HOMs and heating with smaller central IP beam pipe

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Outline

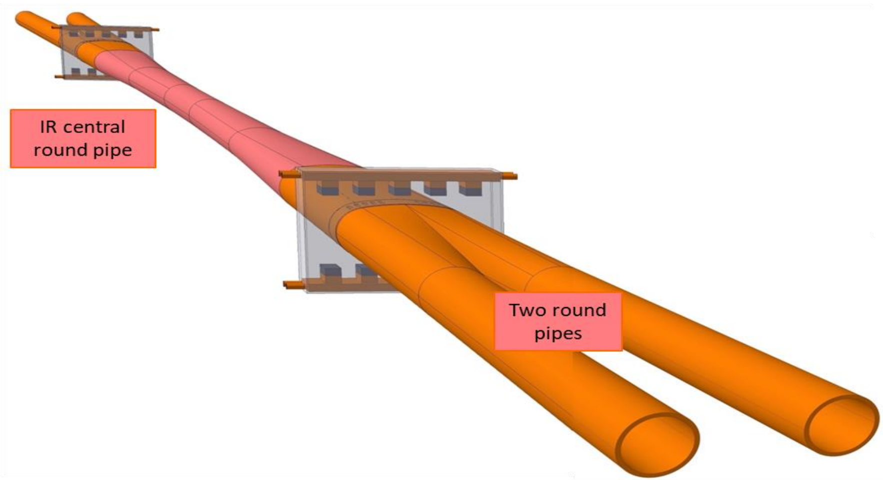
I. The design and RF properties of the FCC ee IR beam pipe.
II. Improving the trapped mode impedance.
III. Wake fields of the IR beam pipe with smaller central part.
IV. Discussion on the resistive-wall wake field losses in IR.
V. Summary

Electromagnetic fields in IR

- We can consider three types of electromagnetic fields exciting in the IR by colliding beams:
  1. Propagating waves that can leave IR and then be absorbed somewhere in the rings
  2. Electromagnetic fields that can be trapped and absorbed in IR (RF trapped modes). Under resonant conditions, the trapped mode fields can be strongly magnified.
  3. Resistive-wall wake fields that are responsible for unavoidable heating of the metal walls of the beam chamber.

Excitation and absorption of these fields in IR can lead to additional detector background.

