Higher power couplers at Helmholtz-Zentrum Berlin

BESSY VSR and bERLin Pro

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FG-ISRF, Helmholtz-Zentrum Berlin / BESSY II

World Wide Fundamental Power Coupler
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Outline

- BESSY VSR overview
- 1.5 GHz coupler specs
- Initial mechanical design
- Design modification for improved assembly and performance
  - RF contact at waveguide to coax transition
  - Ceramic window re design
  - Tip redesign
- Current mechanical design
- Thermal challenges
- Un-answered questions
- bERLinPro Coupler overview
- Coating testing and analysis
- Fabricated parts

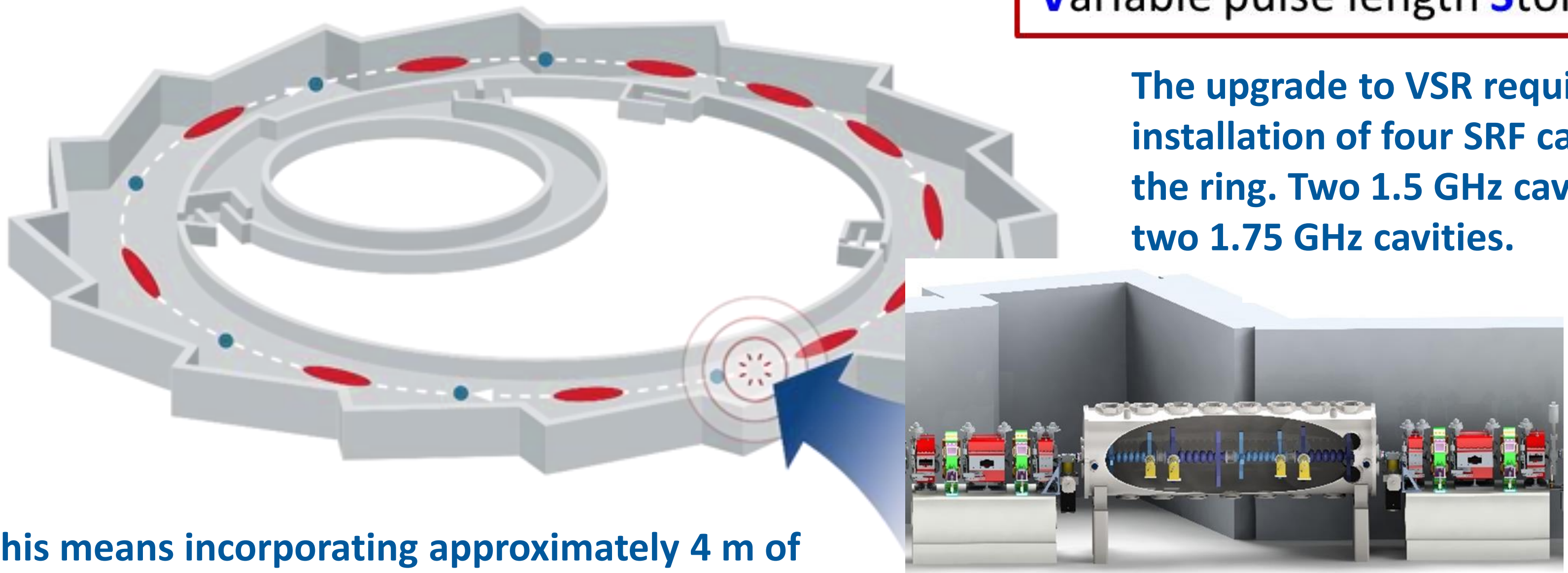
BESSY VSR Couplers

Subproject leader: Dr. Emmy Sharples

BESSY VSR: Challenges

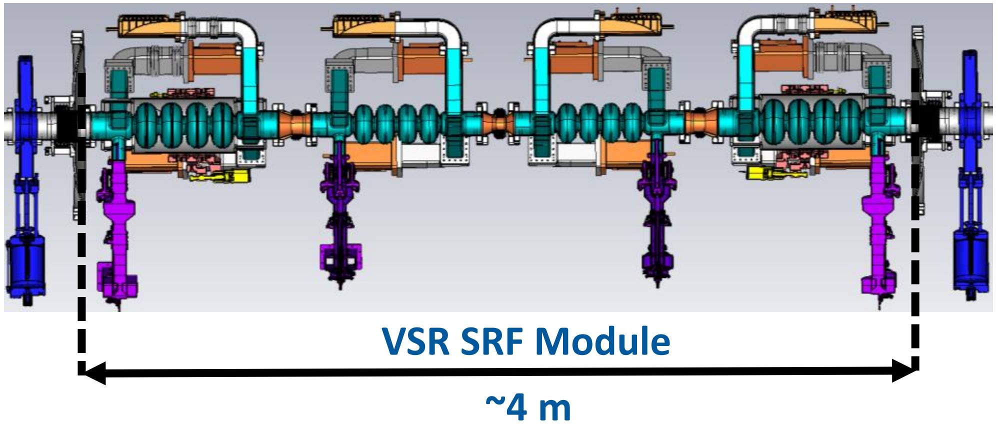
Focus on changing the hardware not the optics to allow for shorter bunches with more current and a higher gradient

BESSY VSR
Variable pulse length **S**torage **R**ing



The upgrade to VSR requires the installation of four SRF cavities into the ring. Two 1.5 GHz cavities and two 1.75 GHz cavities.

This means incorporating approximately 4 m of SRF technology into the 240 m of the existing normal conducting machine.

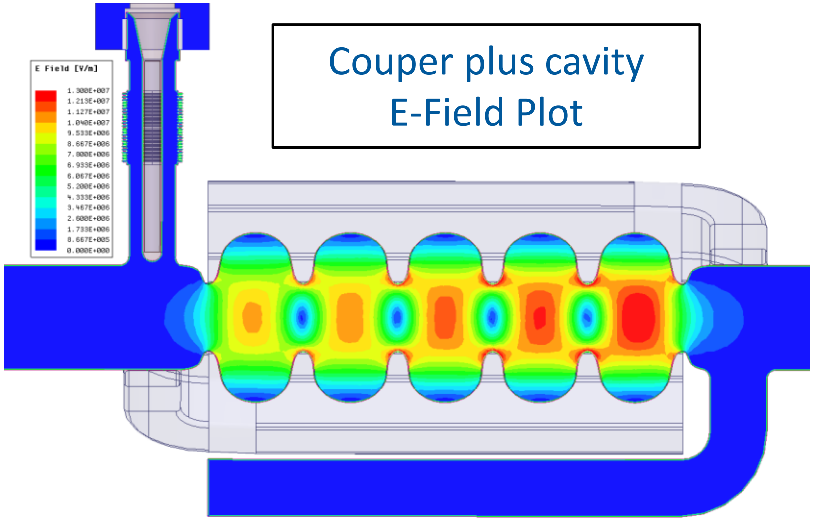


Design challenges

- CW operation @ high field levels E=20MV/m
- High beam current (Ib=300mA),
- High peak fields on surface
- Exotic cavity design (damping end-groups)
- Cavity HOMs must be highly damped (CBIs)
- Transparent Parking of SRF Module.
- Integrating into existing storage ring

