Optimization of the FCC-ee IR beam pipe elements for minimum of the wake field loss responsible for the heat load

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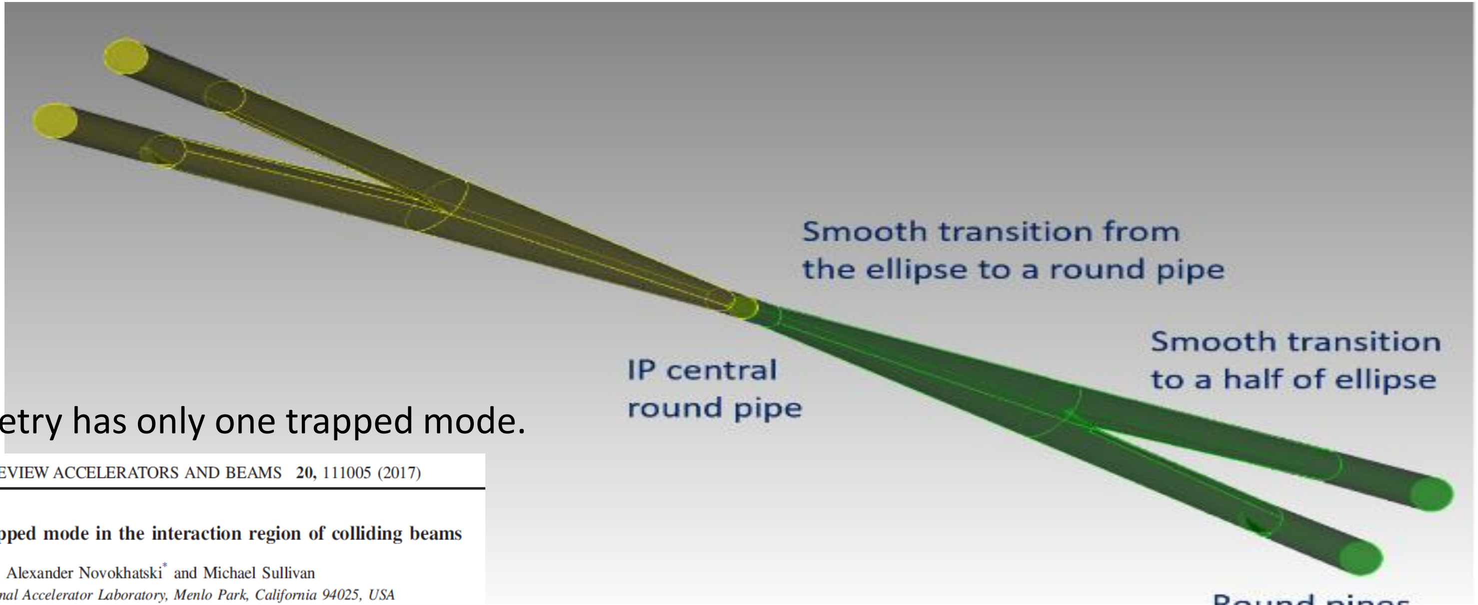
Outline

- The design of the FCC Interaction Region vacuum chamber is based on the optimization study of the wake field losses of colliding beams. Naturally these losses are responsible for the heat load of the chamber. Minimization of the heat load is very important for the design of the cooling system.
- On this way we developed a special beam pipe shape, which have a minimum possible impedance.
- We analyzed how the shape of the synchrotron radiation masks can change the beam energy losses.
- We study how to decrease wake field losses of the beam pipe elements, like the Beam Position Monitors.
- Currently we study how to improve the geometry the IR bellows in order not only to decrease the beam energy losses but also to capture and absorb electromagnetic fields excited in the interaction region.
- Professional CAD files for numerical wake field calculations were done by Francesco Fransesini. Many thanks.

In order to achieve minimum electromagnetic interaction of the colliding beams with a metal wall of the IR vacuum chamber, we have developed special smooth transitions from two beam pipes to a mutual pipe at the Interaction Point. The incoming pipes have a diameter of 30 mm and the IP pipe has a diameter of 20 mm.



This geometry has only one trapped mode.

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Unavoidable trapped mode in the interaction region of colliding beams

