HOM absorbers in IR

Alexander Novokhatski, Eleonora Belli, Miguel Gil Costa

Michael K. Sullivan and Roberto Kersevan

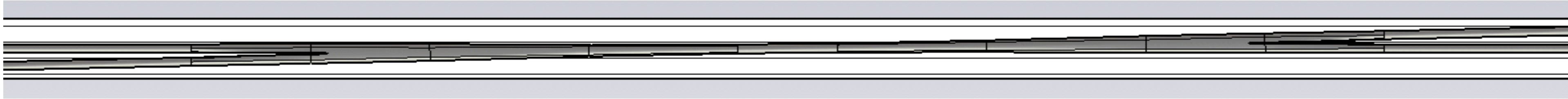
CERN and SLAC National Accelerator Laboratory

Workshop on the mechanical optimization of the FCC ee MDI
February 1, 2018

Outline

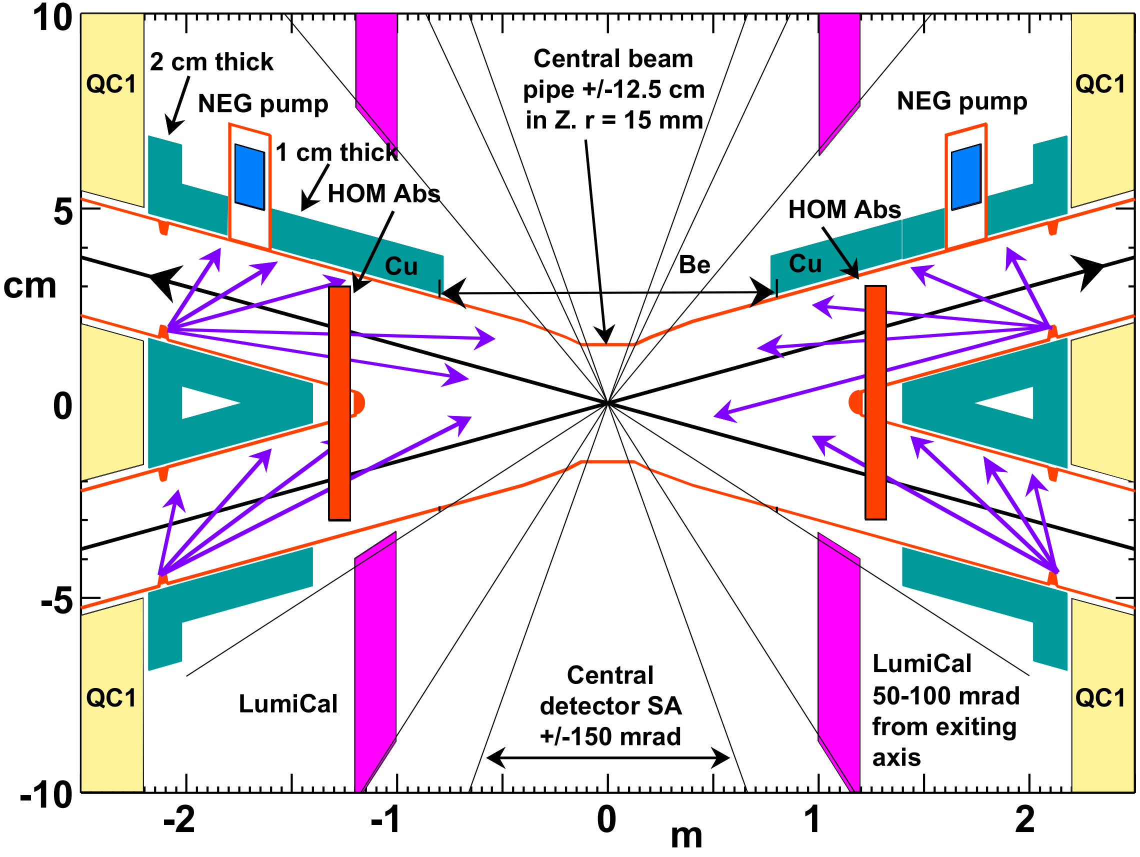
I. Design of the minimum impedance IR beam pipe.
II. Primary concept of the HOM absorber.
III. How absorber works?
IV. Geometry of the IR beam pipe with water-cooled HOM absorbers.
V. Next steps

To achieve minimum impedance of IR we developed a smooth transition from two beam pipes to a common pipe

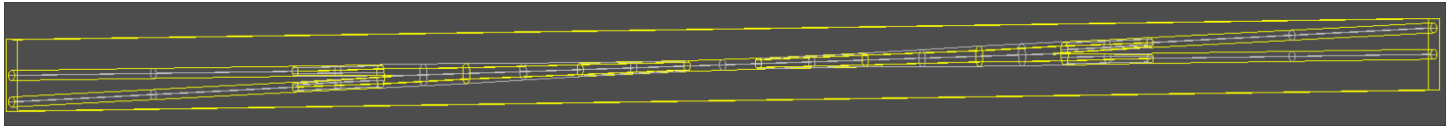


For precise HOM study we used CAD files from "CATIA"
Great work of Miguel Gil Costa

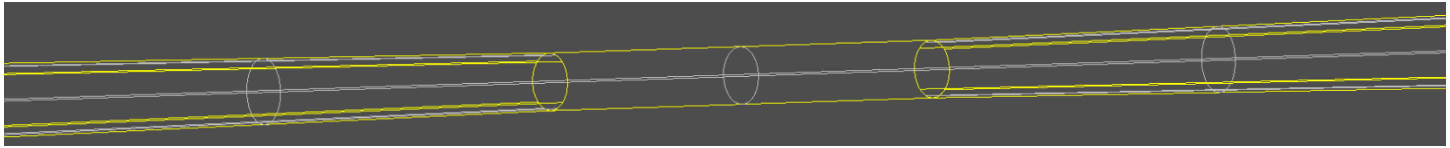
CAD model is based on the M. Sullivan design (FCC 2017, May 2017)