Coupler specs: 1.5 GHz coupler

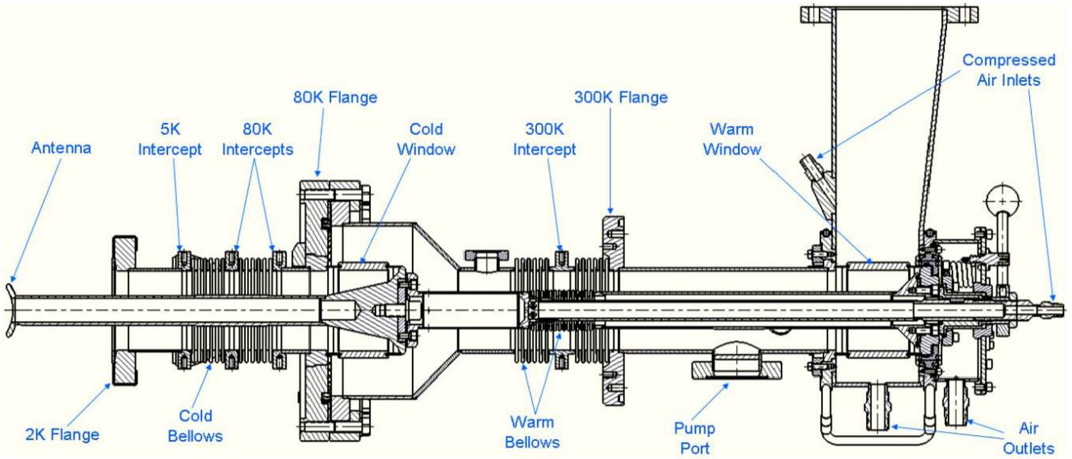
Parameter	Value
Central Frequency	1.5 GHz
Bandwidth	±0.01 GHz
Max RF Supplied by amplifier	16 kW (13 kW+3 kW)
Peak power in the coupler	13 kW
Mean power	1.5 kW
Number of ceramic windows	2
Q_{ext} range	6×10^6 to 6×10^7
Q_{loaded}	5×10^7
Peak detuning	60 Hz
RMS detuning	6 Hz
Heat leak to 2 K	<0.2 W
Heat leak to 5 K	<3 W
Heat leak to 80 K	<80 W



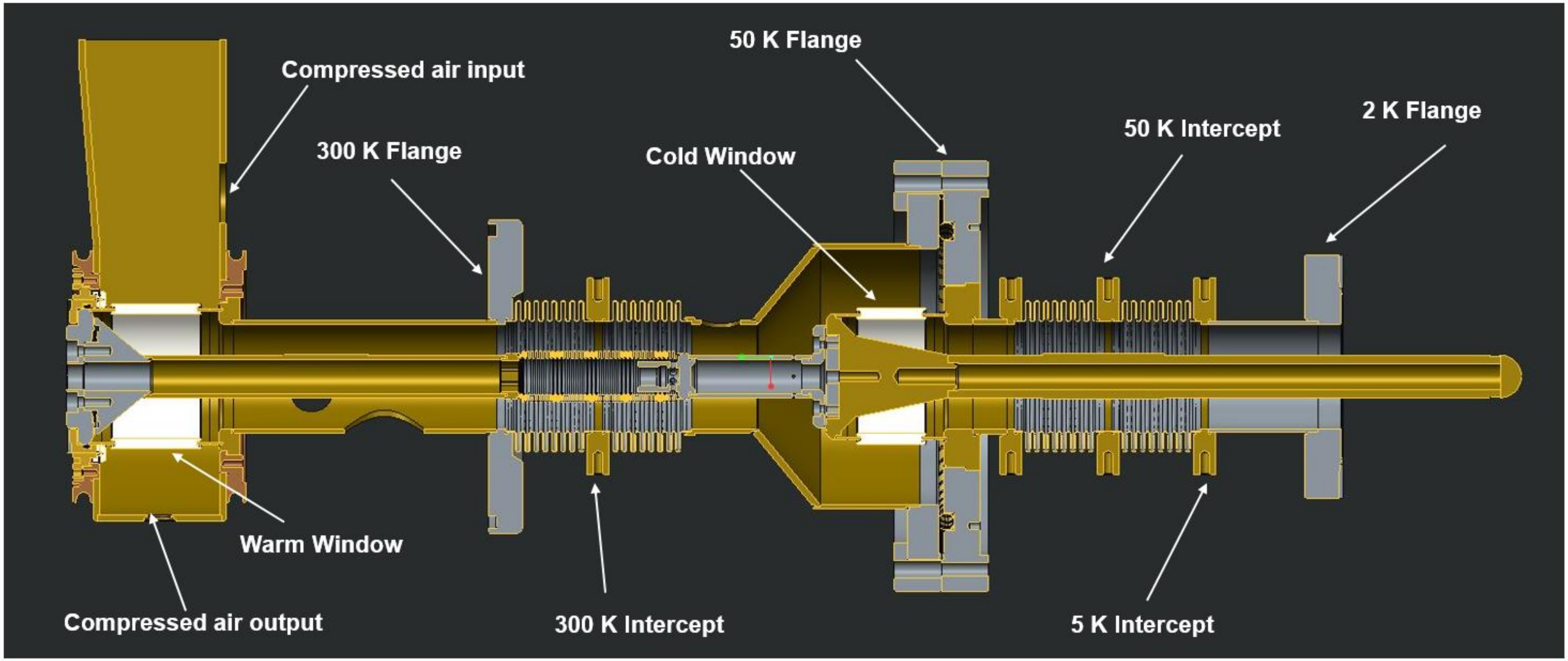
Couper plus cavity
E-Field Plot

Evolution from the Cornell/ TTF3 deign

- Reduced power
  - Peak power 16 kW (13 kW+ 3kW low level)
  - Reduced cooling systems
- Increased Frequency
  - Operating at 1.5 GHz (and 1.75 GHz)
  - Coax impedance reduced to around 50 Ω
  - Coax diameter significantly reduced: 49 mm outer 20 mm inner
  - Same coax diameters for both warm and cold parts
- Reduced coupling:
  - Q_{ext} $6\text{x}10^6$ to $6\text{x}10^7$
  - Simplified rounded tip design



Mechanical design



Initial Engineering model of the 1.5 GHz coupler

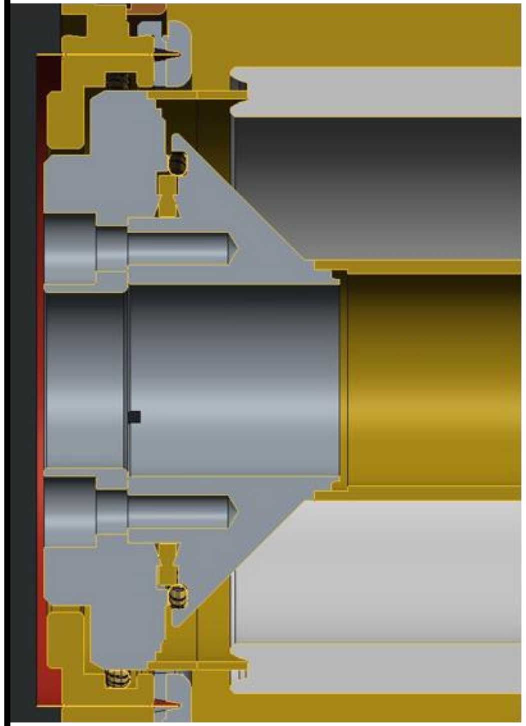
Coupler consists of warm and cold coaxial parts with a waveguide for input power. Both warm and cold coax $Ø_O$ 49mm, $Ø_i$ 20mm, z=54Ω. Coupler is fabricated from copper and copper plated stainless steel with a plating of 20/30µm. With two alumina oxide ceramic windows to preserve the vacuum.

Note: preliminary thermal tests indicated that due to poor thermal transport the coupler tip was not cooling sufficiently so the thickness of the inner conductor of the cold part was increased to combat this.

