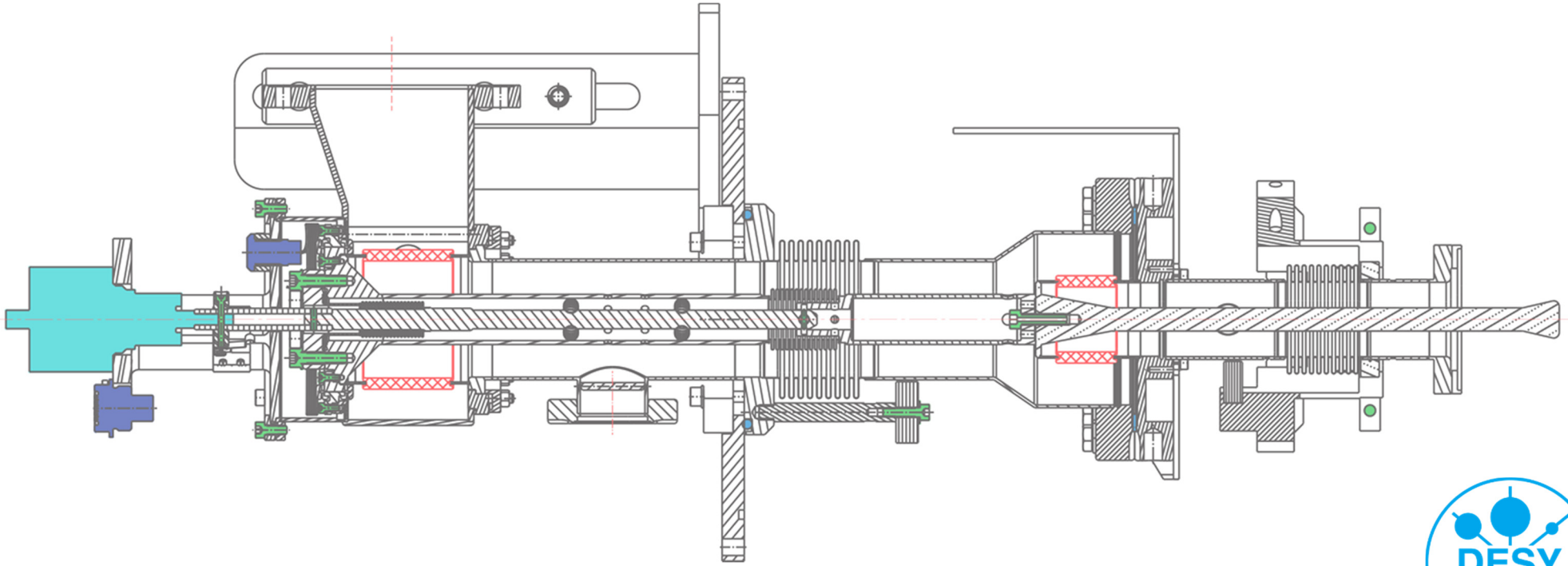
Denis Kostin, MHF-SL, DESY.

Visit of IRDA delegation at DESY 21.11.2016.

E-XFEL Input Coupler Design and Simulations



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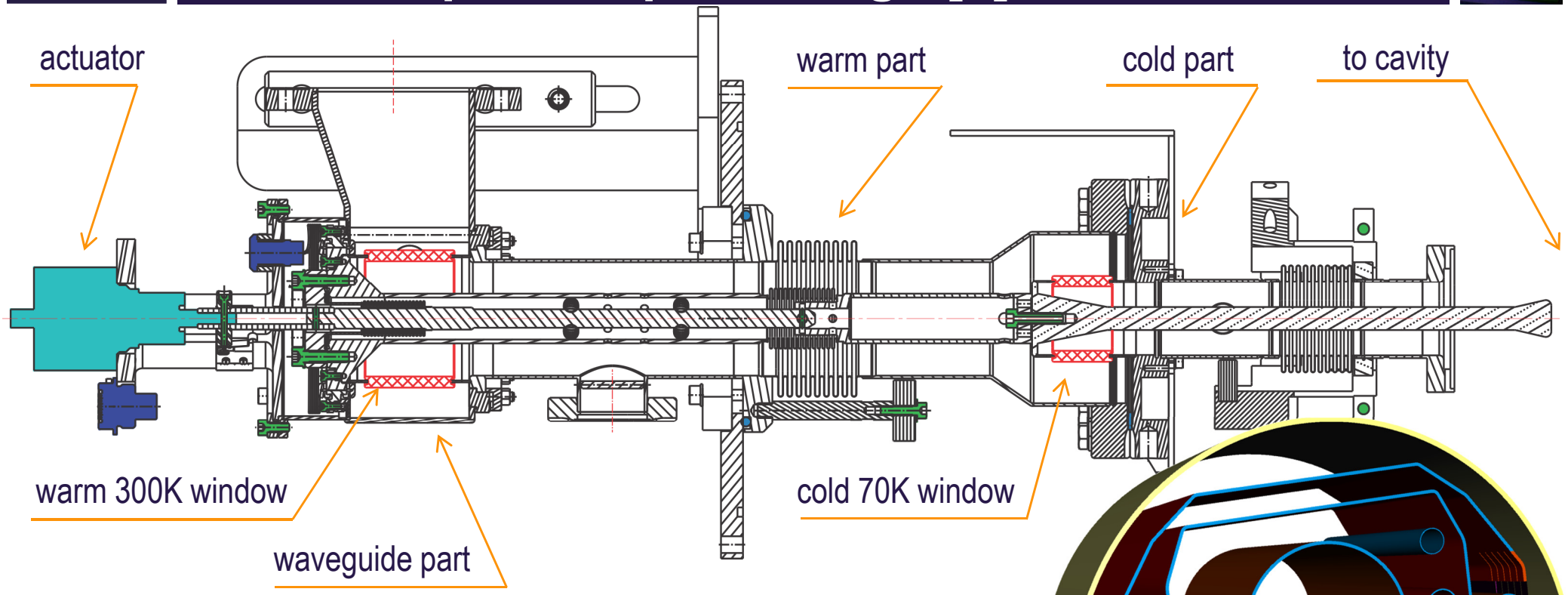
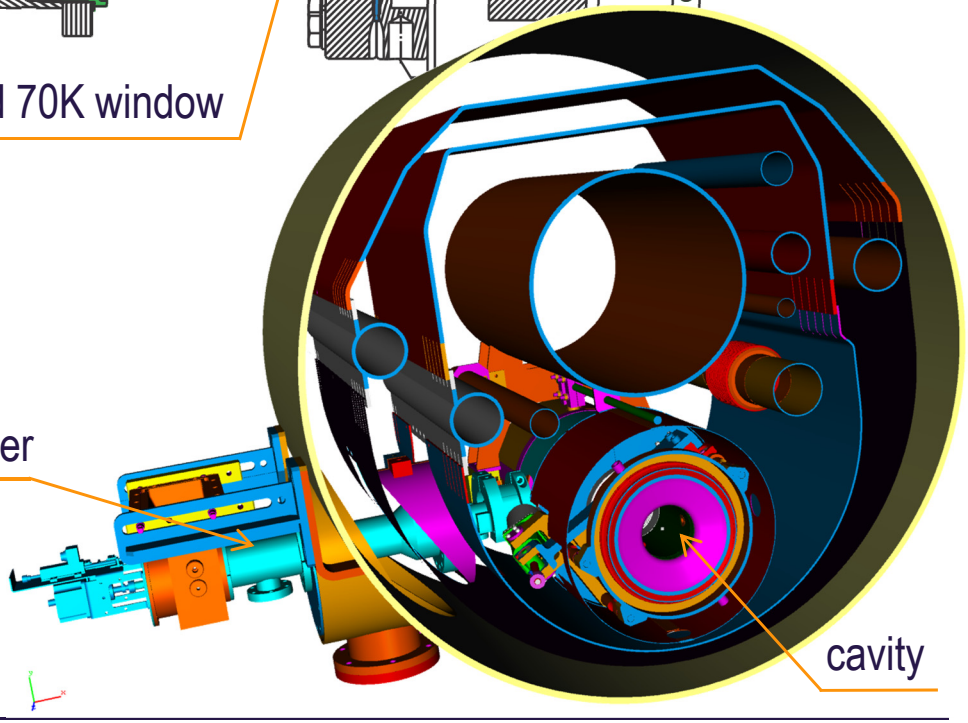
E-XFEL Input Coupler Design [1]



E-XFEL Input RF power coupler consists of warm, cold and waveguide main parts. Coaxial coupler is made of copper and copper plated (10/30μm) stainless steel with alumina TiN coated ceramic windows. Motorized antenna tuning (+/-10mm) allows for Q_{ext} adjustment (10^6..10^7).