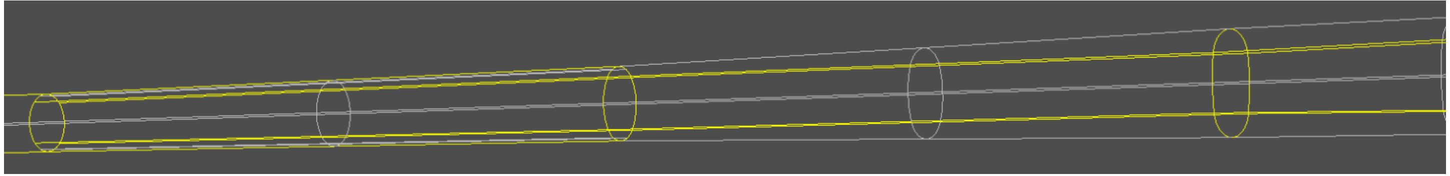
Details of the beam pipe transitions



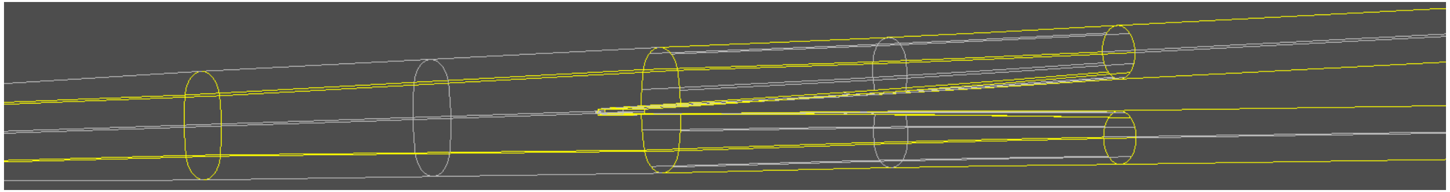
General view



Central round pipe ∅30 mm

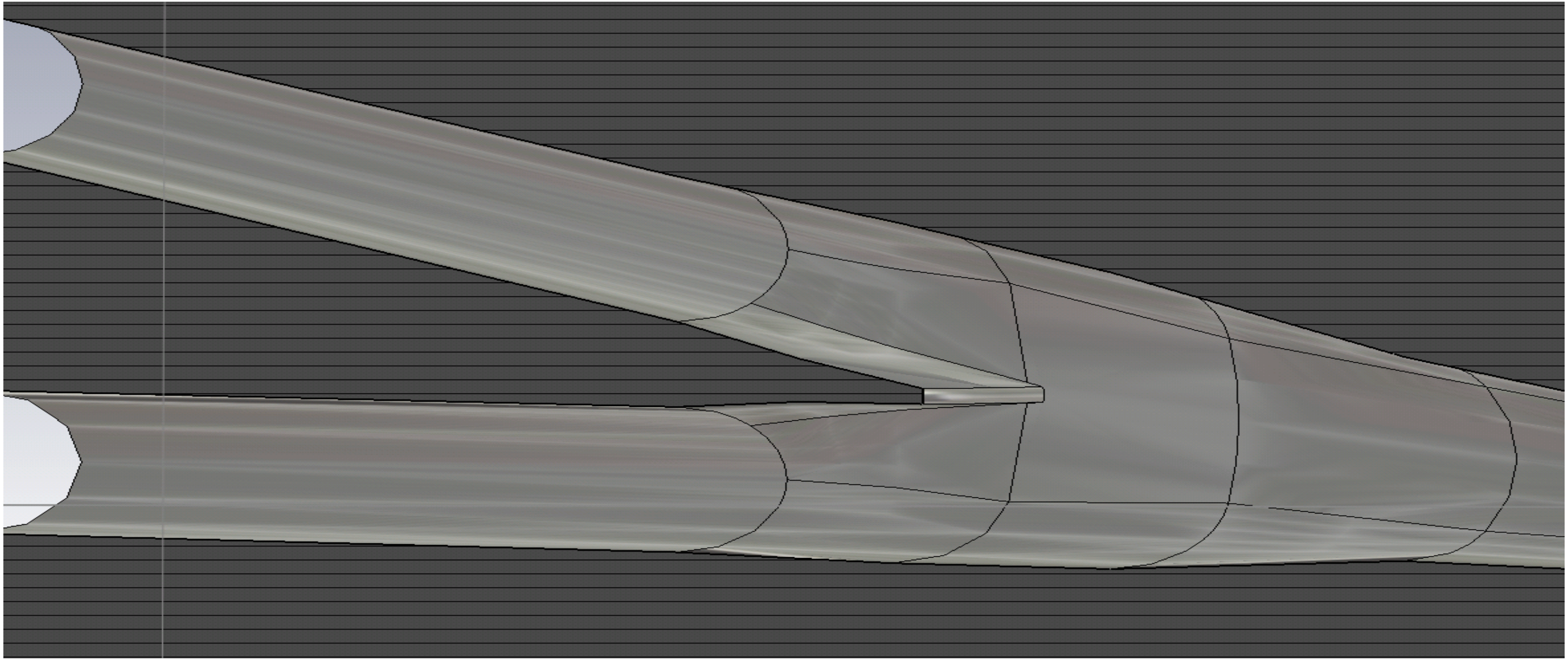


Transition from round to an “ellipse”

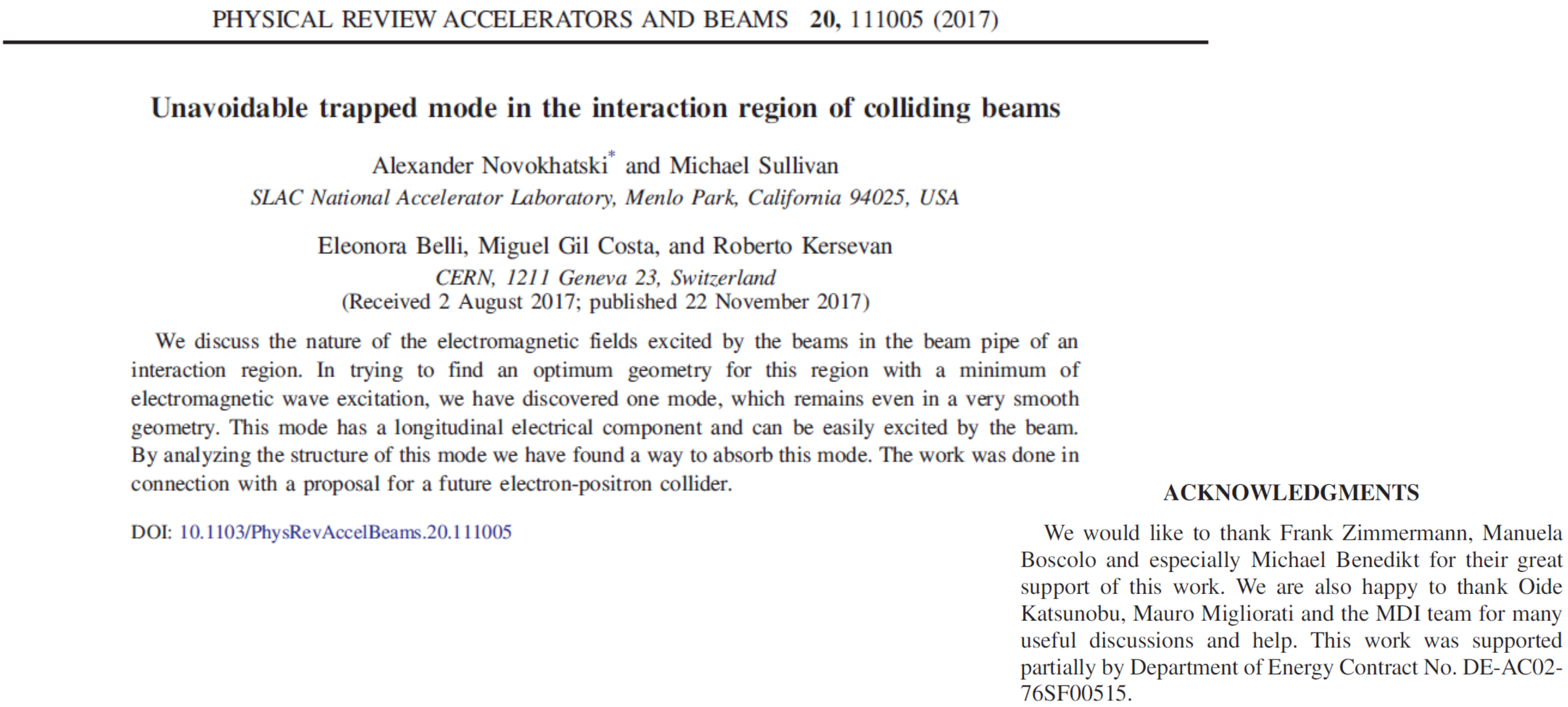


Transition of incoming circular pipes ∅30 mm to half of an “ellipse”

3D model



Results of impedance study were published recently. Thanks MDI team for the help and support.