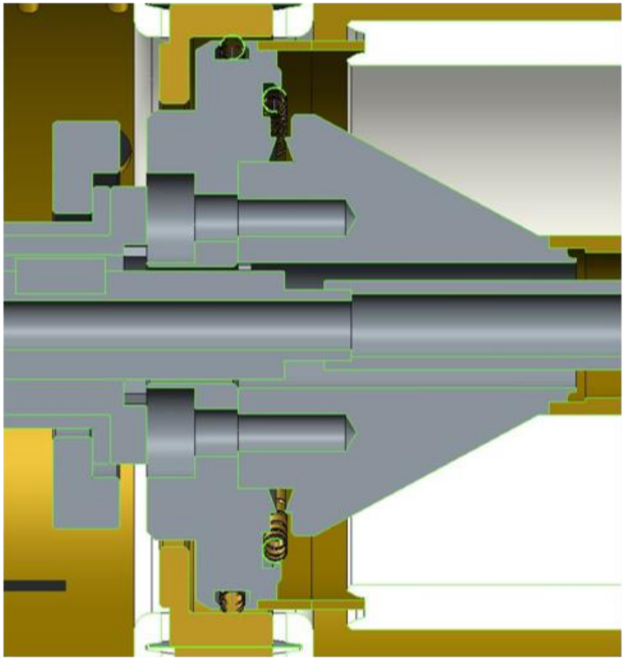
RF contact at cone

For horizontal mounting, the inner conductor warm part must be mounted before the outer conductor. Thus the size of the cone at the waveguide/coax transition must be reduced to allow for this.

Original Cone

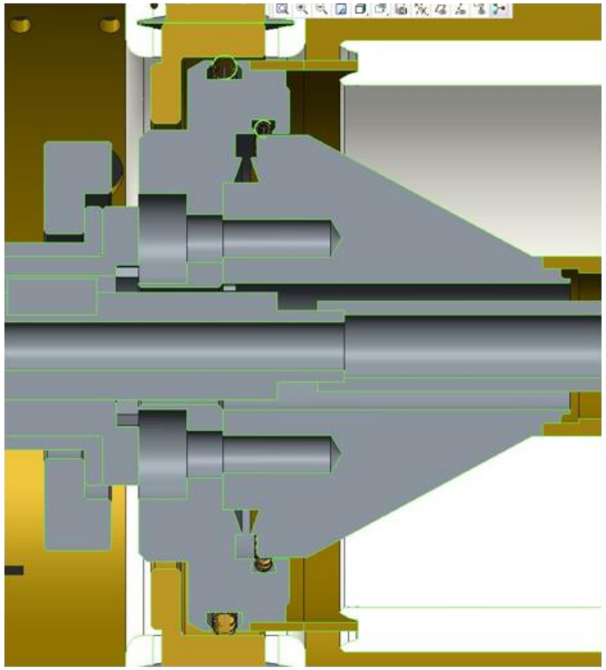


Cornell Cone w/ spring contact



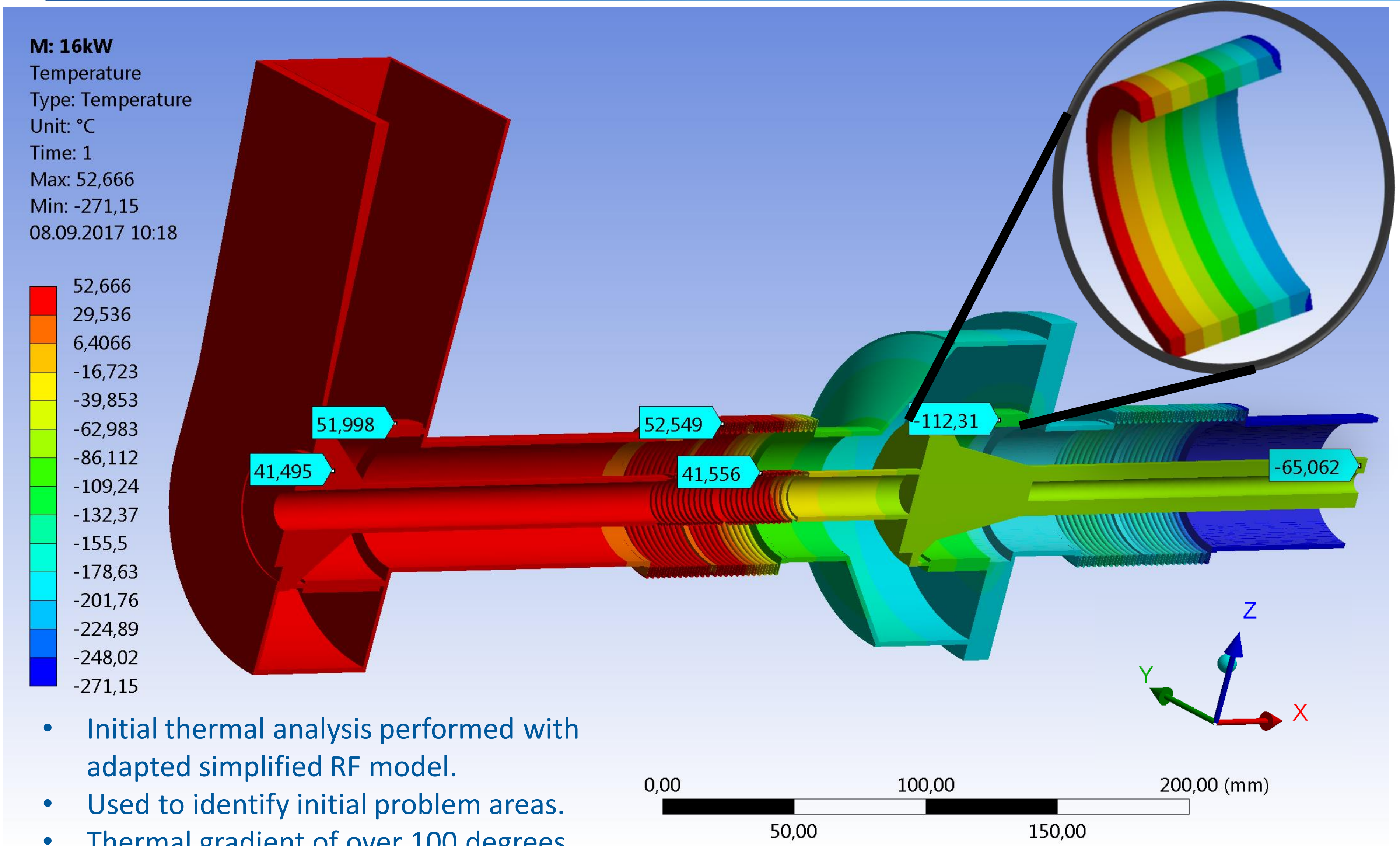
Problem created when the cone radius was reduced to 23.5 mm

Final cone design



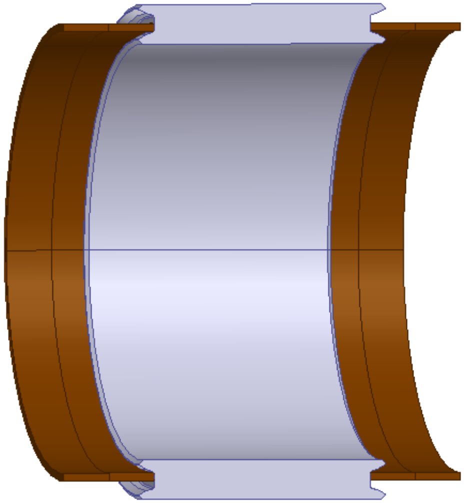
New small cone that fixes the problem and gives RF contact as well as providing a vacuum seal.