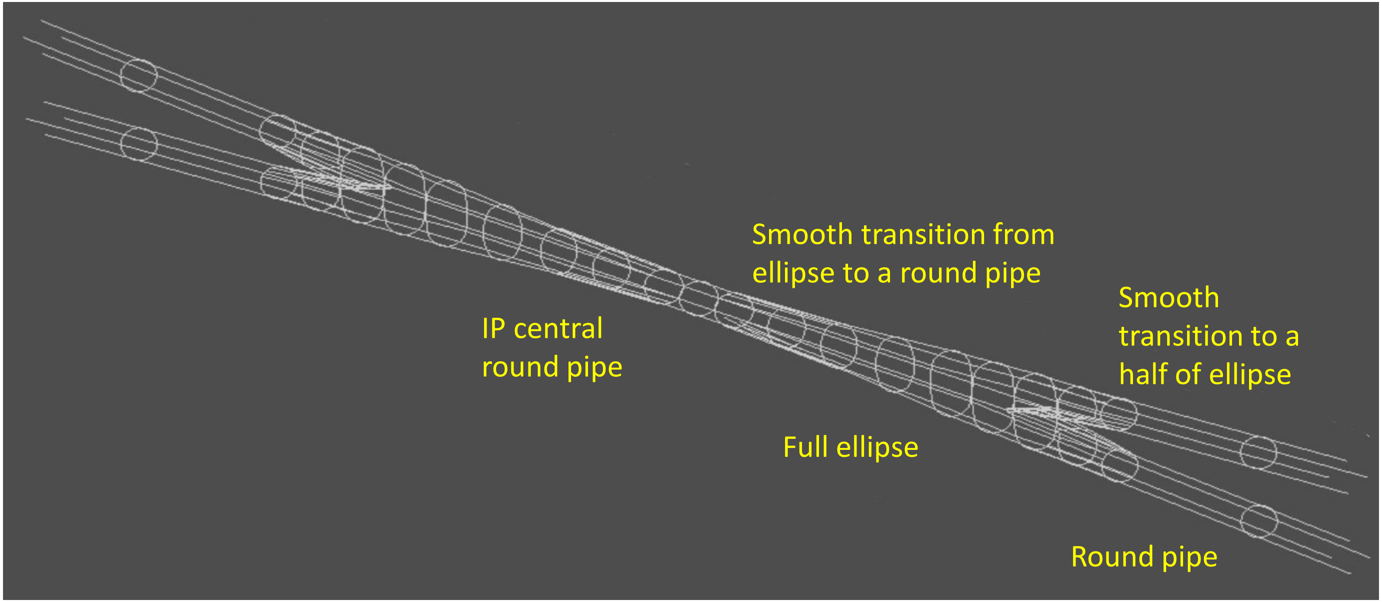
The choice of the IR beam pipe



In the design we tried to achieve the minimum of the electromagnetic interaction of the colliding beams with metal walls of the IR beam pipe.

We developed a special smooth transition from two beam pipes to a common central pipe.

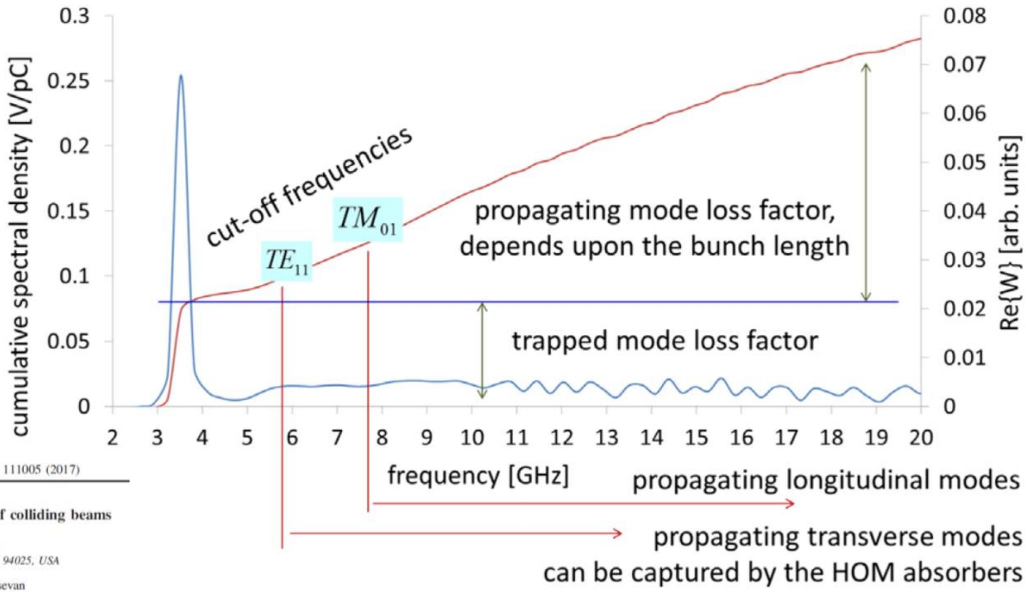
Smooth transitions



Spectrum and cumulative spectral density of the energy losses

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

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



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Unavoidable trapped mode in the interaction region of colliding beams

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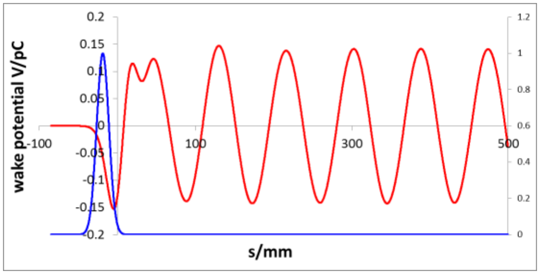
Estimates of heating power in trapped modes and propagating waves.