PHYSICAL REVIEW ACCELERATORS AND BEAMS **20,** 111005 (2017)

Unavoidable trapped mode in the interaction region of colliding beams

Alexander Novokhatski* and Michael Sullivan
SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA

Eleonora Belli, Miguel Gil Costa, and Roberto Kersevan
CERN, 1211 Geneva 23, Switzerland

(Received 2 August 2017; published 22 November 2017)

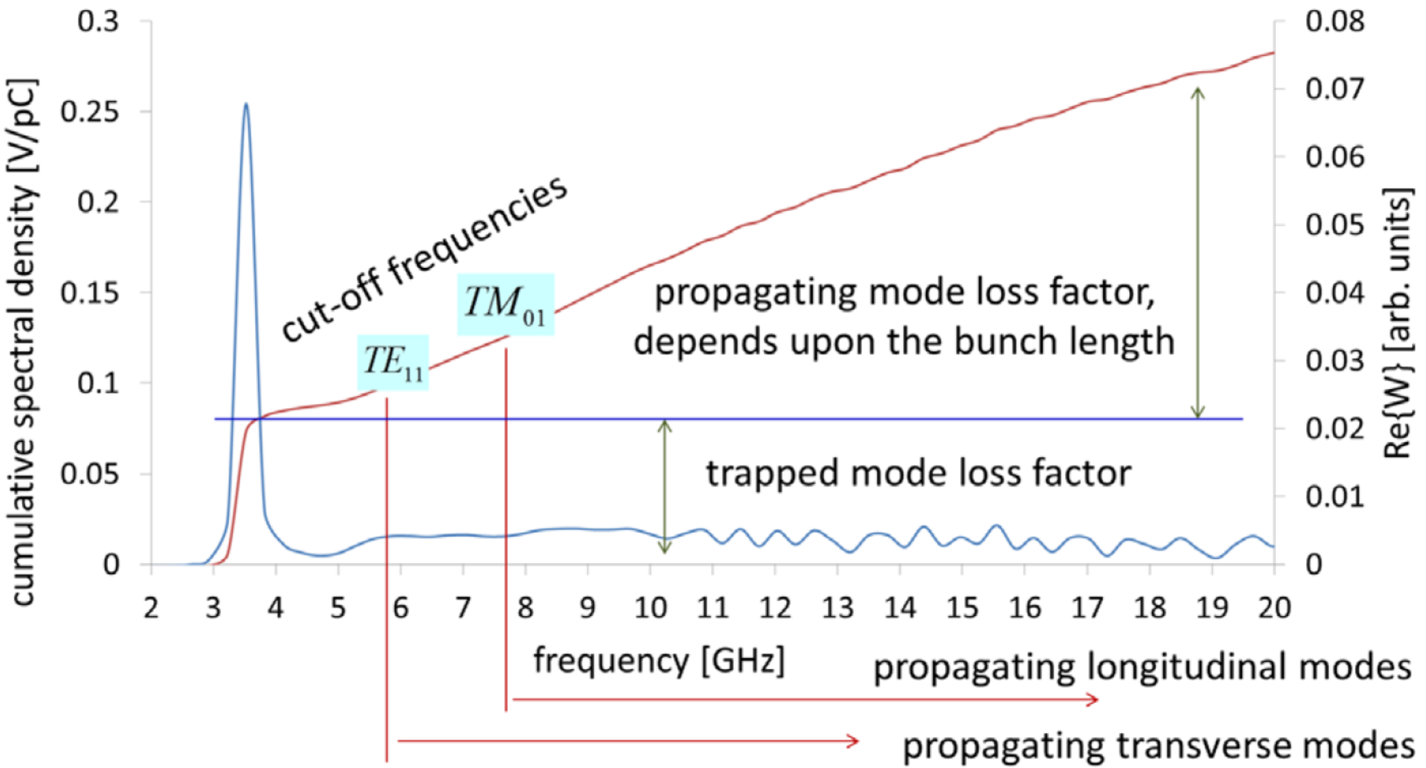
We discuss the nature of the electromagnetic fields excited by the beams in the beam pipe of an interaction region. In trying to find an optimum geometry for this region with a minimum of electromagnetic wave excitation, we have discovered one mode, which remains even in a very smooth geometry. This mode has a longitudinal electrical component and can be easily excited by the beam. By analyzing the structure of this mode we have found a way to absorb this mode. The work was done in connection with a proposal for a future electron-positron collider.

DOI: 10.1103/PhysRevAccelBeams.20.111005

ACKNOWLEDGMENTS

We would like to thank Frank Zimmermann, Manuela Boscolo and especially Michael Benedikt for their great support of this work. We are also happy to thank Oide Katsunobu, Mauro Migliorati and the MDI team for many useful discussions and help. This work was supported partially by Department of Energy Contract No. DE-AC02-76SF00515.