Initial Thermal Analysis

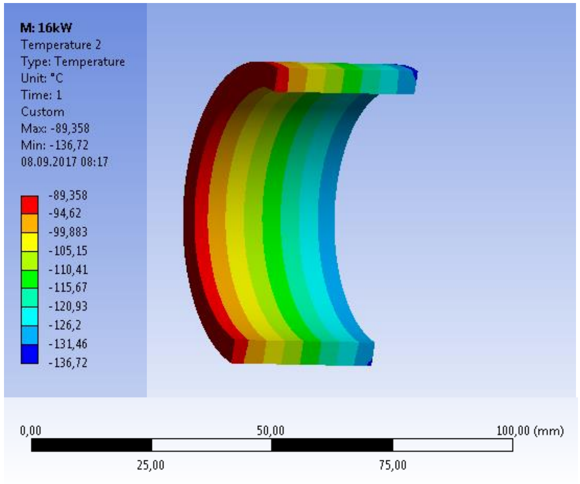


- Initial thermal analysis performed with adapted simplified RF model.
- Used to identify initial problem areas.
- Thermal gradient of over 100 degrees identified at the ceramic.

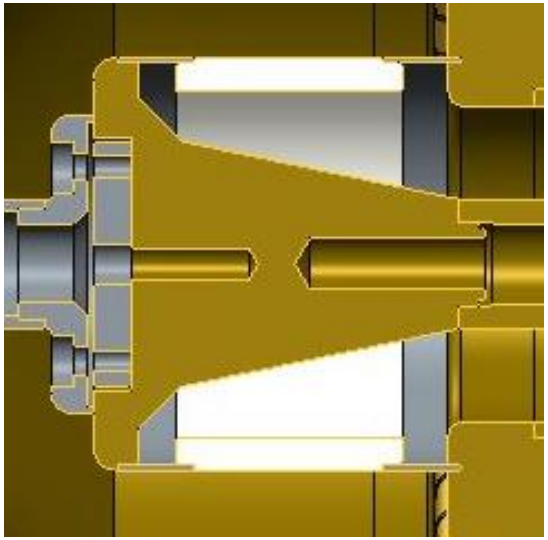
Ceramic window redesign



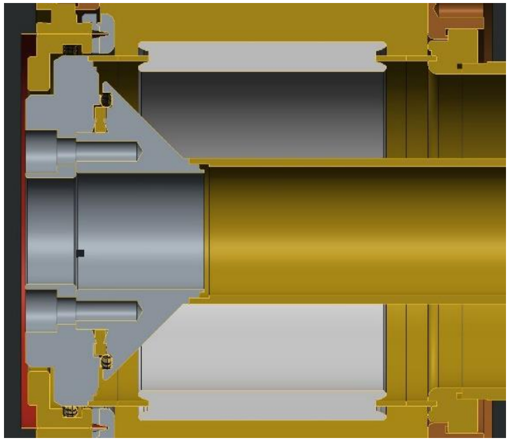
Cut through of original ceramic window support design



Temperature gradient over the cold window



New cold window design

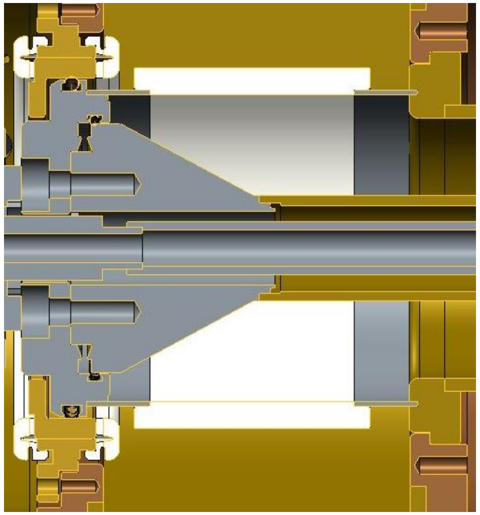


The warm window in the full coupler

Challenges:

- High thermal gradients on the ceramic
- Poor heat dissipation
- High chance of damage due to stresses

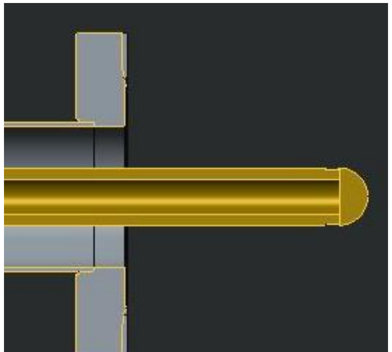
Significant issues at the cold window where it acts as a thermal bridge between inner and outer conductor at the 80K intercept. Design developed in communication with Friatec



New warm window design

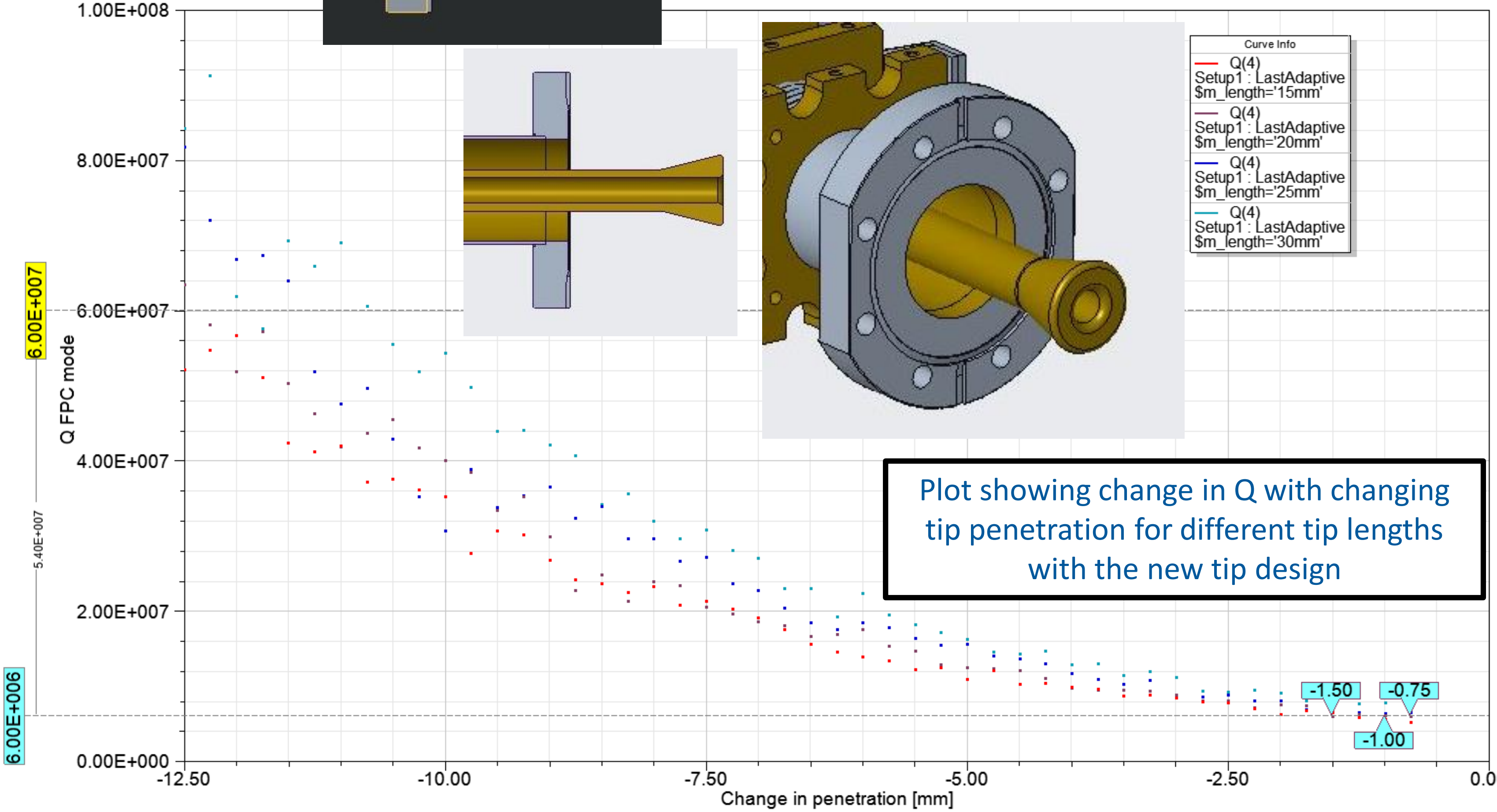
Tip Optimisation

Initial tip design was a simple rounded tip, as coupling levels for VSR allow for it.