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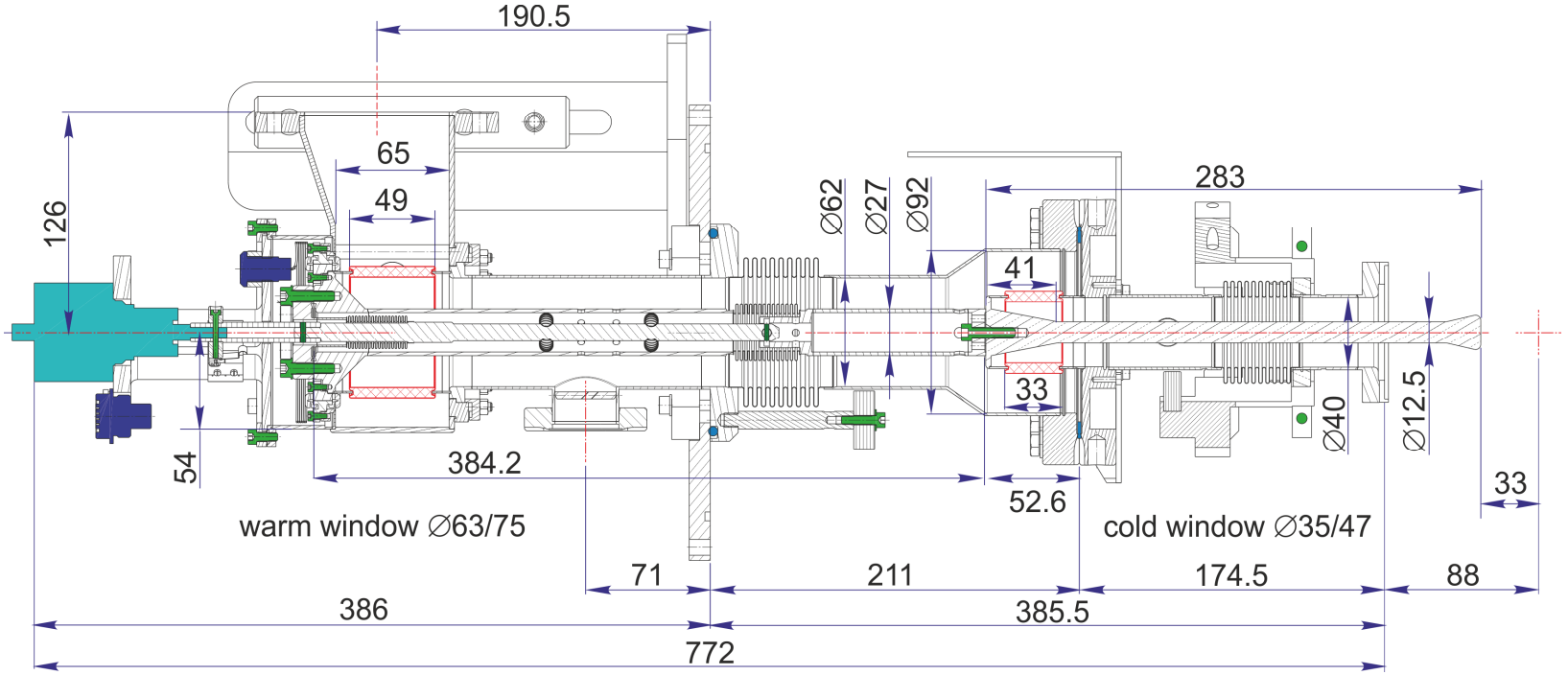
E-XFEL Input Coupler Design [2]



> Geometry

> Copper Plating

part	inner [µm]	inner RRR	outer [µm]	outer RRR
cold	solid copper	solid copper	10±20% bellow: ±30%	30..80
warm	30±20% bellow: ±30%	30..80	10±20% bellow: ±30%	30..80

> RF Power

peak power	rep.rate	equivalent CW power
150 kW	10 Hz	1.9 kW

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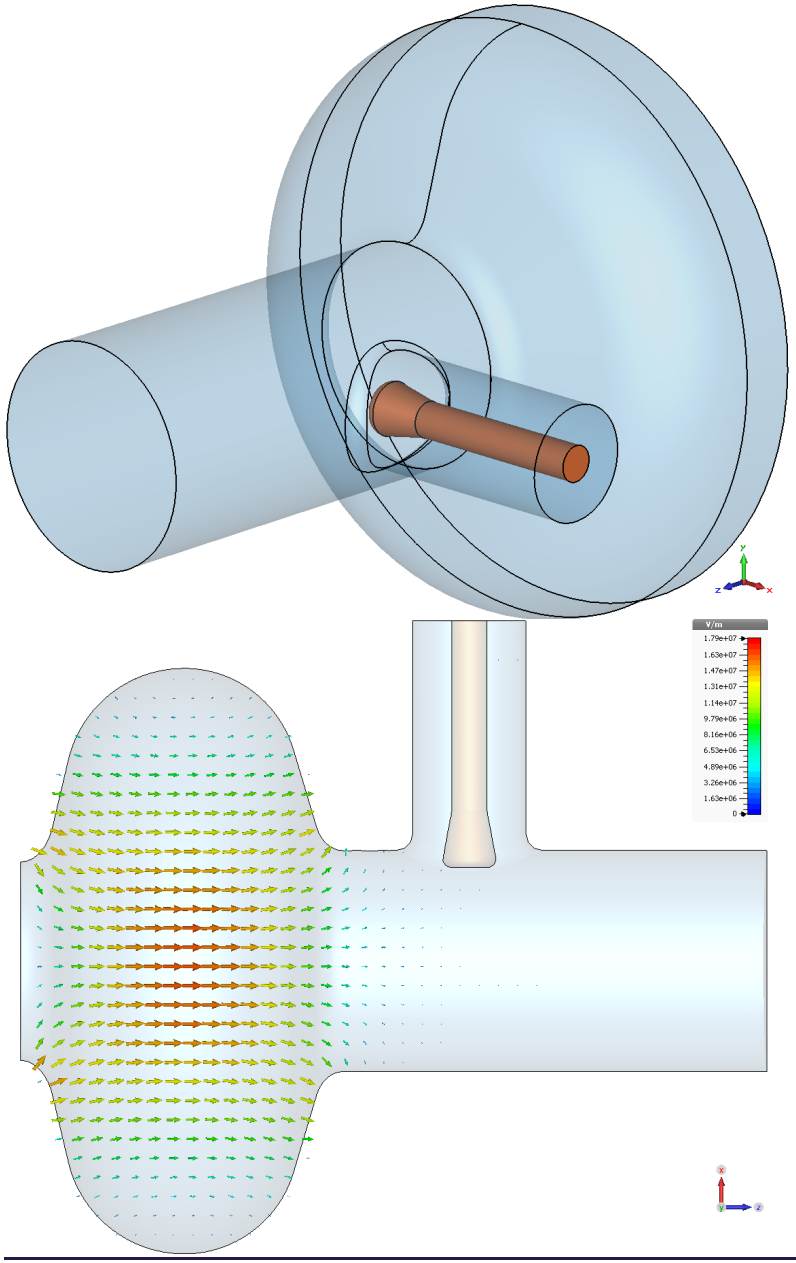
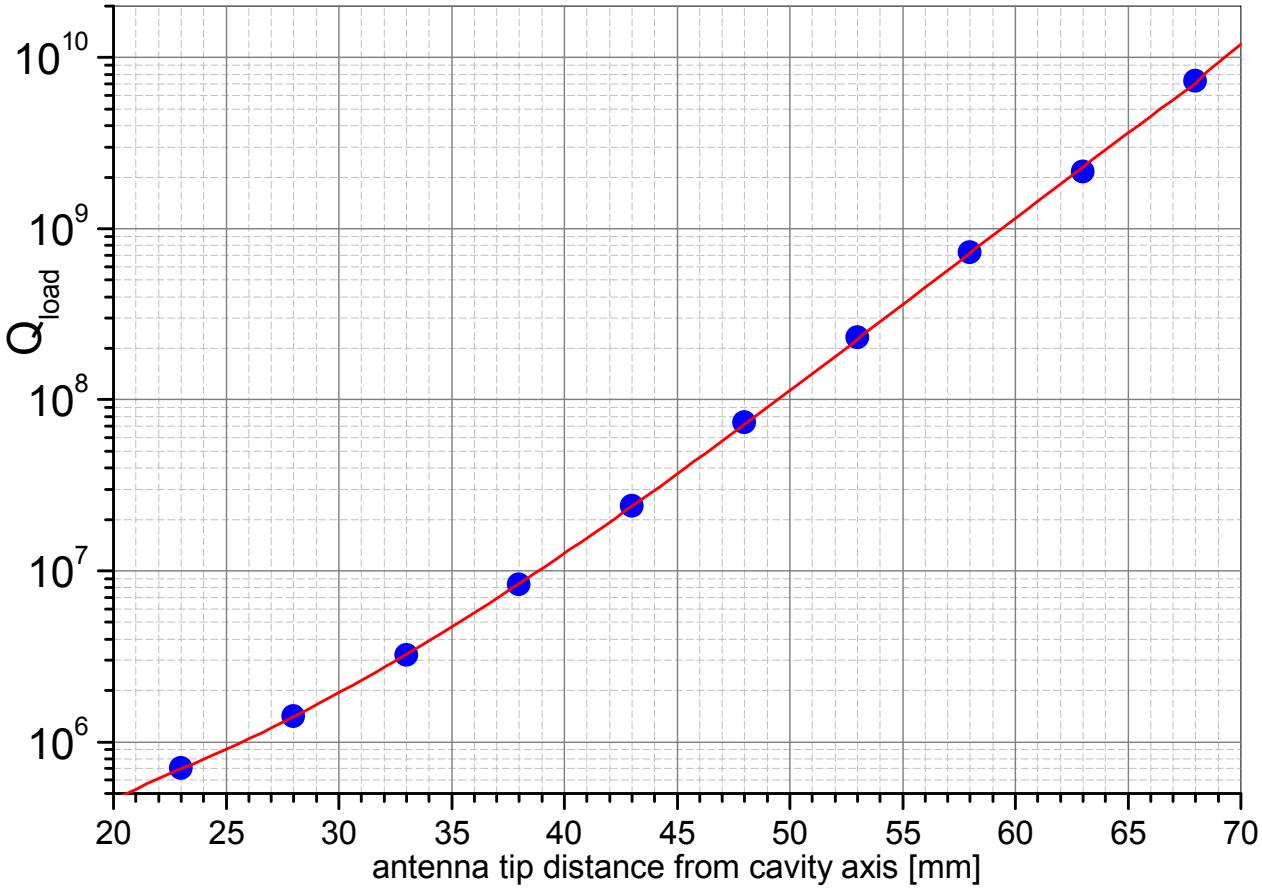
E-XFEL Coupler CST MWS Simulations [1]



Input Coupler Loaded Q Calculation



input coupler antenna simulation yields the loaded quality factor (coupling) dependencies on geometry.