Spectrum and cumulative spectral density of the energy losses



cut-off frequencies

propagating mode loss factor, depends upon the bunch length

trapped mode loss factor

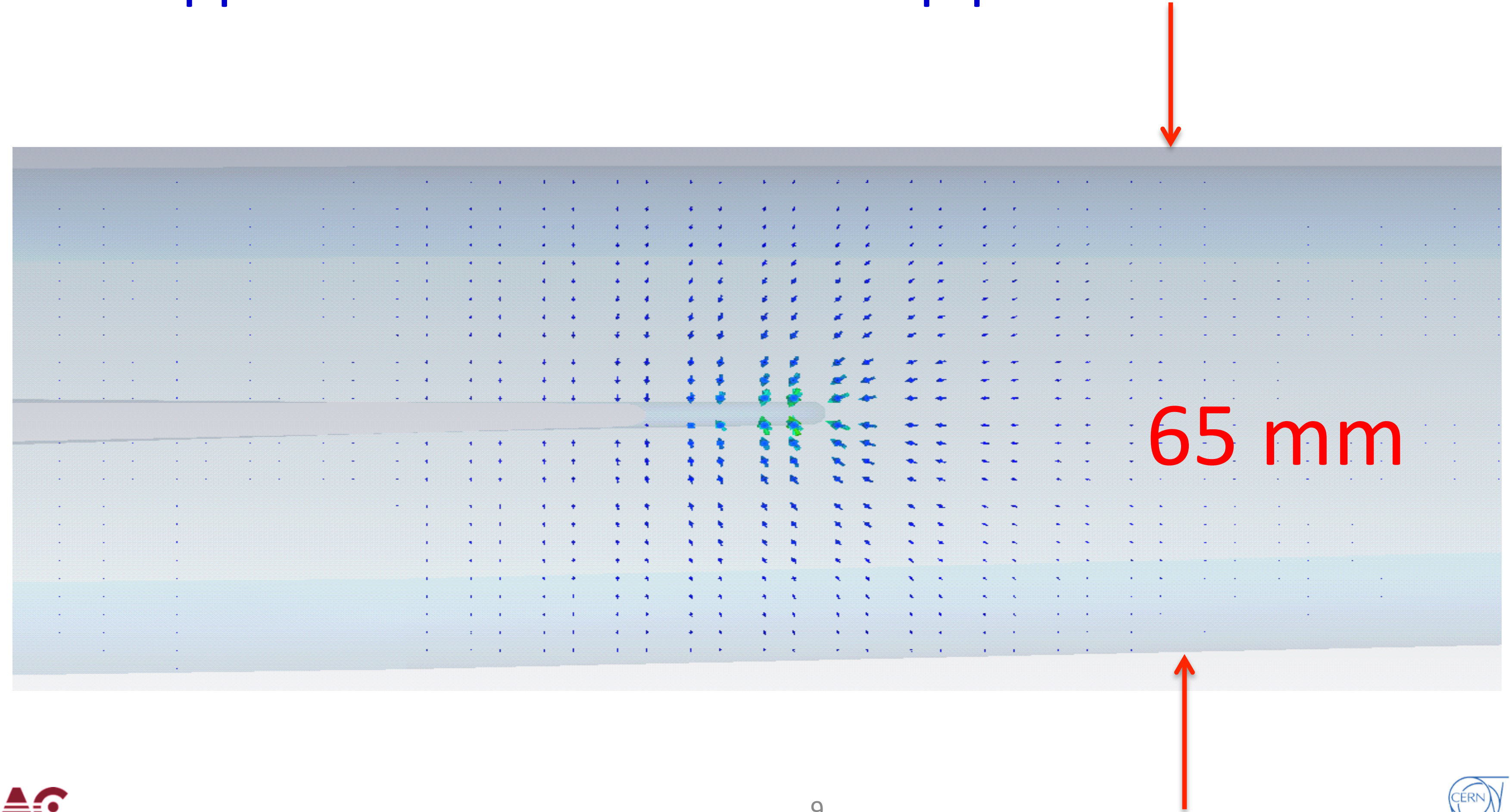
propagating longitudinal modes

propagating transverse modes can be captured by the HOM absorbers

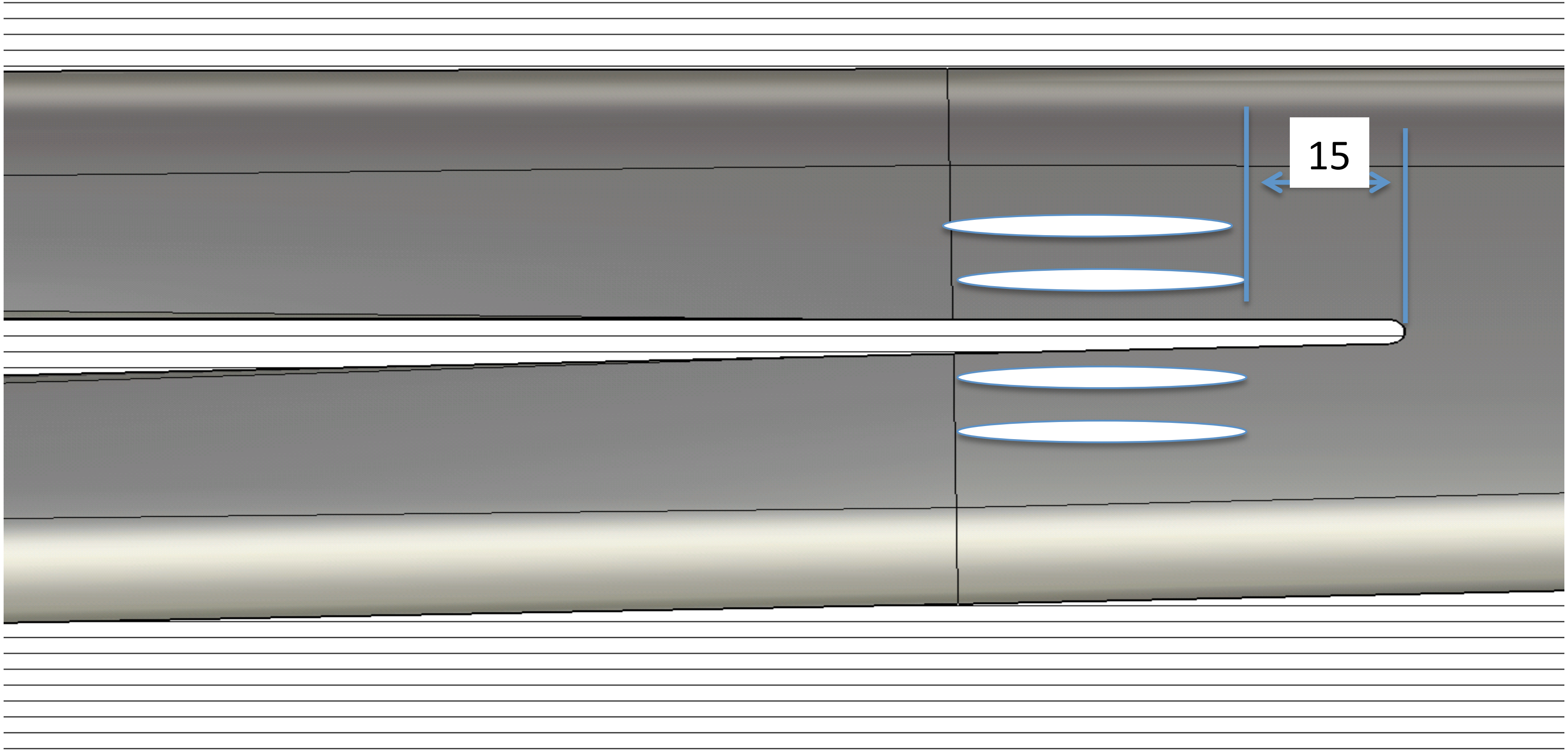
$$P_{prop} = I^2 \left(k - k_{HOM}\right) \times \tau_b$$

$$P_{HOM} = 2 I^2 k_{HOM} \tau_{l,HOM}$$

A trapped mode near the beam pipe connections.



Slots to take out the trapped mode



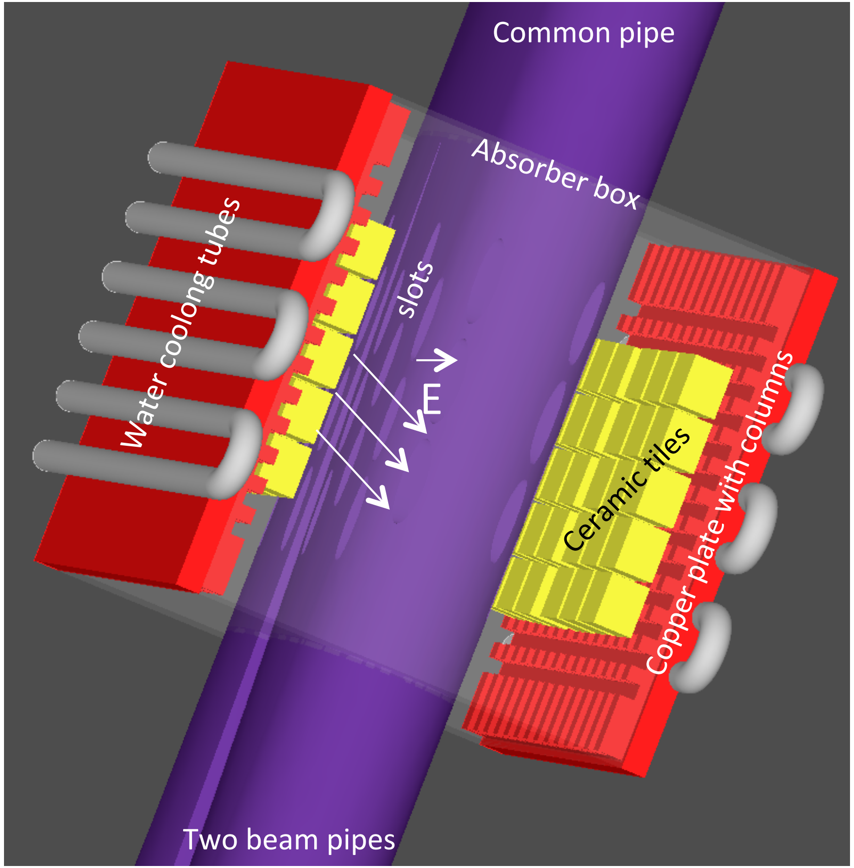
Primary concept of the HOM absorber

The absorber vacuum box is situated near (around) beam pipe connection. Inside the box we have ceramic absorbing tiles and copper plates (walls). The beam pipe in this place have longitudinal slots, which connect the beam pipe and the absorber box. Outside the box we have stainless steel water-cooling tubes, braised to the copper plates.