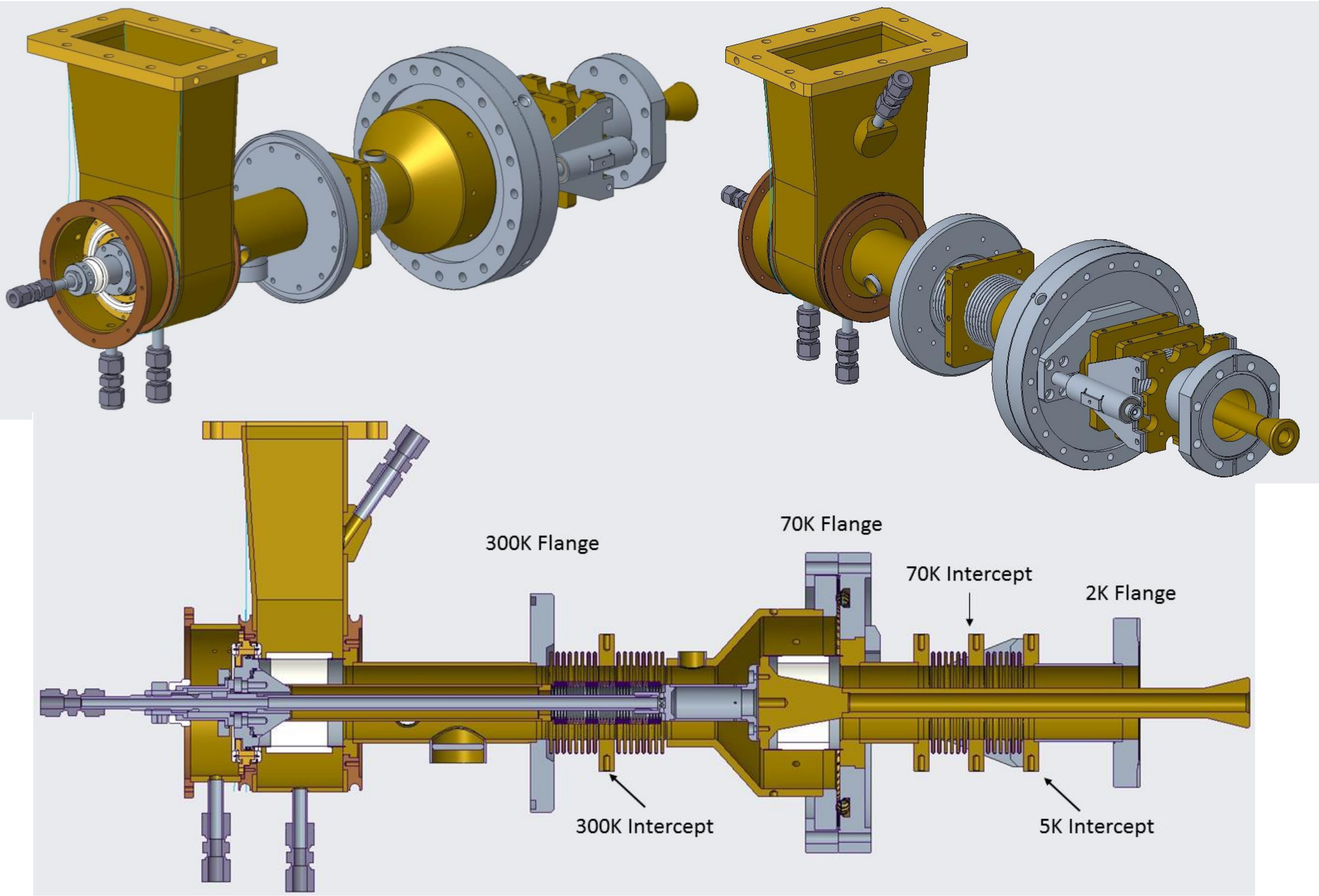
Problem: Weight of coupler tip is causing stresses on ceramic window. **Solution:** Make coupler tip hollow.

New problem: to effectively clean tip it must be open at cavity end. Therefore new design needed to ensure correct coupling.



Plot showing change in Q with changing tip penetration for different tip lengths with the new tip design