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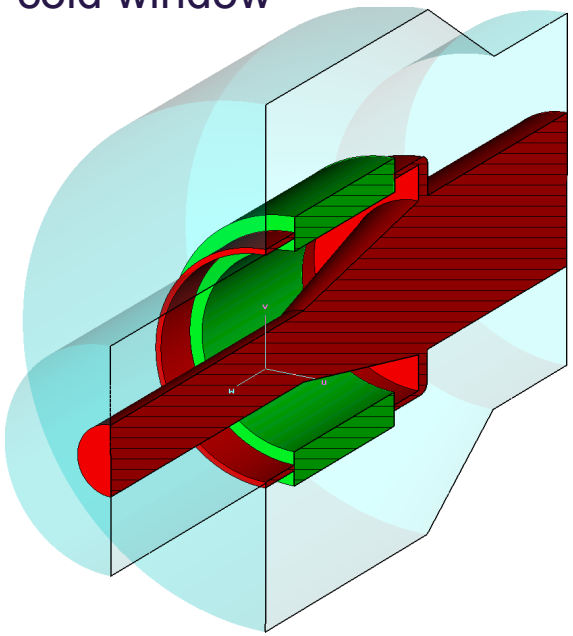
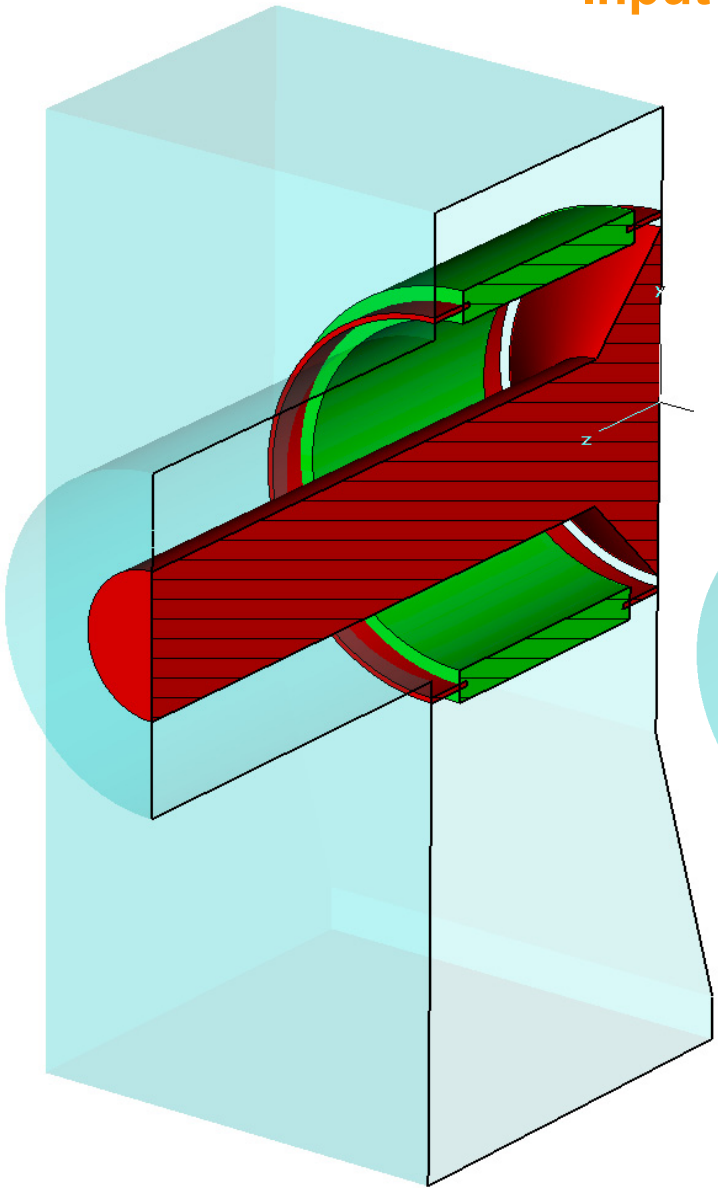
E-XFEL Coupler CST MWS Simulations [2]

Input Coupler Parts Simulations

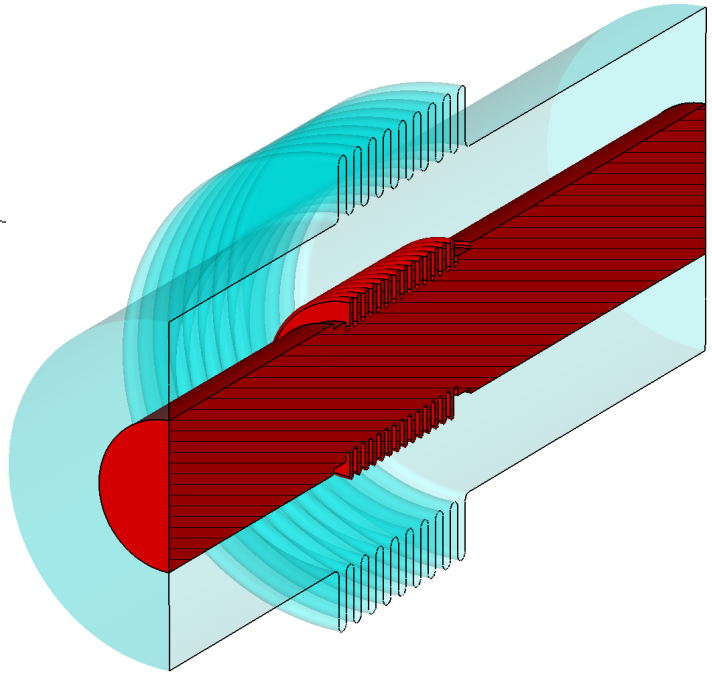
cold window



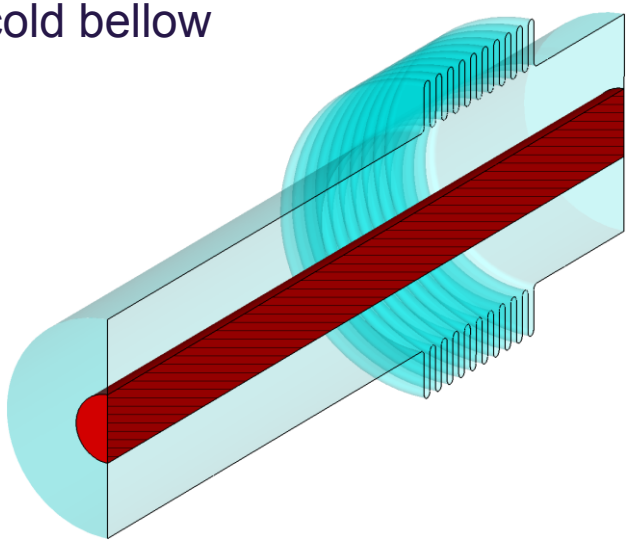
warm window



warm bellow



cold bellow



coupler parts simulations are the next step in the design.