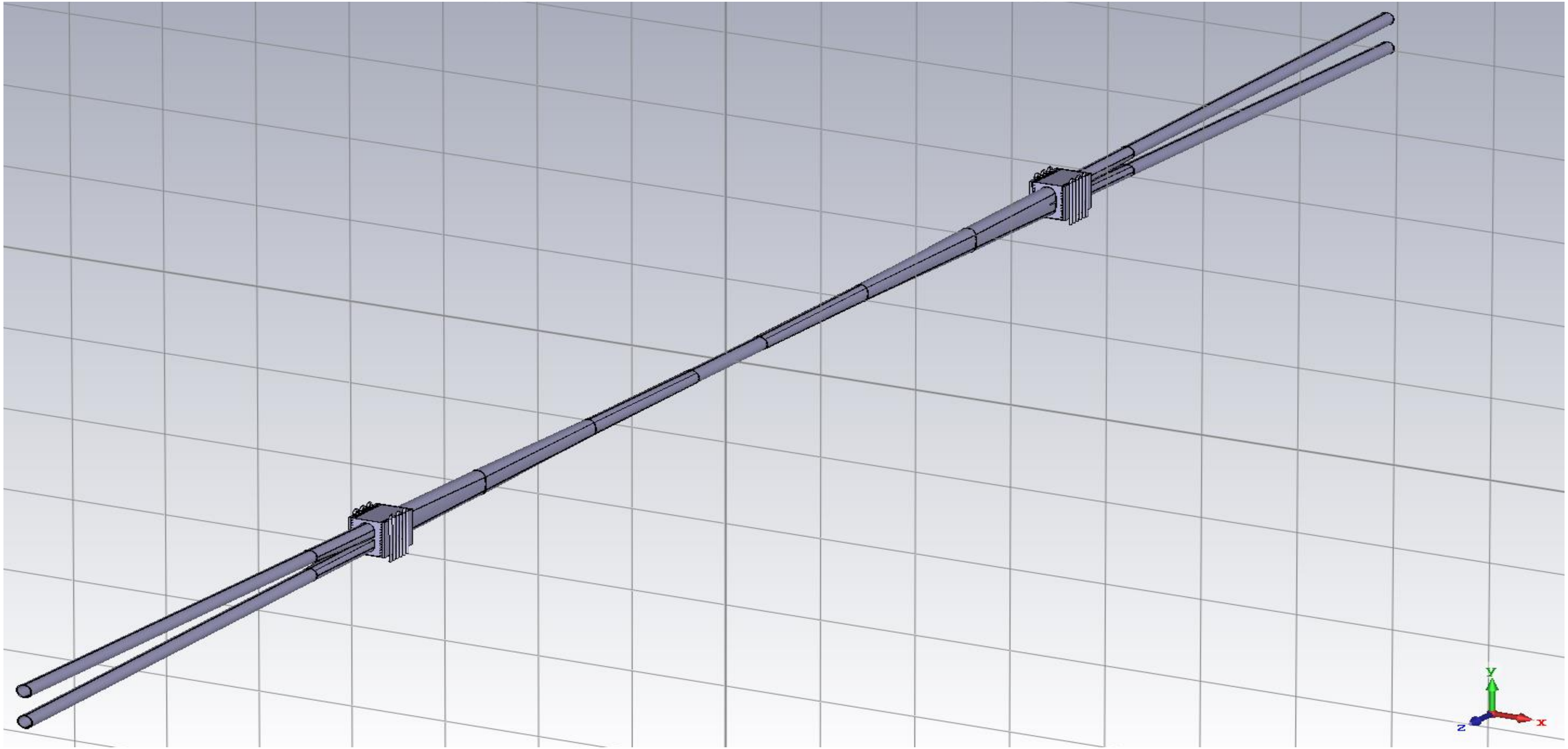
HOM fields, which are generating by the beam in the IR have a transverse electrical component and can pass through the longitudinal slots in the beam pipe.

Inside the absorber box these fields are absorbed by ceramic tiles, which have high value of the loss tangent.

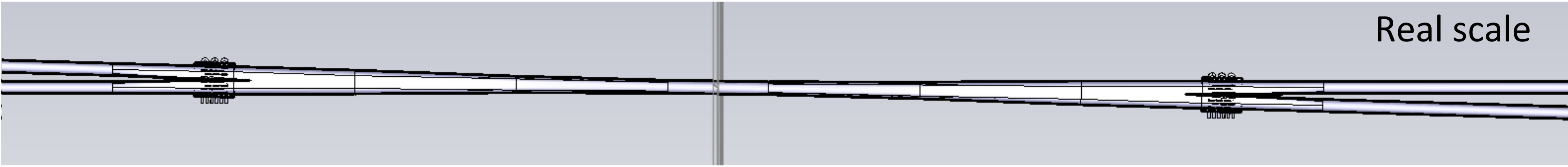
Ceramic tiles are braised to copper plates with columns. The heat from ceramic tiles is transported through the copper plates to water cooling tubes.