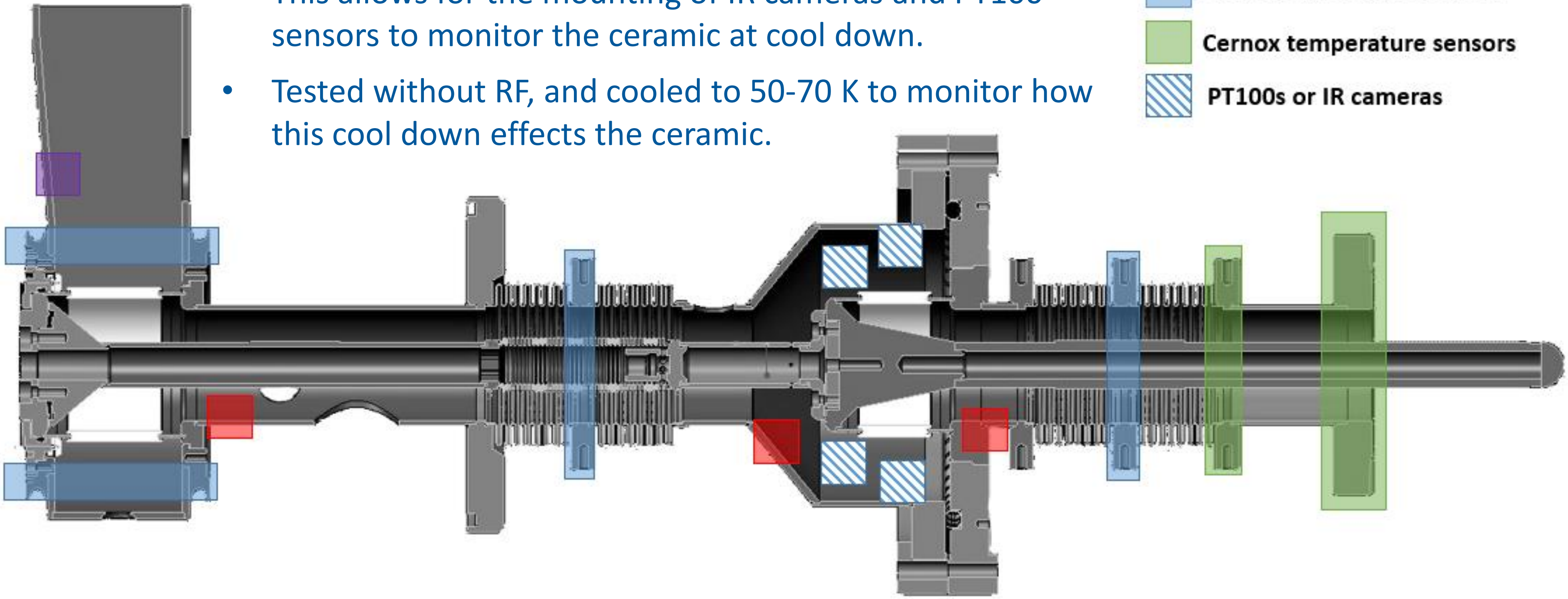
Current design



Diagnostic prototype

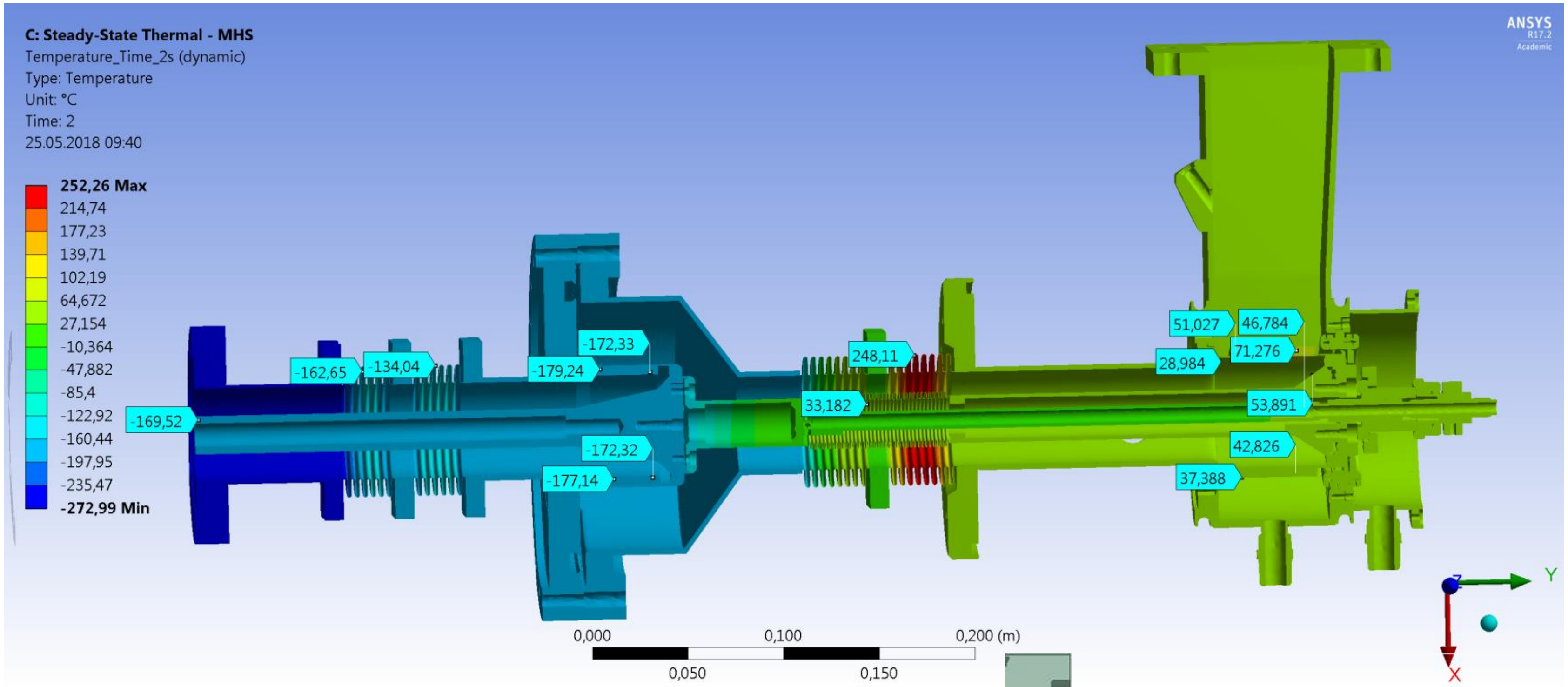
- This will have 6-8 CF 16 ports spaced around the cold window, in two offset rings.
- This allows for the mounting of IR cameras and PT100 sensors to monitor the ceramic at cool down.
- Tested without RF, and cooled to 50-70 K to monitor how this cool down effects the ceramic.

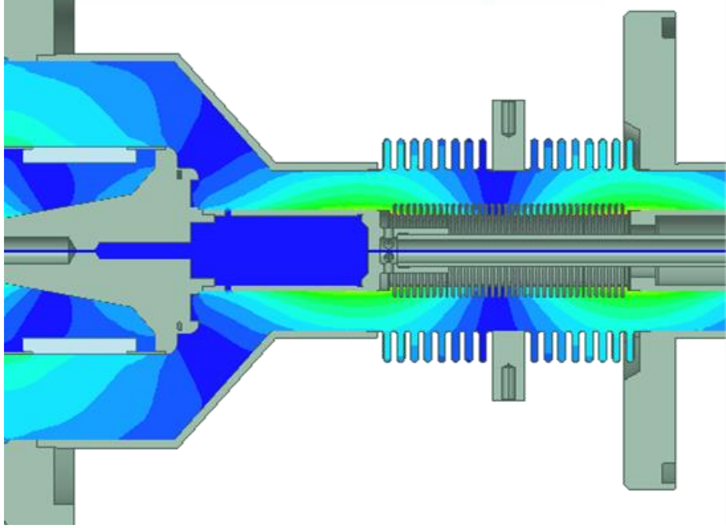
🟥 **Electron Pick ups**
🟪 **Arc detector**
🟦 **PT100 temperature sensors**
🟩 **Cernox temperature sensors**
▨ **PT100s or IR cameras**



- PT100s: 2-4 @ 80K and 300K intercept, 2-4 around cold window, 4-6 at WG/coax transition
- Cernox/PT1000: 2-4 at both the 5K and 2K flanges
- Biased electron pickups: 2-3 as shown in figure
- IR cameras: 2 around the cold window, position determined by diagnostic prototype.
- Arc detector: Above warm window on the WG