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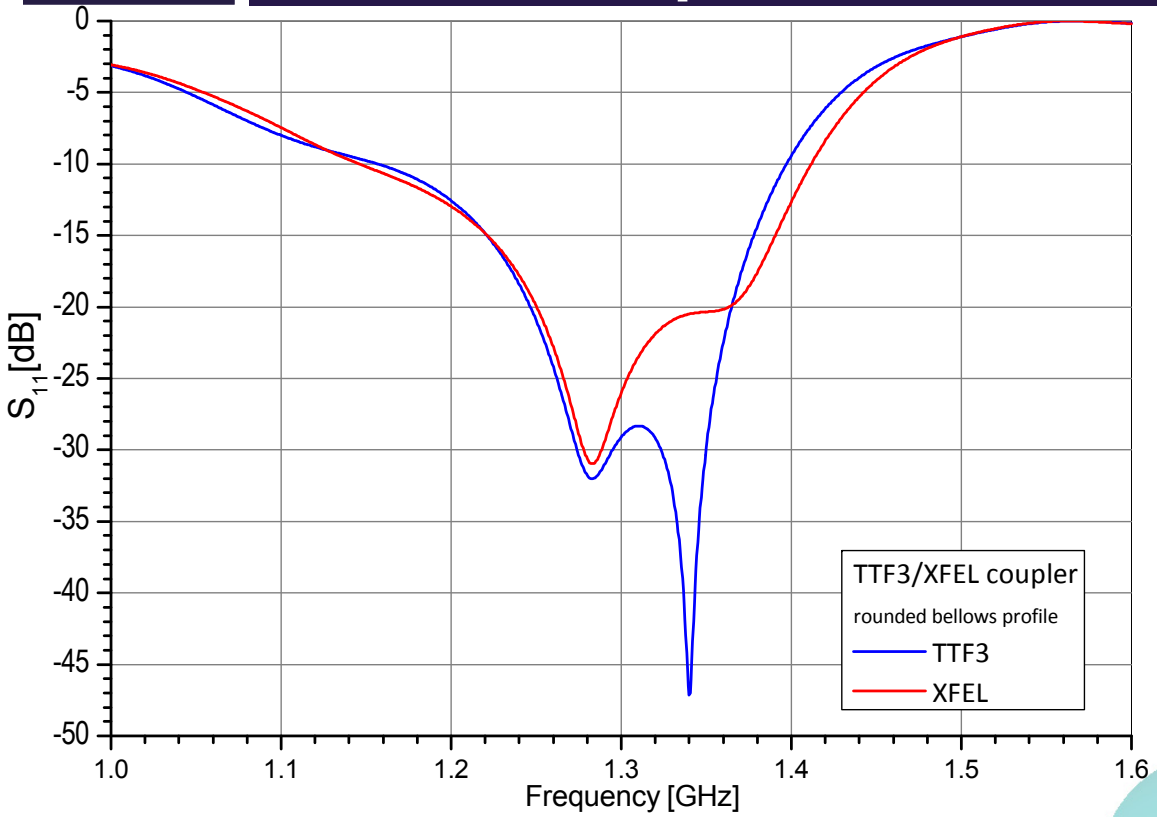
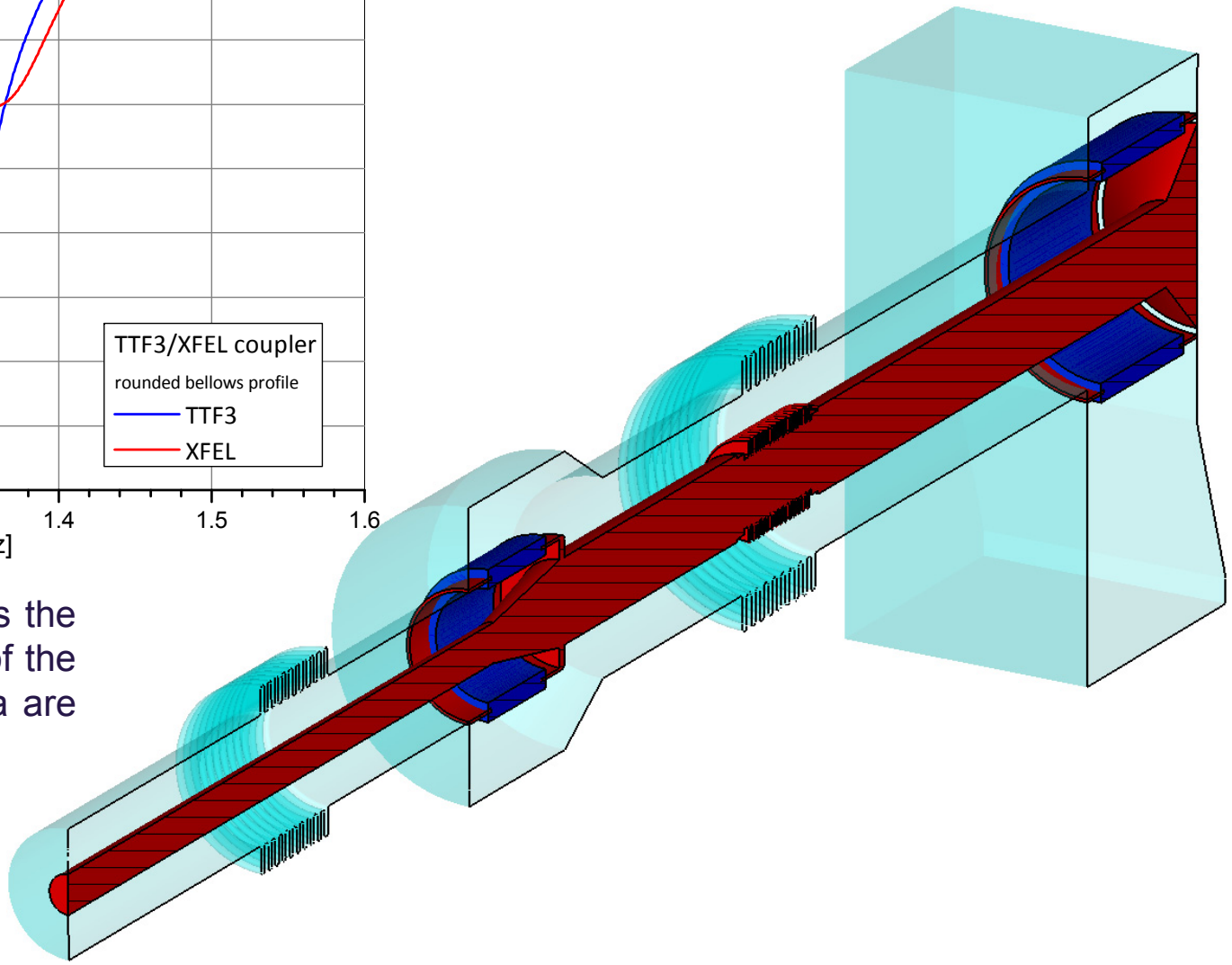
E-XFEL Coupler CST MWS Simulations [3]

Complete Input Coupler Simulation



full coupler model simulation yields the S-matrix data and is a final proof of the RF design. RF fields/voltages data are the simulation goal as well.



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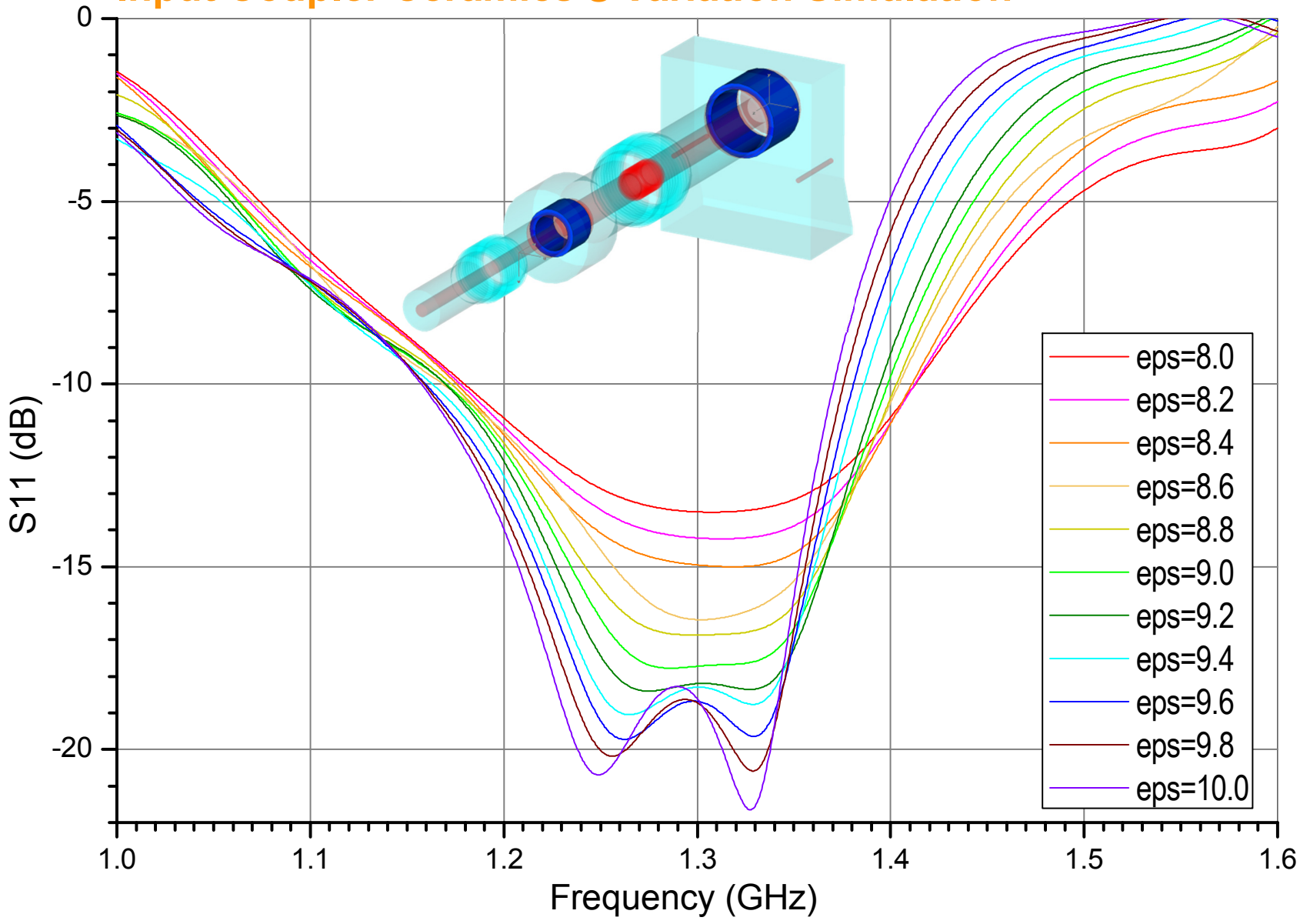
E-XFEL Coupler CST MWS Simulations [4]

Input Coupler Ceramics ε Variation Simulation



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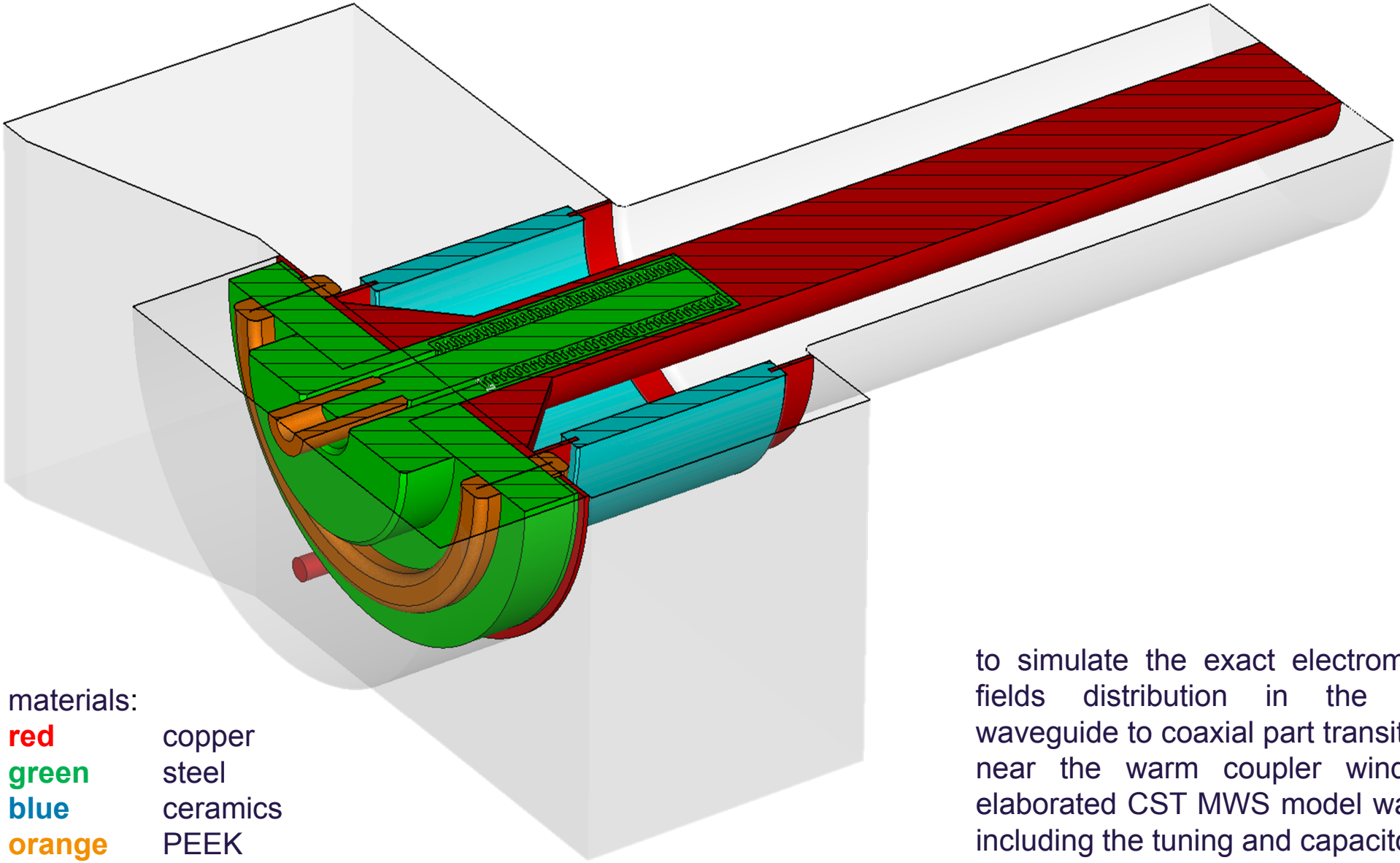
E-XFEL Coupler CST MWS Simulations [5]