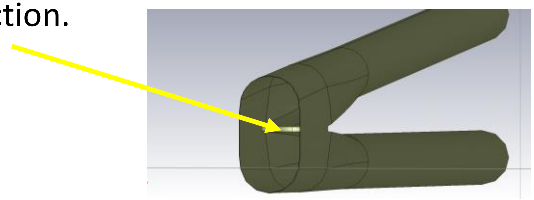
Wake potential of a 10 mm bunch, clearly seen excitation of a trapped mode with an additional higher frequency staff

In the extreme case (shorter bunches) each beam of 1.45 A will produce electromagnetic power of approximately 5 KW from both connections.

To absorb this power we have designed a special water-cooled HOM absorber, which can capture the trapped mode and some part of the propagating waves.

Improvement of the beam chamber

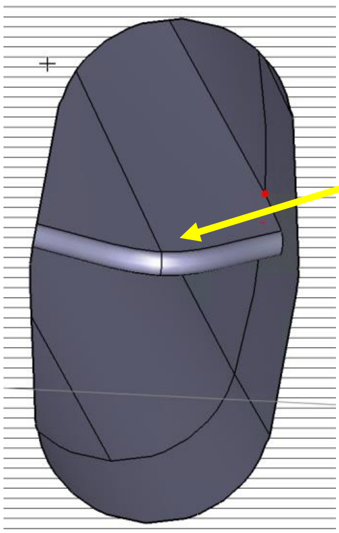
Carefull study of the structure of a trapped mode shows that the excitation power can be decreased by a small variation of the shape in the aria of the beam pipe connection.



The main idea was to push higher the trapped mode frequency ω_0
If we managed to do this then the interaction of the trapped mode with a bunch of finite length σ will be diminished and the excitation power will go down as

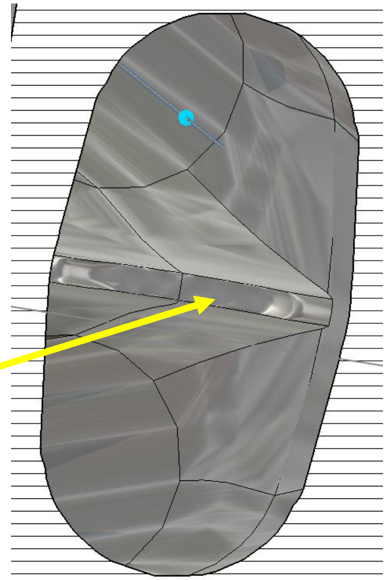
$$\frac{P_{[\Delta\omega]}}{P} \sim \exp\left(-2\frac{\Delta\omega}{\omega_0}\left(\omega_0\frac{\sigma}{c}\right)^2\right)$$

How we changed the shape of intersection

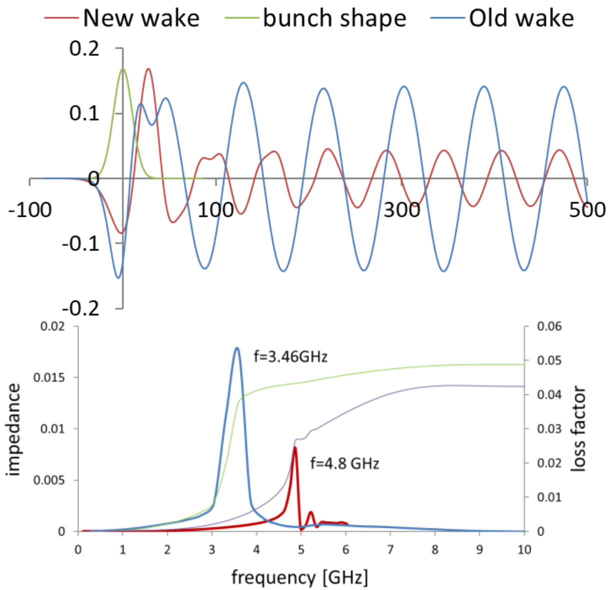


Elliptical shape.
Initial design.

