
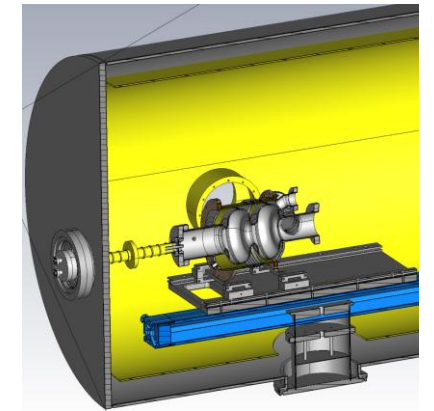
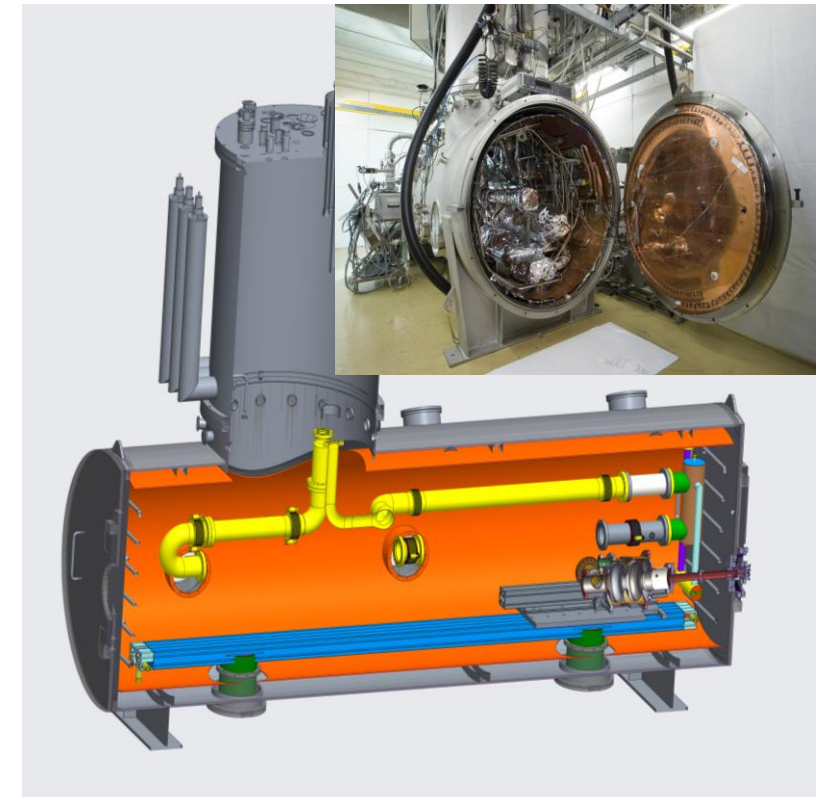
Current work

Material studies

- Radiation hardness
 - Measure FE properties before and after exposure to radiation in BESSY II
- Metalisation
 - Attempt gold sputtering on highly polished FE

Microphonics compensation @ 1.3GHz (ISAS/BE-FRT)

- RF bench testing in next weeks – delayed till after thermal test
- Thermal test of BE-FRT transmission line in HoBiCaT: **This week + second acceptance test of Booster cavities**
- First cold test of BE-FRT with 2-cell booster in HoBiCaT: Q4 2026

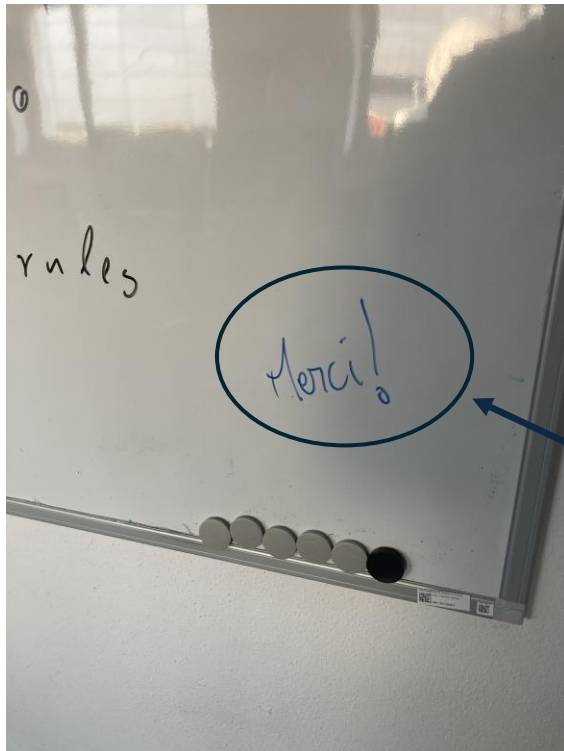


WP1– FE-FRT: points of attention

- Points of attention (see last coord. Panel meeting Sep. 26, task 1.4)

WP1

- **Budget transfer** from CERN to HZB to hire young researcher at HZB (contingent on the one-year extension being granted for iSAS)
- M#2 Design ready for FE-FRT integration in 802 MHz cavity **delay** from M30 August 2026 to M56 Oct 2028
- D#1 Report of FE-FRT integration with PERLE cavities **delay** from M36 Feb 2027 to M60 Feb 2029



Idea: Use the experience made at CERN and HZB together with the young researcher at HZB to fully concentrate on the IJCLab deliverable D1 (FE-FRT integration with PERLE cavities)

This allows also more time for the PERLE/IJCLab team to incorporate issues seen with the first (iSAS) cryo-module

Message left behind by our friends from IJCLab after their visit last Tuesday