CST MWS model with capacitor and push-rod bellow



materials:

red	copper
green	steel
blue	ceramics
orange	PEEK

to simulate the exact electromagnetic fields distribution in the coupler waveguide to coaxial part transition and near the warm coupler window an elaborated CST MWS model was done including the tuning and capacitor.

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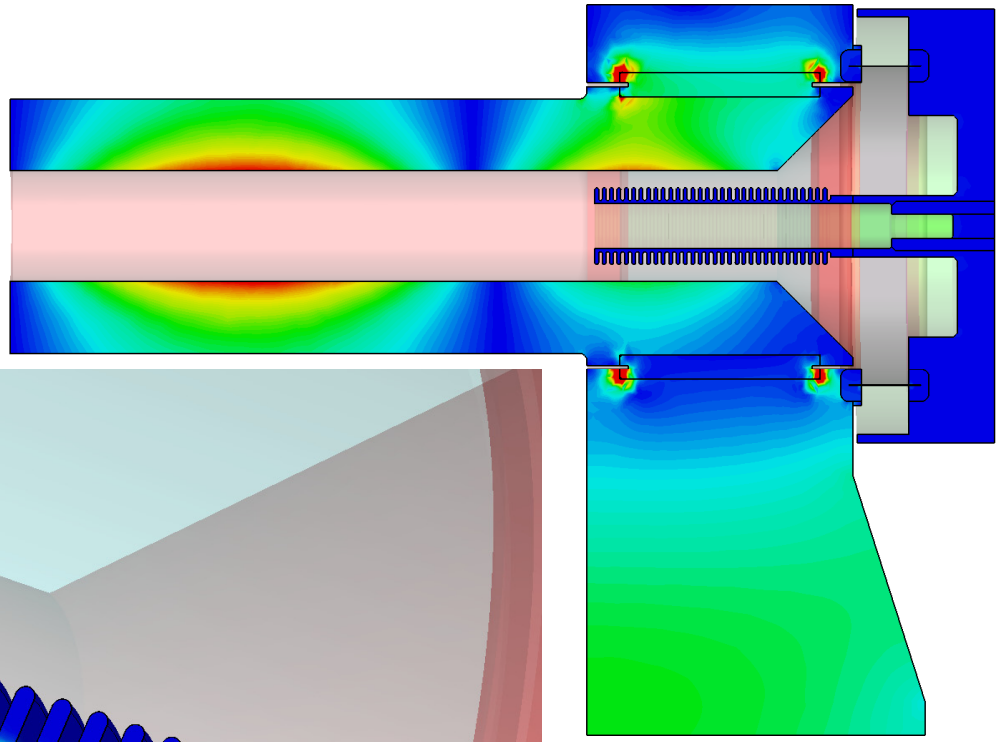
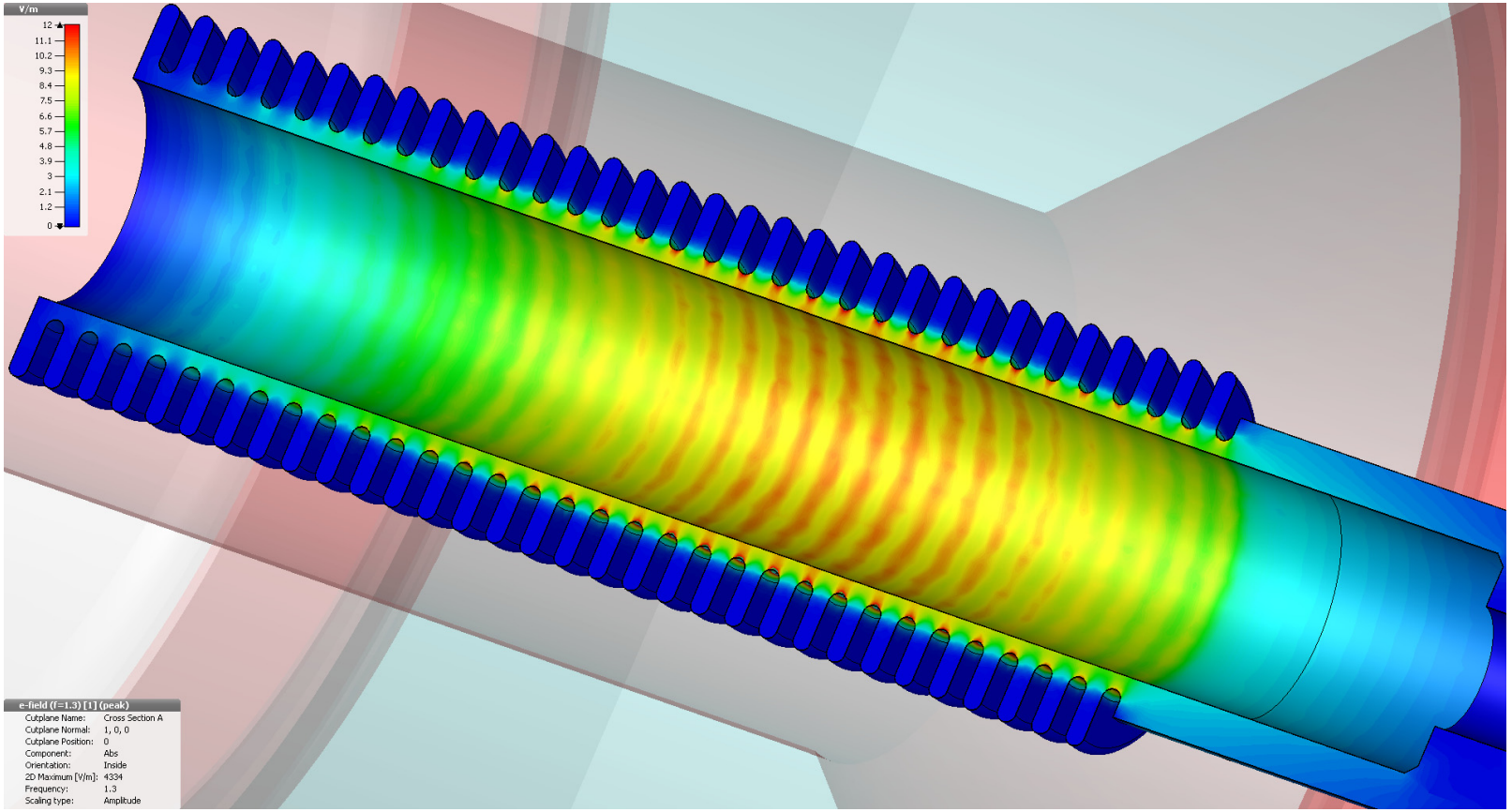
E-XFEL Coupler CST MWS Simulations [6]

Warm window push-rod bellow simulation

E-XFEL input coupler push-rod vacuum leak investigation: electromagnetic field peak inside the push-rod bellow.