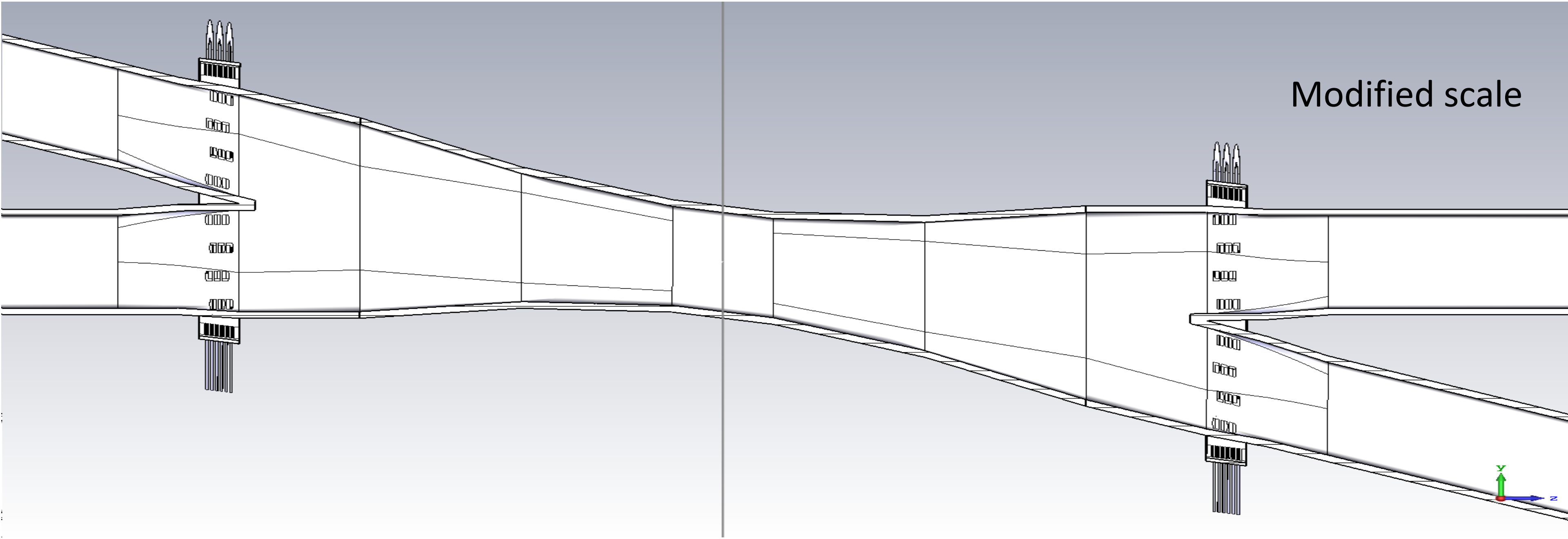


FCC ee IR beam pipe with water-cooled HOM absorbers

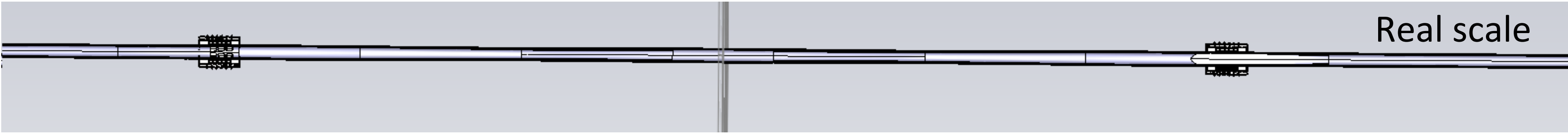


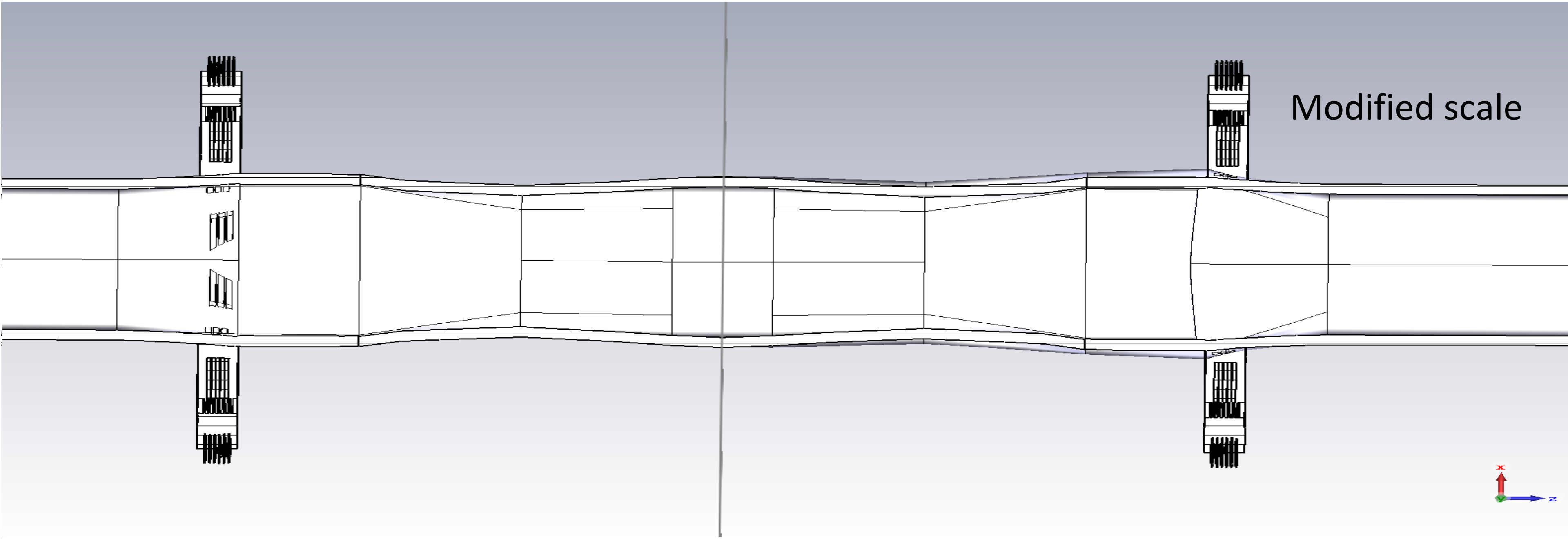
X-projection



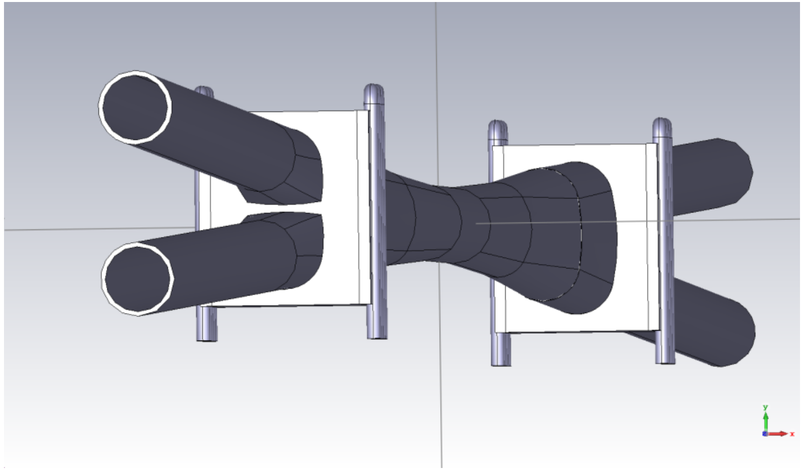


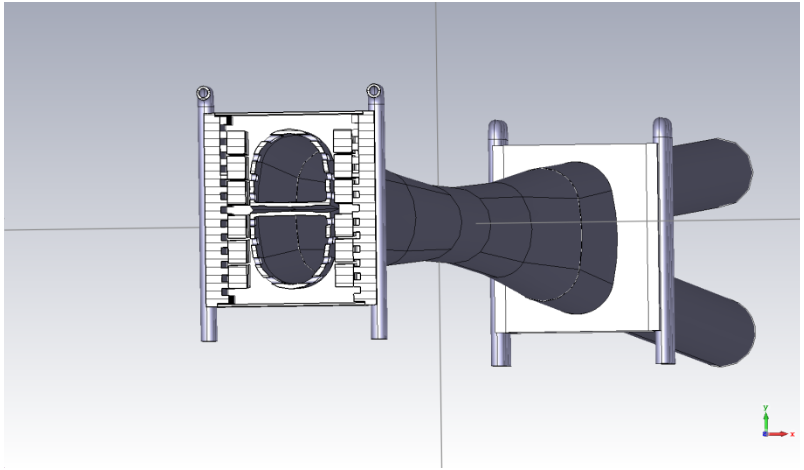
Y-projection

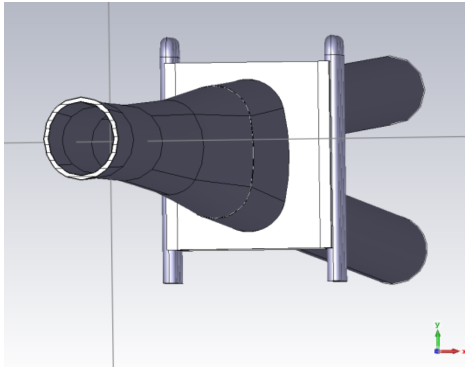


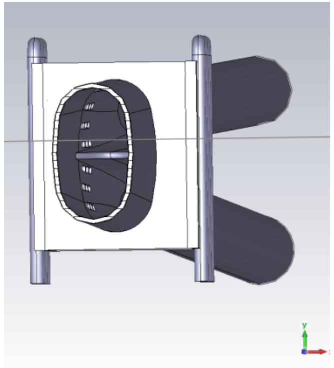


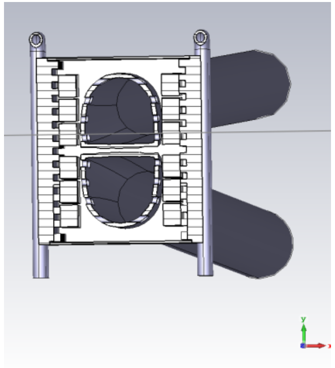
Z-projections





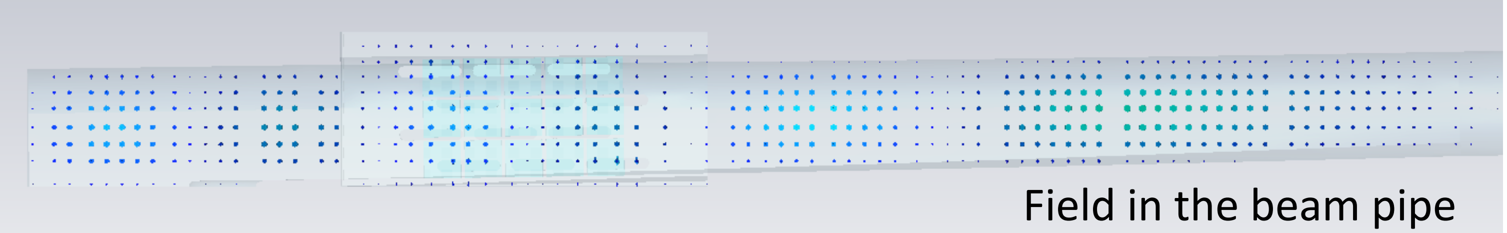




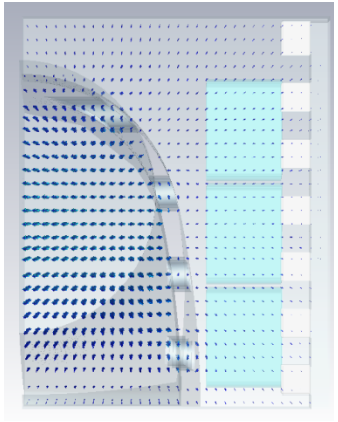


To show the how HOM absorber works we simulate two cases when ceramic tiles do not absorb HOM power (loss tangent is zero) and absorb the power.