Flattened shape.
Must move
trapped mode
frequency higher



Wake field, impedance and loss factor comparison



The "flattened" shape of intersection has a twice less amplitude of the trapped mode oscillations (red line) in comparison with the "elliptical" shape (blue line)

The frequency of the trapped mode of the modified intersection is 40% higher, and, impedance is two times less and total loss factor is smaller by 20%

Smaller central beam pipe

- As a request for further improvement of the Interaction Region, we analyze the possibility of modifying the IR beam pipe for a smaller diameter of the central beryllium pipe to 20 mm or even 10 mm. This modification gives more freedom for the FCC detector.
- Based on the improvement of the geometrical impedance we can allow the impedance of the smaller central part to be increased to some level.
- However, the heat load can be higher and will require more cooling.

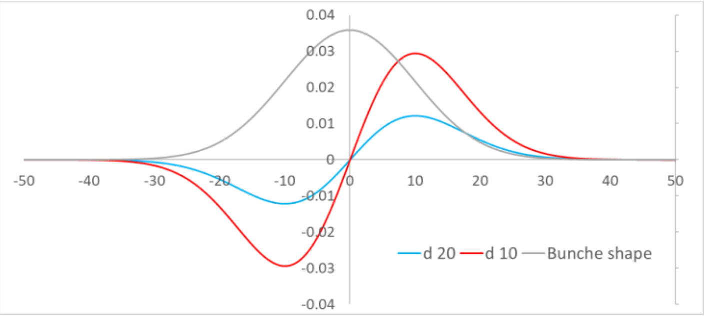
A transition to a smaller central part

Green ø=30 mm Blue ø=20 mm Red ø=10 mm

The additional wake field potential caused by the smaller central beam pipe has an inductive character because of the long transition (for a 10 mm bunch) and brings small change to the loss factor: 0.1 % for a 20 mm pipe

0.25% for a 10 mm bunch

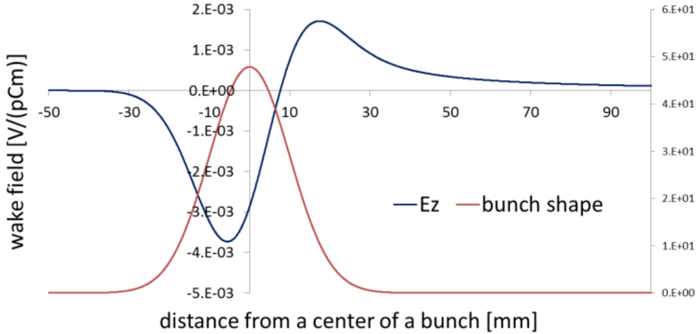
Good news!



IR heat load

Heat load is due to the electromagnetic fields exciting by the beams in the Interaction Region are due to the finite conductivity of the metal walls of the IR beam pipe

10 mm bunch in
Be 30 mm pipe



Electrical conductivity of different materials, which can be used in IR:

Material	Cu	Au	Al	Be	Ni	SS	NEG
conductivity [Ohm/mm]	58000	48800	35000	25000	14600	1400	50 -->1000

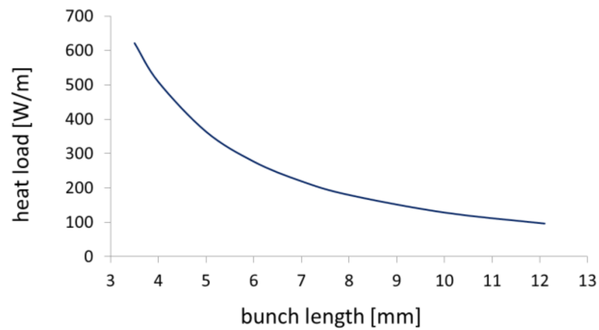
FCC-ee beam parameters

parameter	Z	W	H (ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
horizontal emittance [nm]	0.27	0.28	0.63	1.45
vertical emittance [pm]	1.0	1.0	1.3	2.7
longitudinal damping time [ms]	414	77	23	6.6
SR energy loss / turn [GeV]	0.036	0.34	1.72	9.21
total RF voltage [GV]	0.10	0.44	2.0	10.93
energy acceptance [%]	1.3	1.3	1.5	2.5
energy spread (SR / BS) [%]	0.038 / 0.132	0.066 / 0.153	0.099 / 0.151	0.15 / 0.20
bunch length (SR / BS) [mm]	3.5 / 12.1	3.3 / 7.65	3.15 / 4.9	2.5 / 3.3
bunch intensity [10^{11}]	1.7	1.5	1.5	2.8
no. of bunches /beam	16640	2000	393	39
beam current [mA]	1390	147	29	5.4
Averaged bunch spacing [ns]	19.5			
luminosity [10^{34} cm^{-2}s^{-1}]	**>200**	**>30**	**>7**	**>1.3**
luminosity lifetime [min]	70	50	42	44