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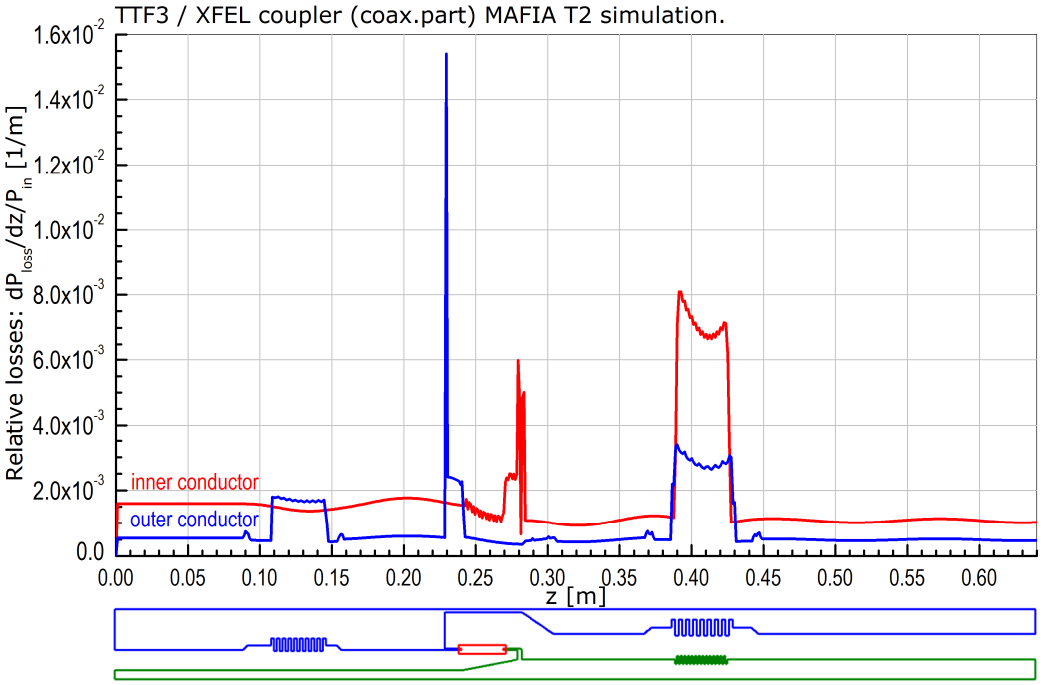
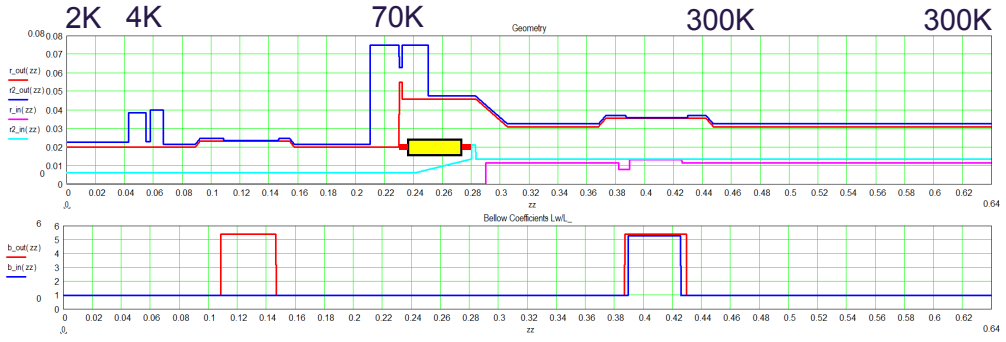
E-XFEL Coupler Thermal Simulations [1]

Coupler Thermal Simulation Basics

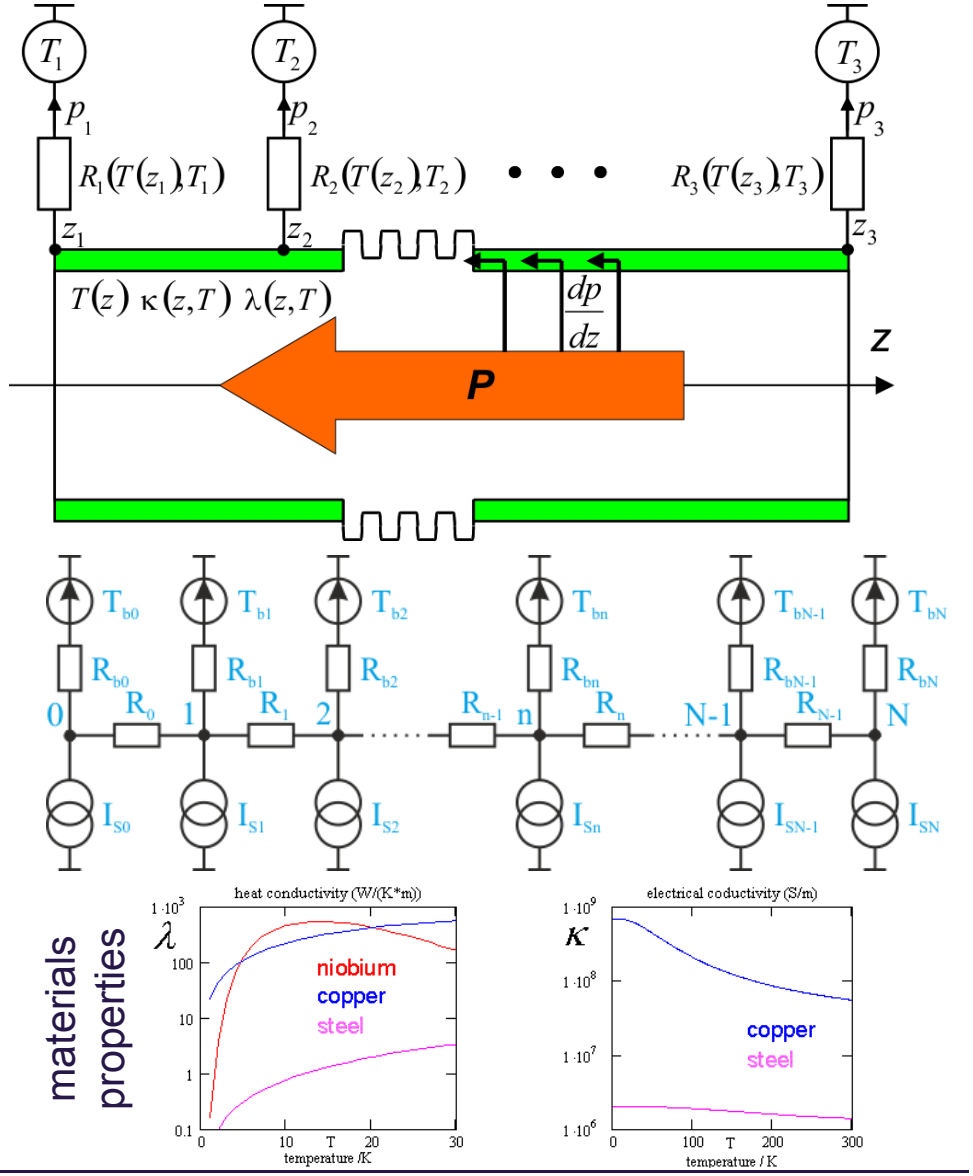
2D thermal losses simulation (mafia)



mathCAD thermal analysis geometry



thermal simulation equivalent diagram



materials properties

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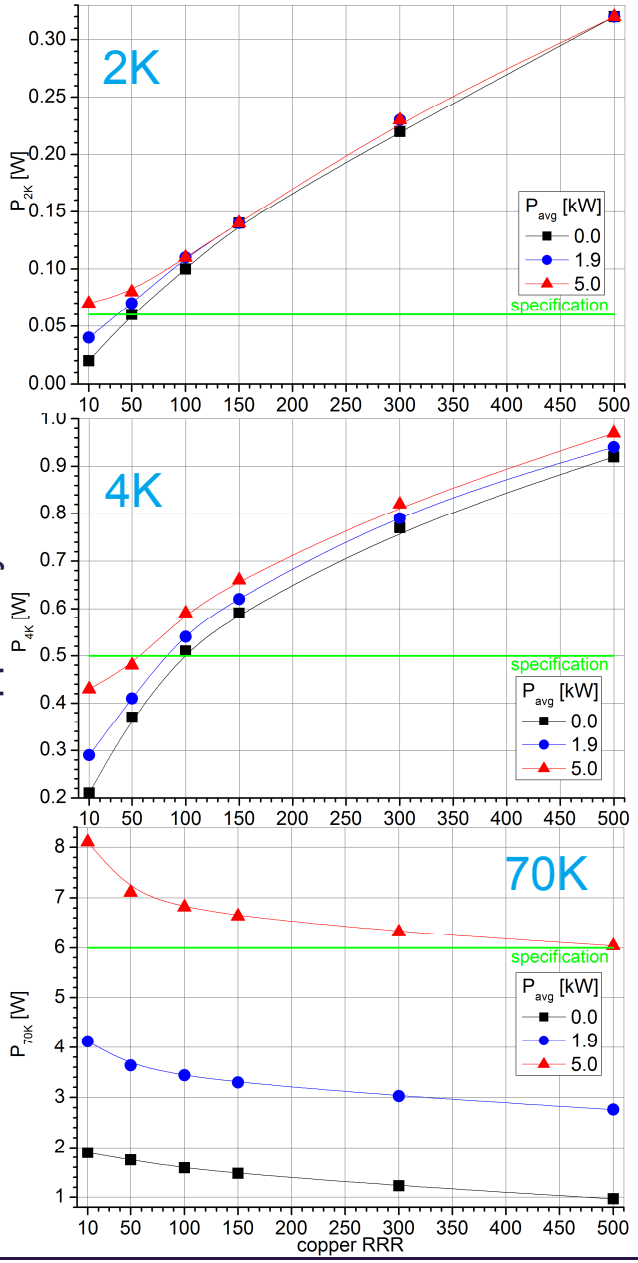
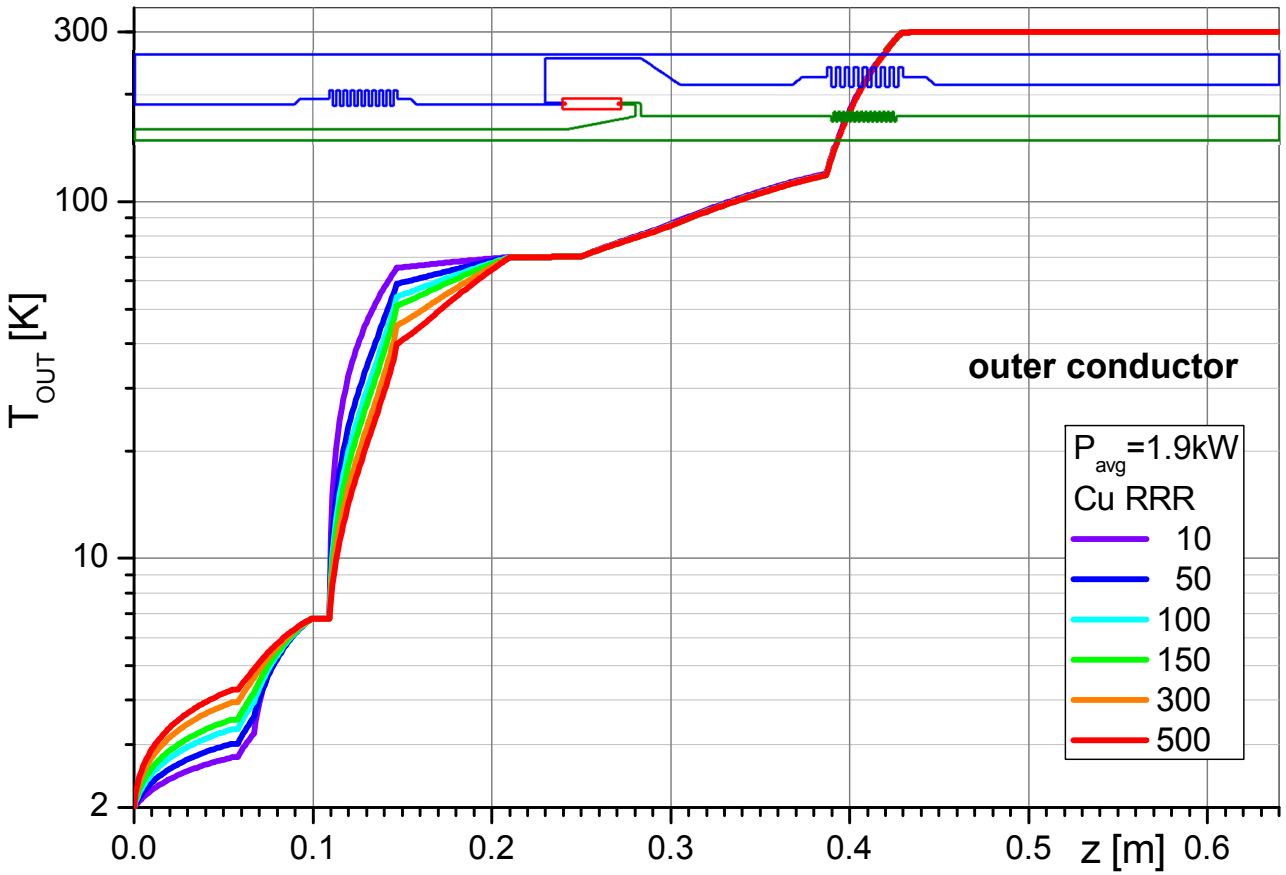
E-XFEL Coupler Thermal Simulations [2]