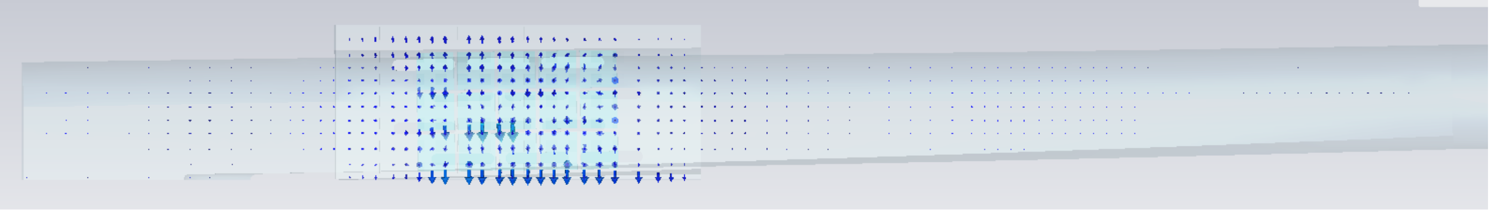
HOM mode in the IR region when ceramic tiles have vacuum parameters : ε=1, δ=0

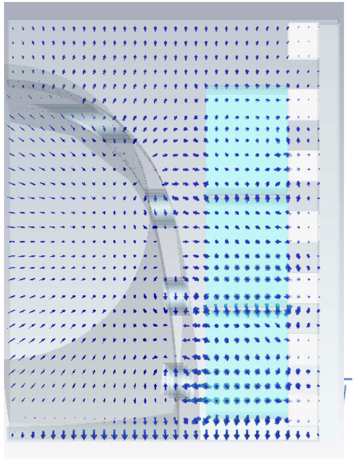


Field in the beam pipe



HOM mode in the IR region when ceramic tiles have real parameters : ε=22, δ=0.1





The field concentrated in the absorber region and in the ceramic tiles

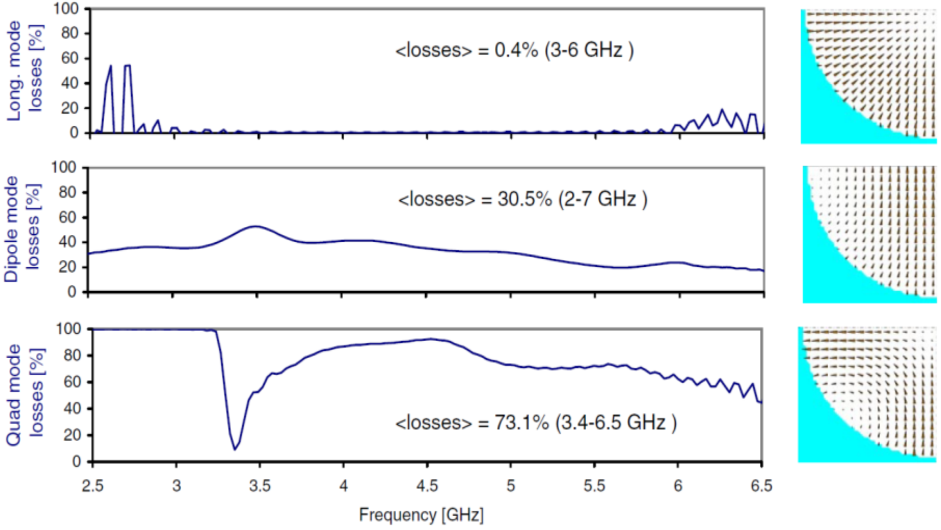
“Good” absorber for trapped and propagating modes

Minimum reflection at the entrance of the region for all modes

Minimum absorption for a monopole mode (beam field)

Maximum absorption for dipole modes

Maximum absorption for quadruple modes



Estimates for HOM and propagating power.

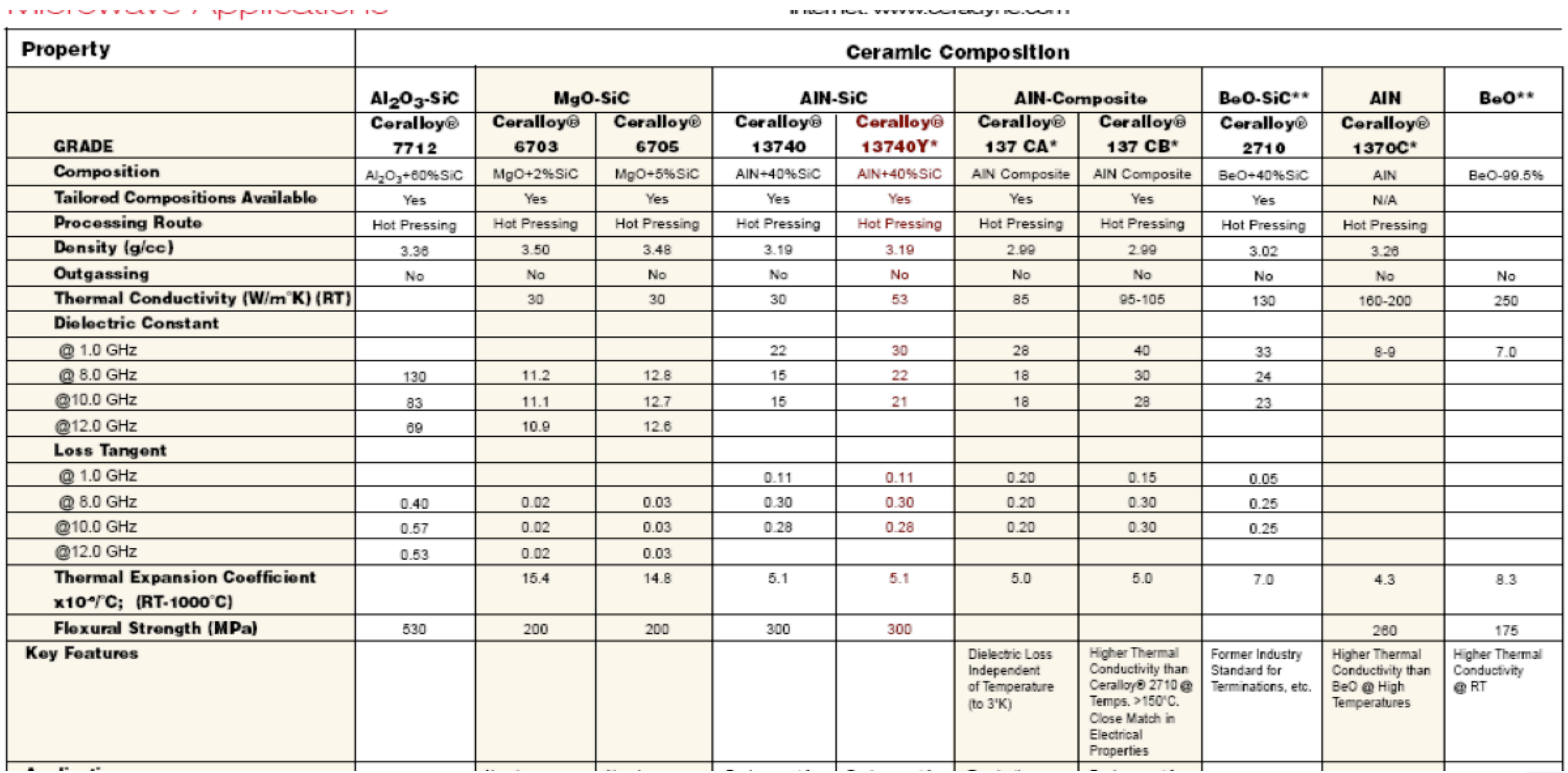
model	trapped mode	close harmonics	mode loss	tau	trapped power	loss factor	of propagating	fields	propagating	power
	frequency	N (frequency)	factor	Ql=100	for I= 1.45 A	bunch 10 mm	bunch 5 mm	bunch 2.5 mm	bunch 5mm	bunch 2.5 mm
	[GHz]		[V/pQ]	[nsec]	[kW]	[V/pC]	[V/pC]	[V/pC]	[kW]	[kW]
III	3.459	8(3.2GHz) 9(3.6GHz)	0.075	9.202	2.912	0.026	0.086	0.400	0.452	2.103

$$P_{HOM} = 2I^2 k_{HOM} \tau_{l,HOM}$$

$$P_{prop} = I^2 \left(k - k_{HOM}\right) \times \tau_b$$

Each beam of 1.45 A will produce electromagnetic power of approximately 5 KW from both connections. This power will be mainly absorbed in the two sets of HOM absorbers.