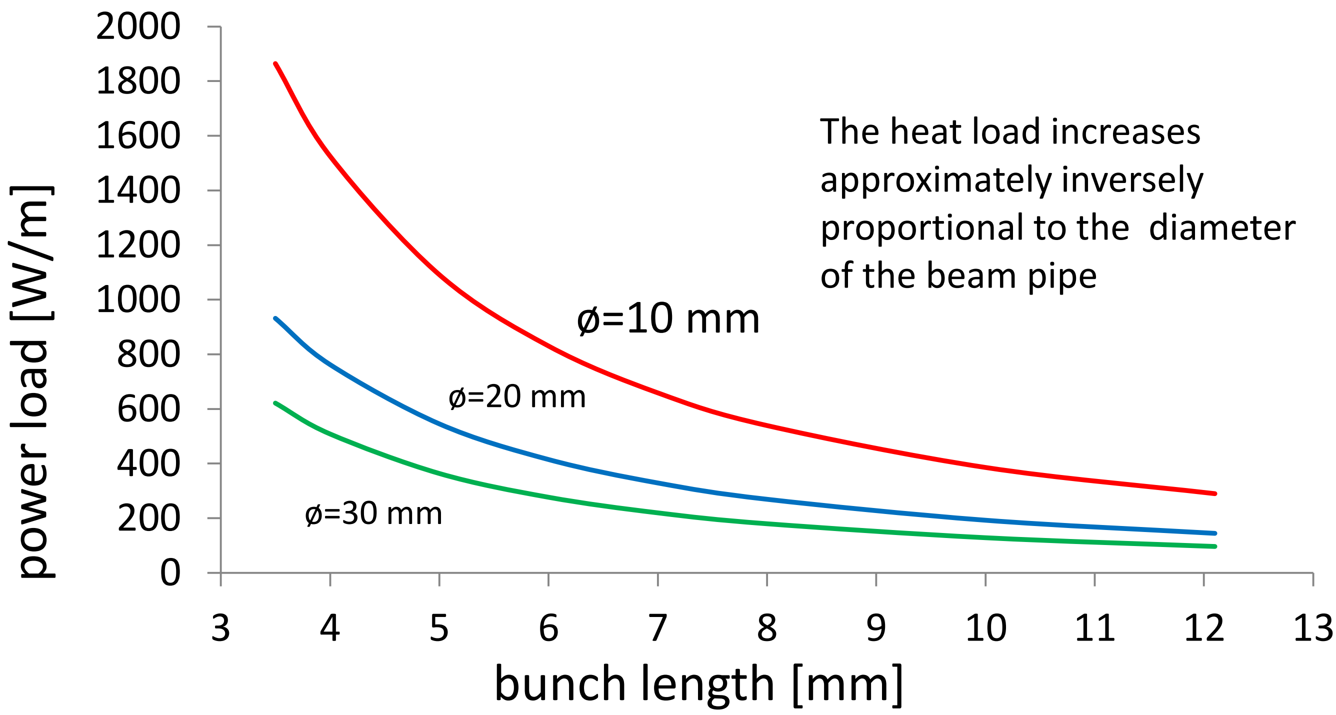
Heat load for 30 mm beam pipe

bunch length [mm]	HEAT LOAD Two beams [W/m]				current [A]	Bunch spacing [ns]	
					2 x 1.39	19.50	
12.10	63.45	69.18	81.68	96.57	125.23	349.64	1473.91
Material	Cu	Au	Al	Be	Ni	SS	NEG

- Beryllium pipe takes 100 W/m for a 12 mm bunch but strongly increasing with shortening the bunch length.
- A gold coating can decrease the heat load by 30%