cryogenic losses

outer conductor copper layer RRR variation





- Static cryogenic losses play major role.
- Copper plating RRR is limited by maximum of 50 with 2K zone cryogenic losses specified by maximum of 0.06 W. This RRR limit is applied to the cold outer conductor only. Inner conductor contributes mostly to 70K zone and its RRR is not limited. Warm part copper plating RRR is also not limited.

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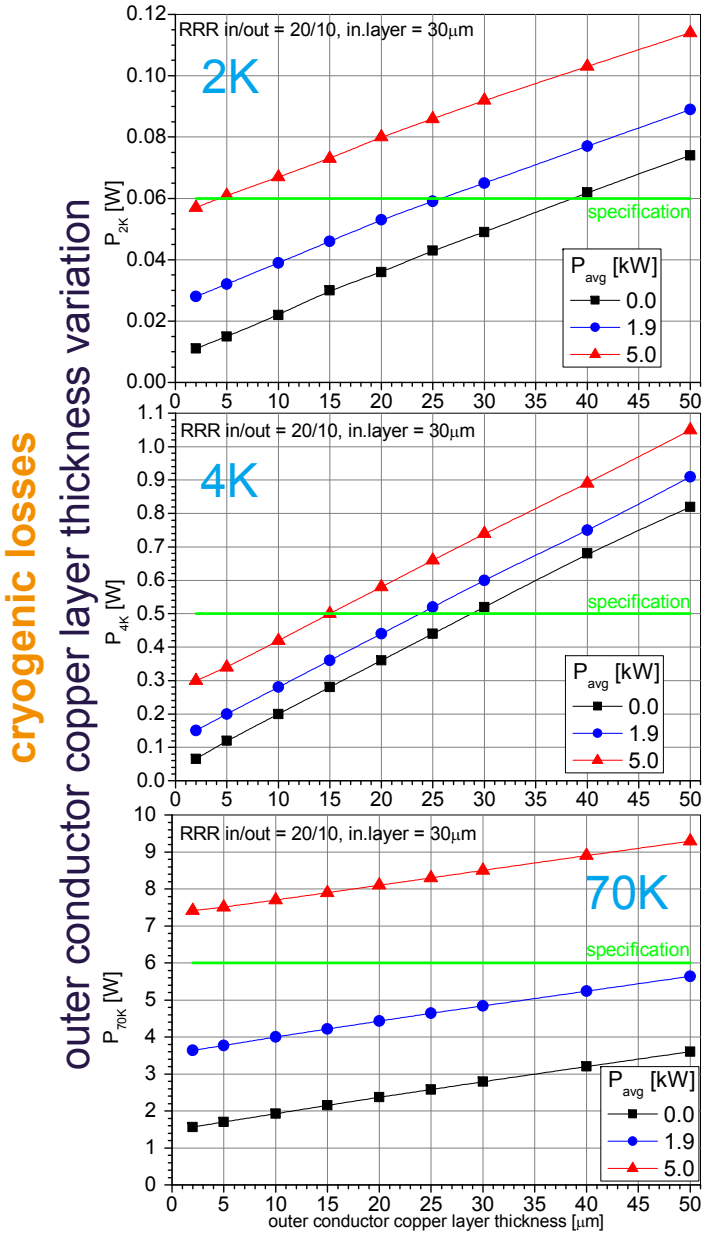
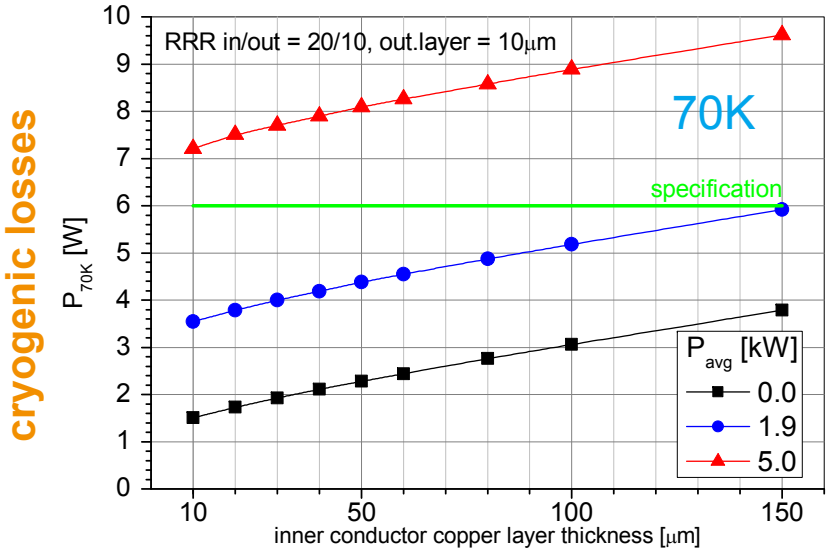
E-XFEL Coupler Thermal Simulations [3]



Coupler Copper Plating Layer Thickness

- outer conductor copper plating layer thickness maximum value is 25μm, limited by the 2K and 4K zone (the cold part) at specified 1.9kW average RF power.
- inner conductor copper plating layer thickness variation changes only the 70K zone cryolosses and is up to 150μm within the specification for specified average RF power of 1.9kW.

inner conductor copper layer thickness variation



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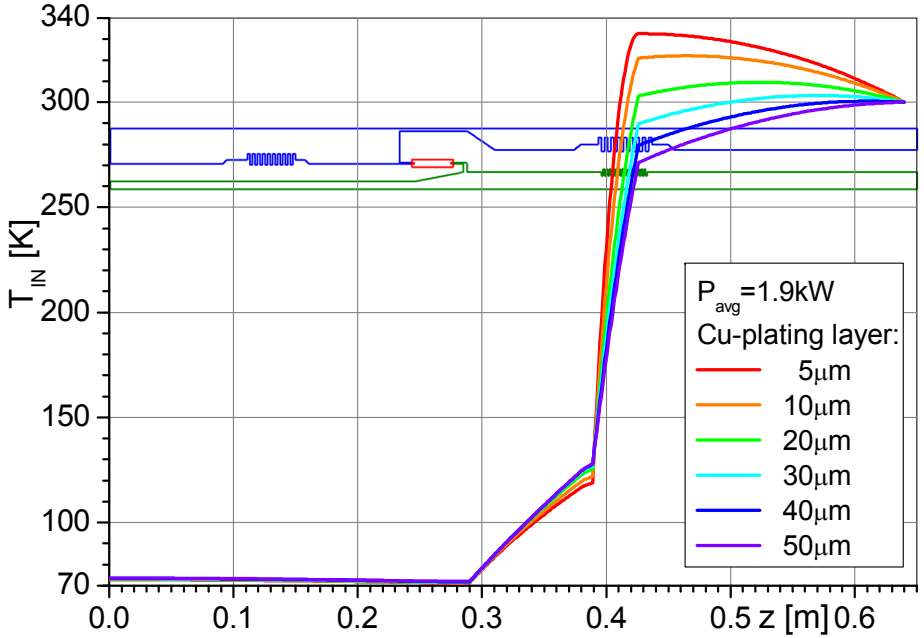
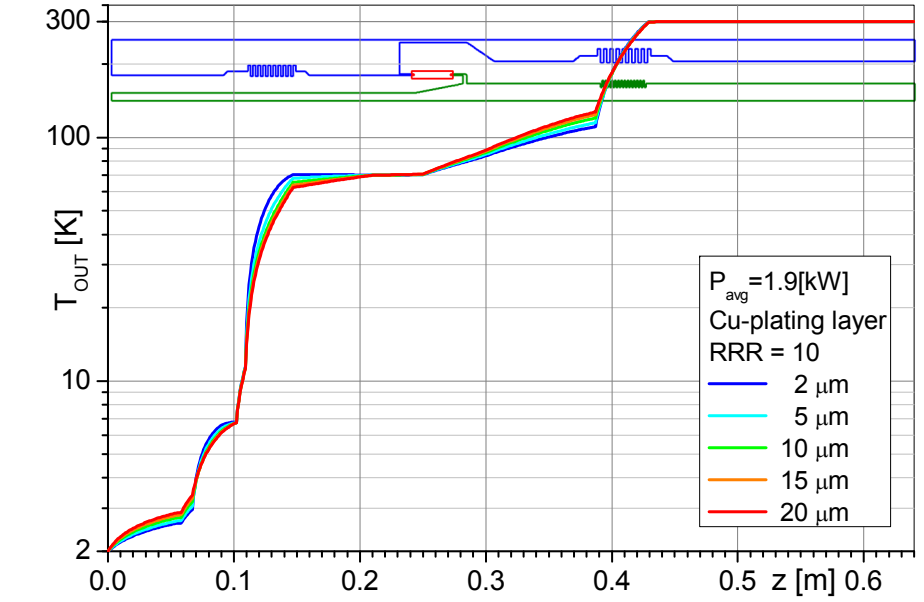
E-XFEL Coupler Thermal Simulations [4]