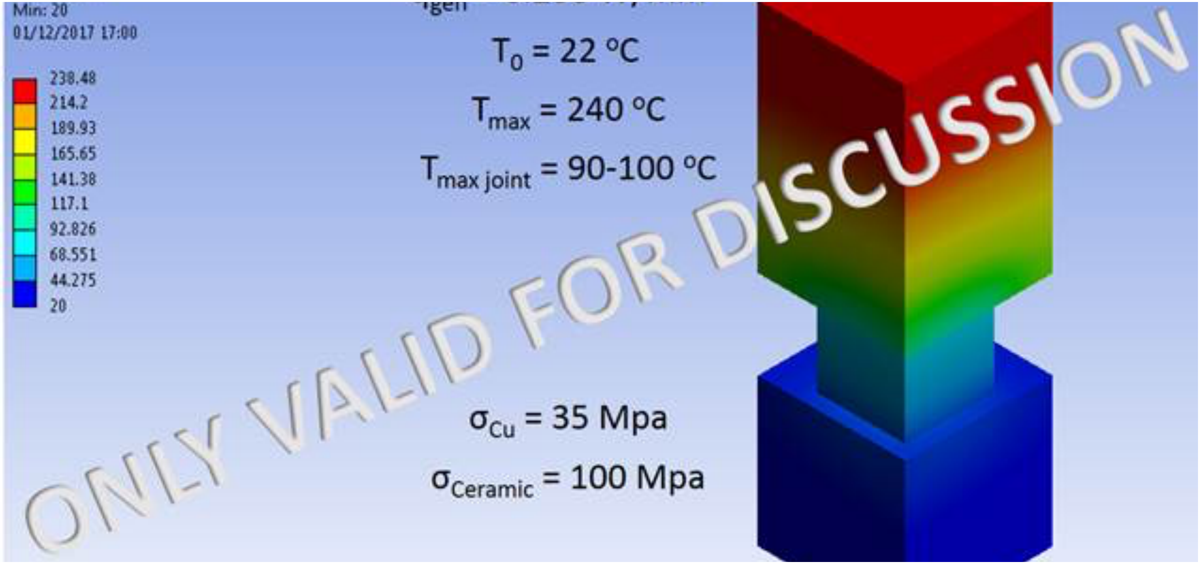
RF and mechanical parameters of the absorbing tiles.



Property	**Ceramic Composition**									
	Al_2O_3-SiC	**MgO-SiC**		**AlN-SiC**		**AlN-Composite**		**BeO-SiC****	**AlN**	**BeO****
GRADE	**Ceralloy® 7712**	**Ceralloy® 6703**	**Ceralloy® 6705**	**Ceralloy® 13740**	**Ceralloy® 13740Y***	**Ceralloy® 137 CA***	**Ceralloy® 137 CB***	**Ceralloy® 2710**	**Ceralloy® 1370C***	
Composition	Al_2O_3+60%SiC	MgO+2%SiC	MgO+5%SiC	AlN+40%SiC	AlN+40%SiC	AlN Composite	AlN Composite	BeO+40%SiC	AlN	BeO-99.5%
Tailored Compositions Available	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	
Processing Route	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	
Density (g/cc)	3.38	3.50	3.48	3.19	3.19	2.99	2.99	3.02	3.26	
Outgassing	No	No	No	No	No	No	No	No	No	No
Thermal Conductivity (W/m°K) (RT)		30	30	30	53	85	95-105	130	160-200	250
Dielectric Constant										
@ 1.0 GHz				22	30	28	40	33	8-9	7.0
@ 8.0 GHz	130	11.2	12.8	15	22	18	30	24		
@10.0 GHz	83	11.1	12.7	15	21	18	28	23		
@12.0 GHz	69	10.9	12.6							
Loss Tangent										
@ 1.0 GHz				0.11	0.11	0.20	0.15	0.05		
@ 8.0 GHz	0.40	0.02	0.03	0.30	0.30	0.20	0.30	0.25		
@10.0 GHz	0.57	0.02	0.03	0.28	0.28	0.20	0.30	0.25		
@12.0 GHz	0.53	0.02	0.03							
Thermal Expansion Coefficient $x10^{-6}$/°C; (RT-1000°C)		15.4	14.8	5.1	5.1	5.0	5.0	7.0	4.3	8.3
Flexural Strength (MPa)	530	200	200	300	300				280	175
Key Features						Dielectric Loss Independent of Temperature (to 3°K)	Higher Thermal Conductivity than Ceralloy® 2710 @ Temps. >150°C. Close Match in Electrical Properties	Former Industry Standard for Terminations, etc.	Higher Thermal Conductivity than BeO @ High Temperatures	Higher Thermal Conductivity @ RT

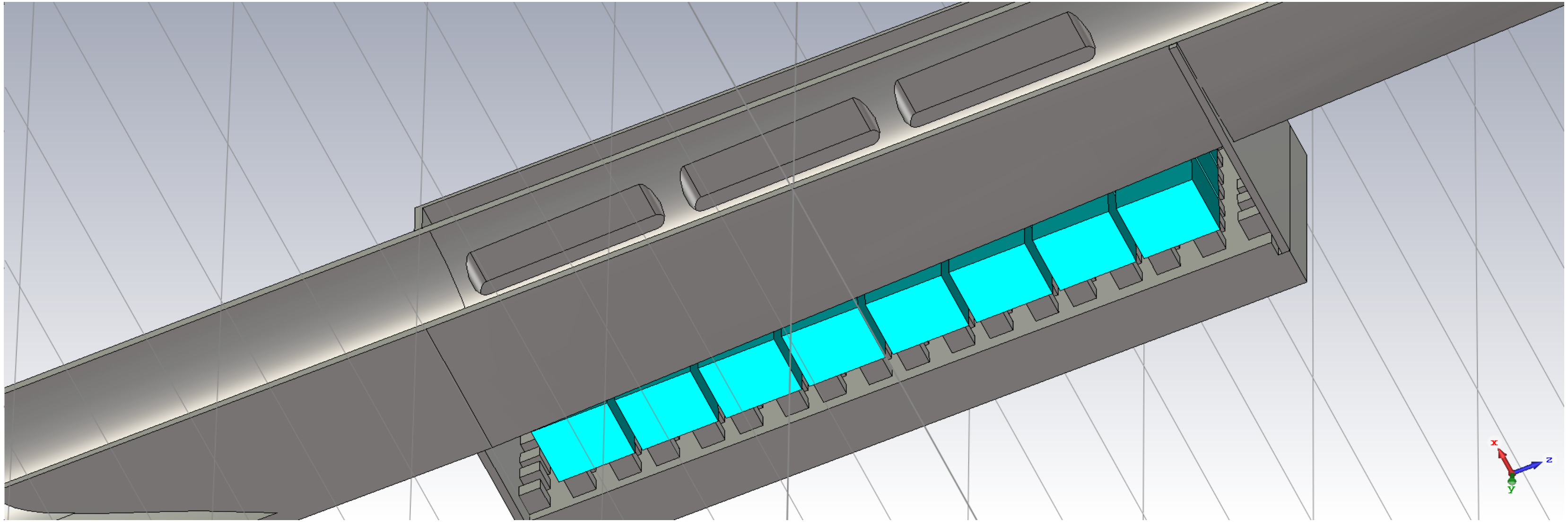
Temperature gradient in the tiles

- Simple formula showed maximum temperature of 200 C at 5 kW HOM power in one absorber
- Miguel made a more accurate estimate using ANSIS



More tiles in the absorber

- We increase number of tiles from 2x15 to 2x24 in one absorber to decrease the maximum temperature up to 120 C.



Next steps

- Optimization of the HOM absorber
  - Longitudinal slots
  - Number of tiles
  - Temperature raise in the absorber
- It may take several iterations to optimize the parameters of the absorber: CAD file -> calculations -> new CAD file => …
- Finally prepare a CAD file of the the more realistic IR geometry including BPS, bellows, flanges for the complete wake field calculations.