Heat load vs bunch length for central beam pipe of 30 mm, 20 mm and 10 mm



The heat load increases approximately inversely proportional to the diameter of the beam pipe

Comparison of heat loads and temperatures

Beam pipe diameter [mm]	Heat load [W/m]	Max Temp. [K] without cooling
30	97	88
20	145	198
10	290	792

Max temperature was calculated by formula

$$\Delta T_{[K^{\circ}]} = \frac{P_{[W]} * L_{[m]}}{k_{[W/(K^{\circ} m)]} * 2\pi R_{[m]} \Delta r_{[m]}}$$

For the pipe length L of 125 mm (half of the Be pipe) with thickness Δr of 1 mm and Be thermo-conductivity of 182 W/m/K

Summary

- Examining the IR beam pipe carefully, we found a way to reduce the impedance of the trapped mode. This progress shows how important each element of the beam pipe surface is.
- However, HOM absorber is still needed.
- Analyses of the smaller central beam pipe shows that geometrical wake field do not change much.
- However, the heat load coming from the resistive – wall wake fields becomes more important.
- The central beryllium tube requires increasing cooling with decreasing the beam pipe diameter.
- First estimates show that this problem can be technically solved.

Acknowledgement

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We are also happy to thank Oide Katsunobu, Michael Sullivan, Manuela Boscolo and MDI team for many useful discussions and help.

Thank you!

Back-up slides

$$P_{[W]} = 146.2 * Q_{[g/m]} * \Delta T_{[F^{\circ}]}$$

Q=0.01 g/m for dt=68F=34C

The concept of the HOM absorber

Based on the property of the trapped mode we have designed a special HOM absorber.

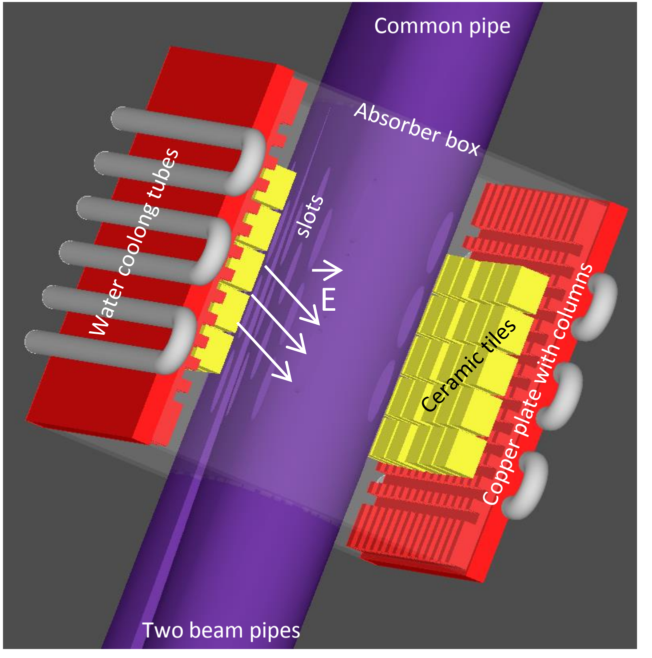
The absorber vacuum box is placed around the beam pipe connection. Inside the box we have ceramic absorbing tiles and copper corrugated plates .

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.