inner conductor

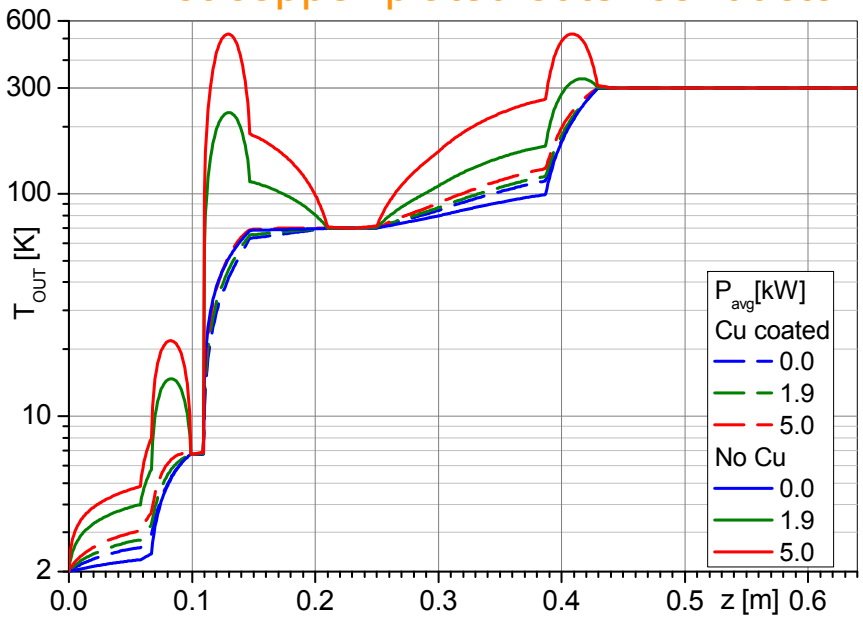


outer conductor



- copper plating layer thickness variation is mostly seen on the inner conductor with a warm inner bellow temperature variation.
- outer conductor plating layer thickness seems to be less important, save it must be at least 2 μm because of a skin depth effect.
- omitting the outer conductor plating is not a solution, dynamic losses at cold end increase drastically and temperature distribution is not acceptable.

not copper-plated outer conductor



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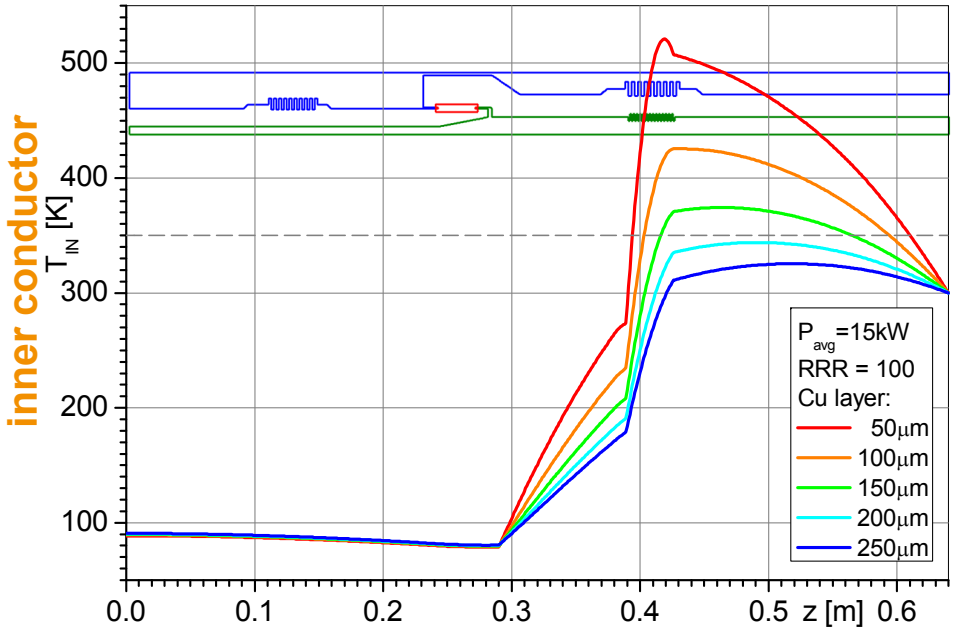
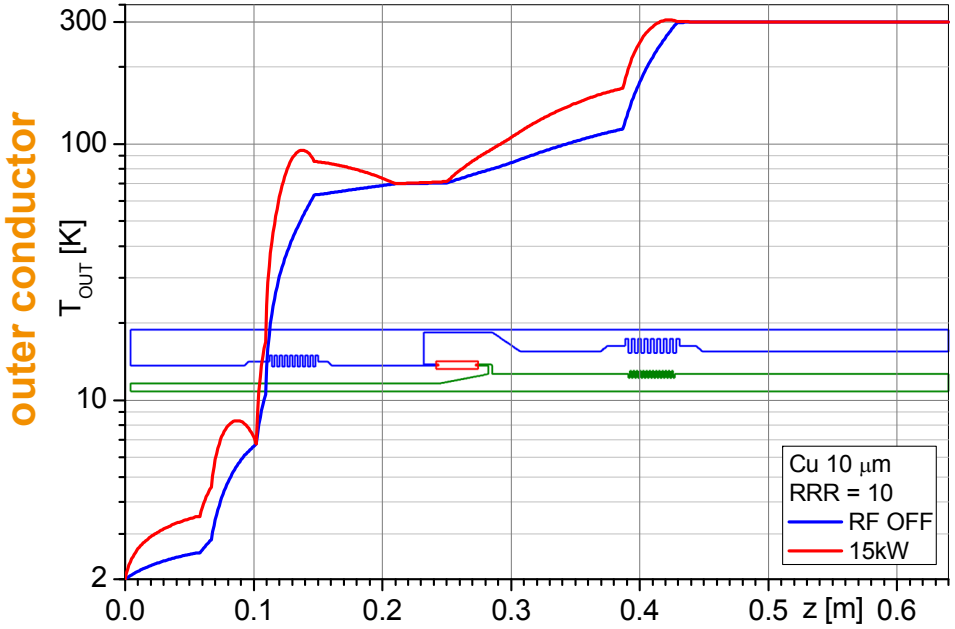
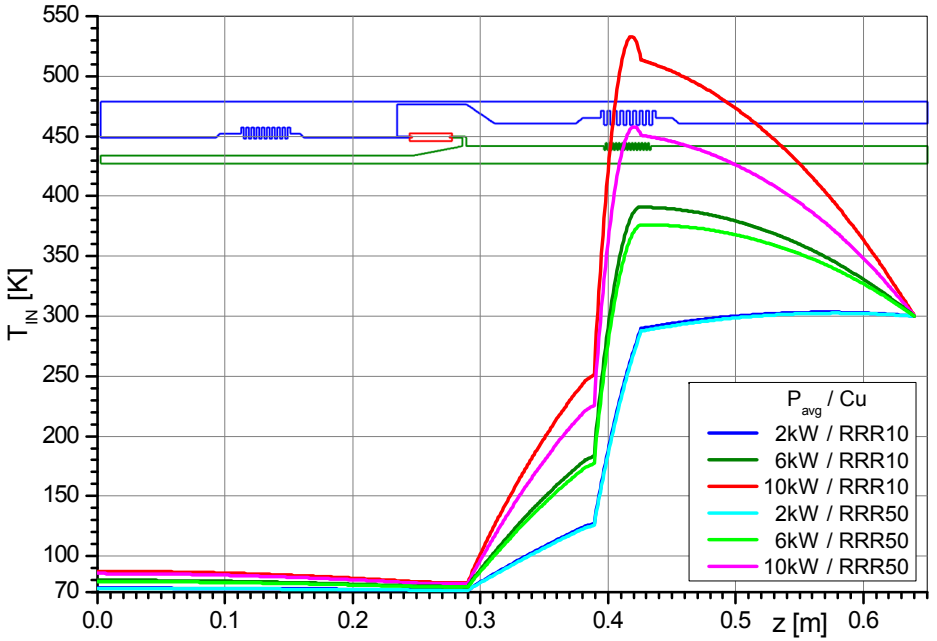
E-XFEL Coupler Thermal Simulations [5]





CW application

- with the CW RF power in a range of 10..15 kW inner conductor overheating will be an issue, with a maximum temperature on the warm inner bellow.
- to decrease the inner conductor temperature it must be gas cooled from inside or copper-plated with increased layer thickness (200μm) and RRR (50).



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Conclusion / Final Notes

- E-XFEL main coaxial input coupler design is based on TTF3 coupler 2 windows design with some minor changes;
- RF simulations done with CST Microwave Studio software at DESY, the simulations started with a coupler parts optimization and concluded with a full coupler 3D model simulation. S-parameter matrix calculation is done for different parameters, such as coupler geometry and material properties;
- Coupler thermal simulation with a 2D model of a coaxial part is done with the MathCAD software using matrix calculations of an equivalent coupler thermal model and its material properties. Thermal simulation yields temperature distribution along the coupler as well as cryogenic losses and their dependencies on such parameters, as copper plating thickness and RRR with RF power variation.