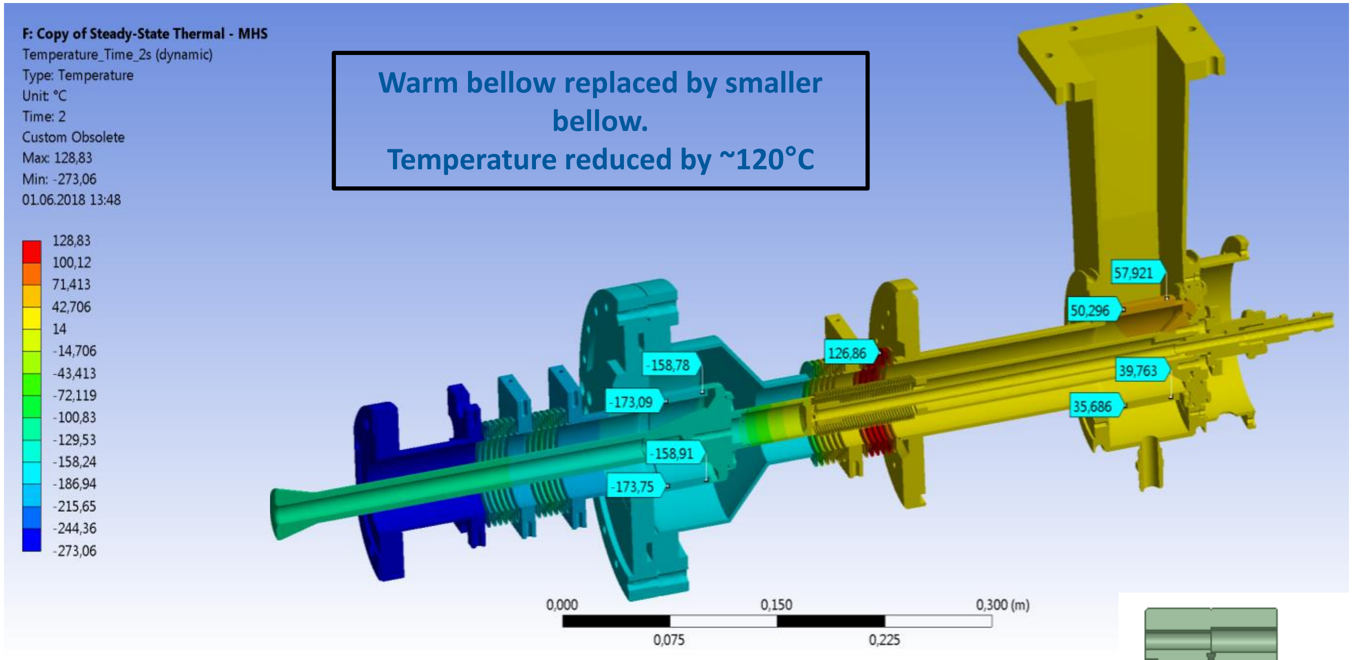
Current Thermal challenges





- Thermal gradients on the ceramic windows significantly reduced
- Temperature at tip now a suitable temperature.
- Slight heating of the input waveguide
- Significant heating on the warm bellows due to magnetic field peak.

Mitigating the bellows heating



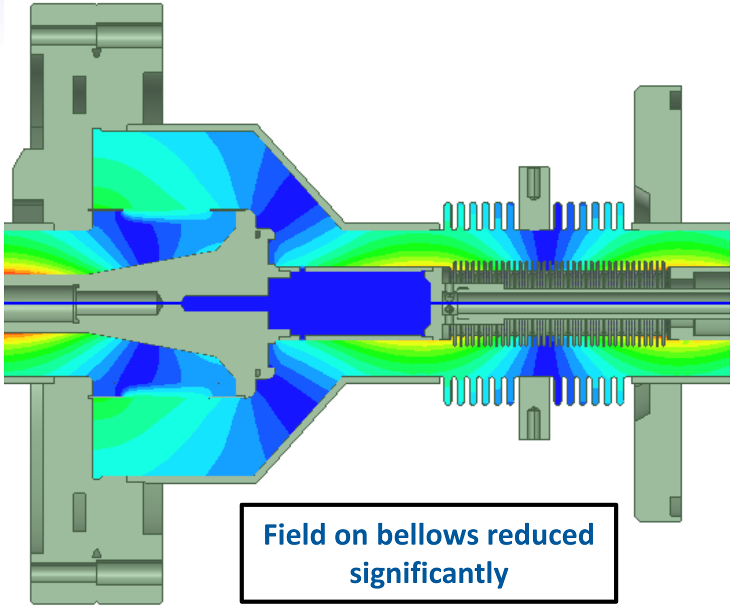
Warm bellow replaced by smaller bellow.
Temperature reduced by ~120°C

Reducing RF peak on the bellows

- Warm bellows reduced from 8 convolutions to 6 convolutions per bellow.
- Range of lateral movement reduced from ± 6,4 mm to ± 4,8 mm per bellow. (still within requirements)
- Bellows moved slightly to avoid field peak.

Alternative options

- Further reduce the bellows length
  - Pros: No need to integrate further cooling, minimal mechanical changes
  - Cons: Rules out higher power operation, reduces adjustability, may not work.
- Introduce water cooling on the 300K intercept
  - Pros: Will fully eliminate heating problem, no reduction in adjustability, allows for higher power operation.
  - Cons: Introduces water within the module, require more involved modifications to the mechanical design.



Field on bellows reduced significantly

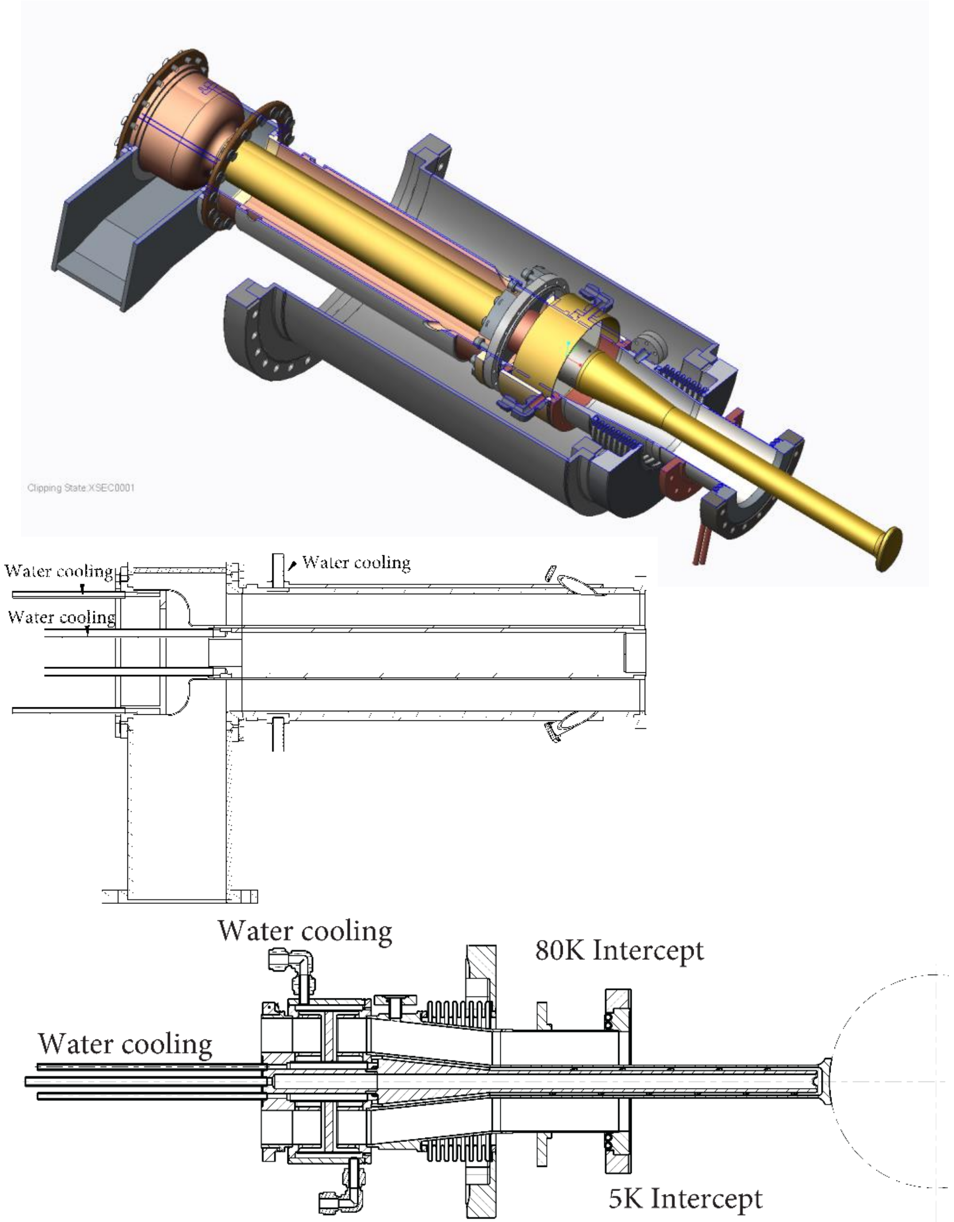
bERLinPro Couplers

Subproject leader: Dr. Ben Hall

bERLinPro couplers Overview

Parameter	Value
Central Frequency	1.3 GHz
Bandwidth	± 1 MHz
Max RF power supplied by the amplifier	120 kW
Mean power per coupler	**110 kW**
Number of ceramic windows	1
Q_{loaded}	1.05×10^5
Total Heat Leak to 2 K	< 1 W
Total Heat Leak to 5 K	< 5 W
Total Heat Leak to 80 K	< 80 W