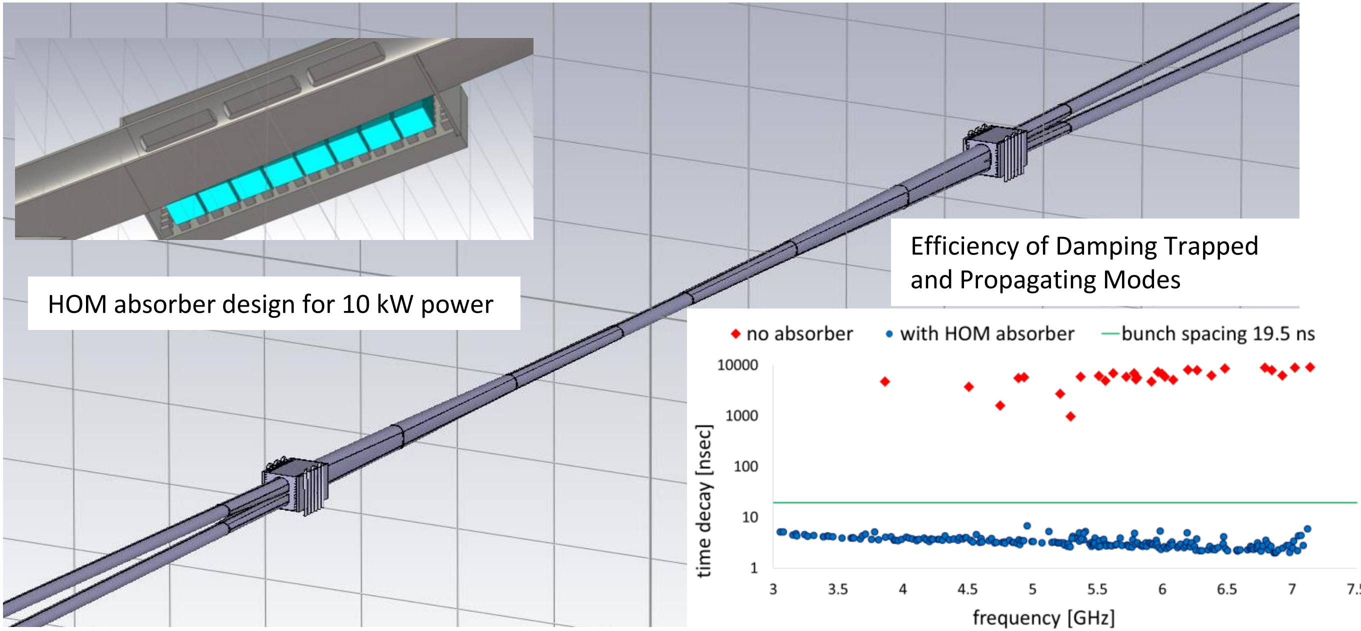
The HOM fields, which are generating by the beam in the Interaction Region pass through the longitudinal slots into the absorber box.

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

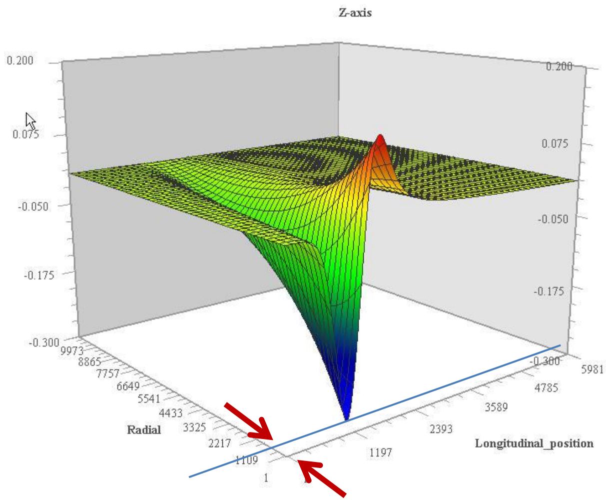
The heat from ceramic tiles is transported through the copper plates to water cooling tubes.



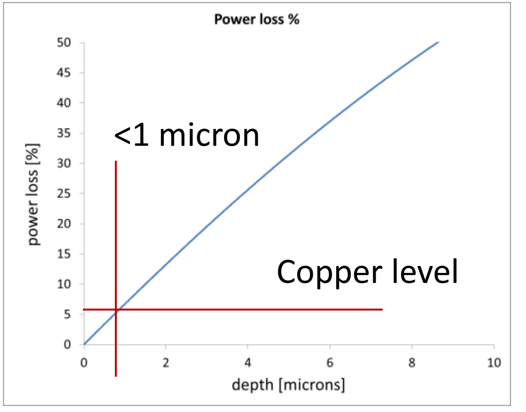
FCC ee IR beam pipe with water-cooled HOM absorbers



10 kW/m energy losses in NEG with a conductivity of 100 Ohm/mm



5 micron



The NEG coating must be less than 1 micron to have the same heat load as copper walls.