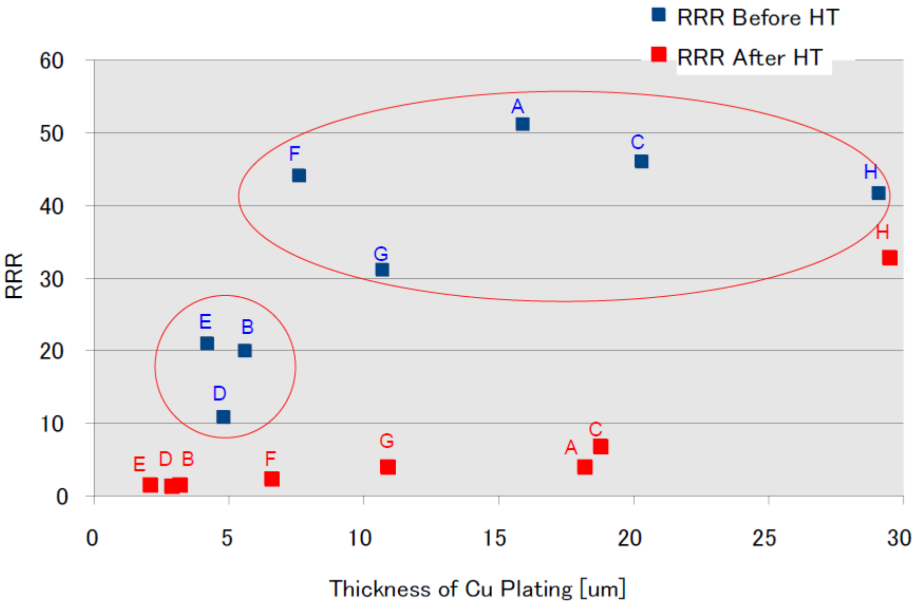
- In standing wave operation the coupler will only experience ¼ of the total power.
- Bellows do not see RF only for compensation of thermal expansion, not active tuning.
- Water cooling of inner conductor
- Currently in manufacturing stage. Warm part: FMB. Cold part: Toshiba.



Copper coating testing

Sample 1	After Brazing (780ºc)
RRR (Steel + Cu):	2.3
RRR (Steel):	1.43
RRR (Cu):	7.4 (calculated)

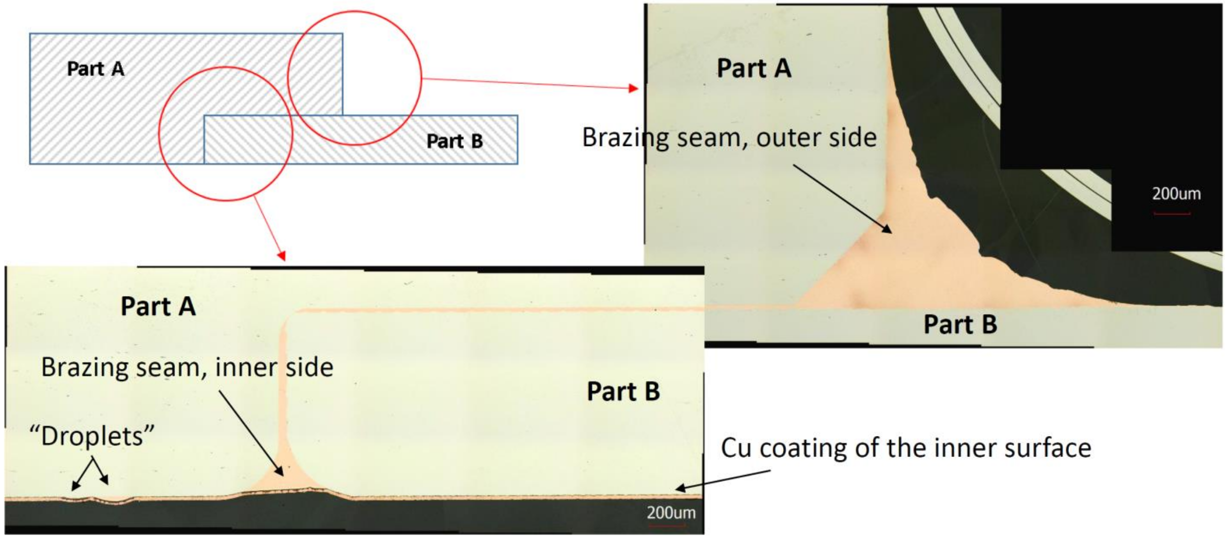
Sample 2	Before Brazing
RRR (Steel + Cu):	8.6
RRR (Steel):	1.43
RRR (Cu):	36.4 (calculated)



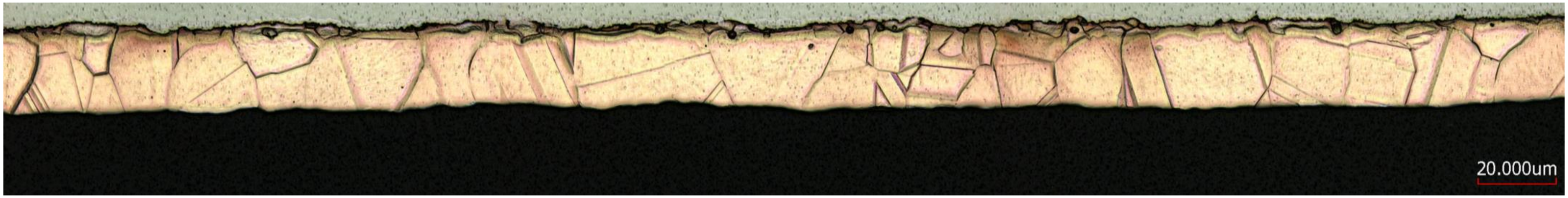
- Samples consistent with work from E. Kako
- Scotch tape samples taken from the sample.
- No separation of the coating was seen

Coating analysis

- Samples were cut from the test assembly to verify the braze and copper coating.
- Braze between parts fully wets the join and appears to have no inclusions



- Droplets not observed on production pieces.
- Cu layer is a uniform thickness across samples with av. thickness of 20.5um, design thickness 20-25 um.



Production of cold part

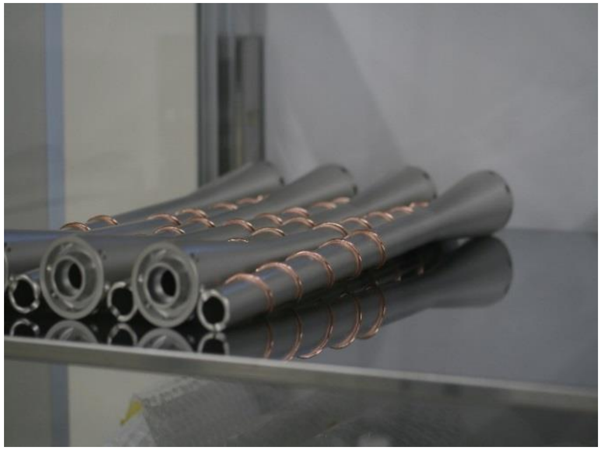
All parts of cold part manufactured and awaiting final braze.

Coupler tips outer

Warm to cold transition flange

Outer conductor including cavity flange (including cooling)

Ceramic windows and supports



Coupler tips inner part showing cooling channels

Thank you for your attention

Any Questions?