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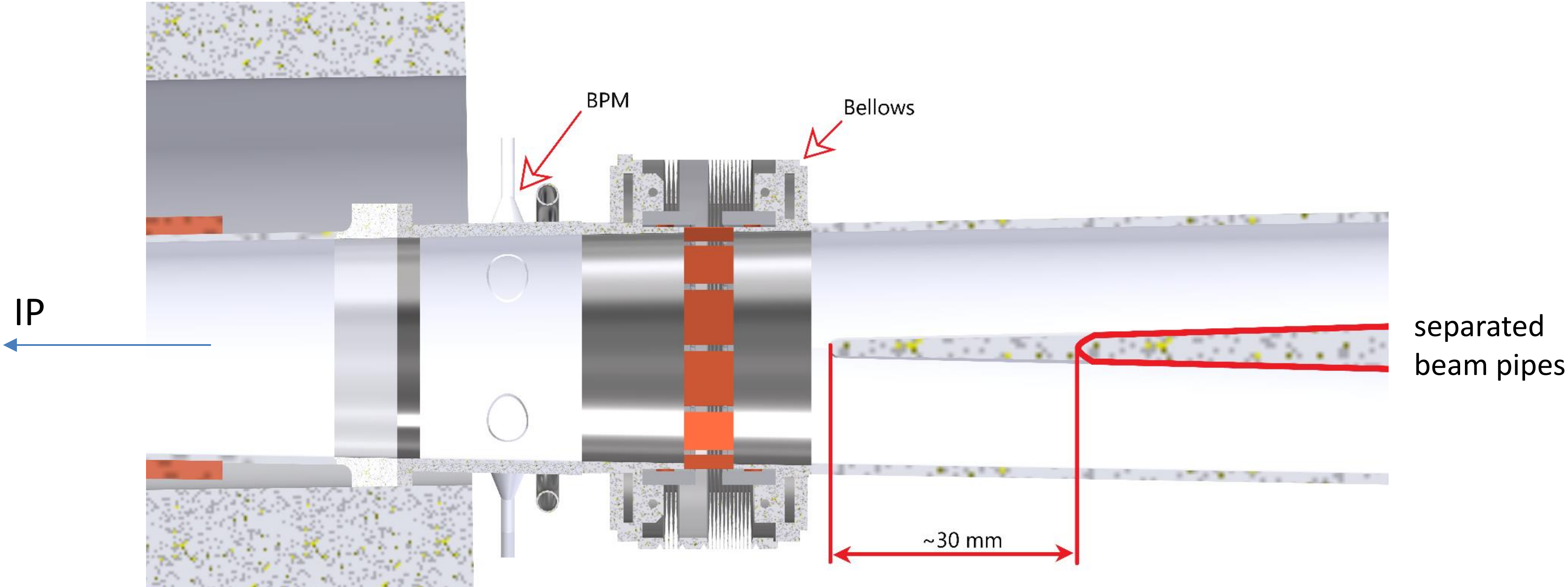
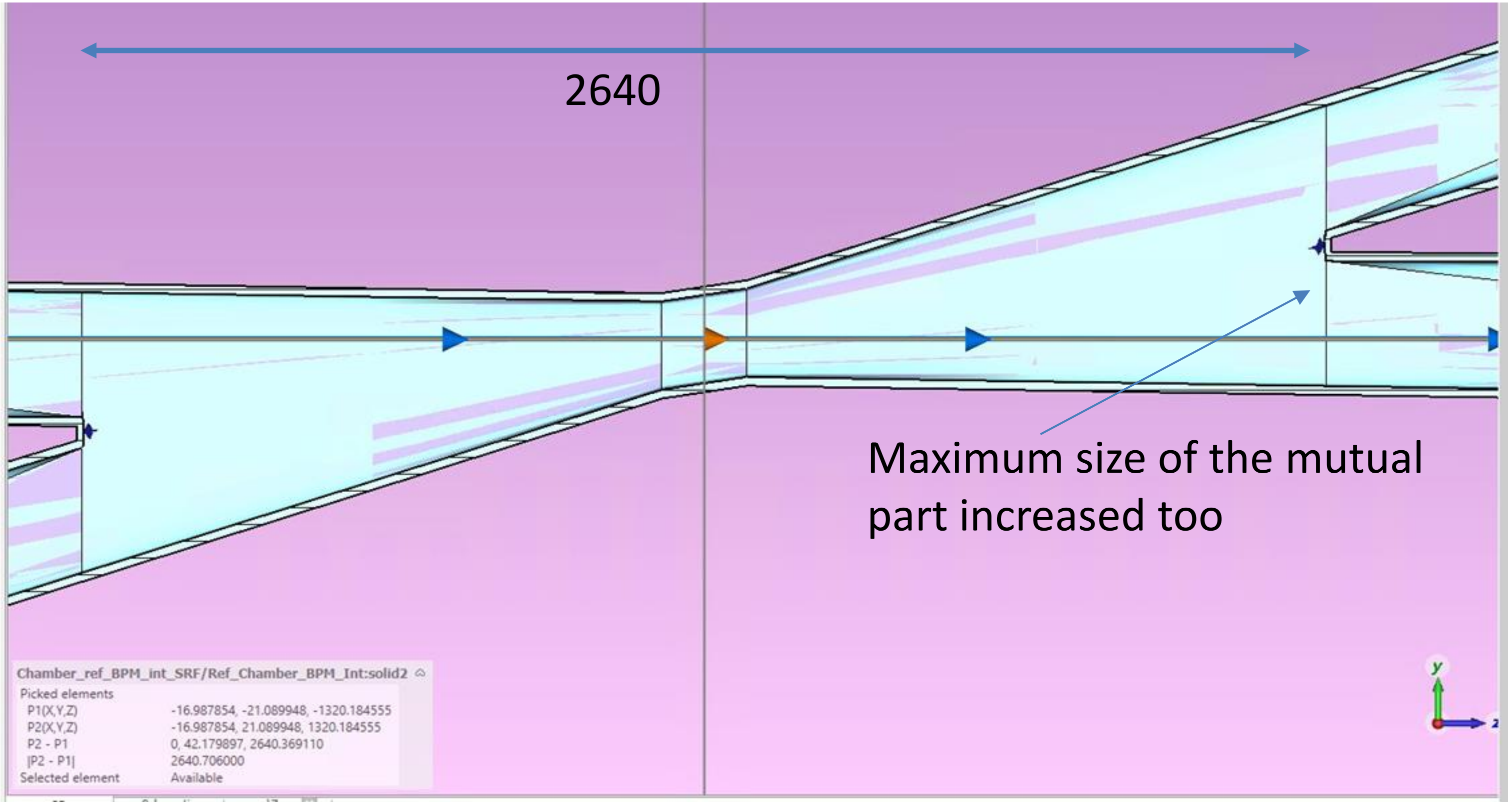
The position of a BPM and a bellows

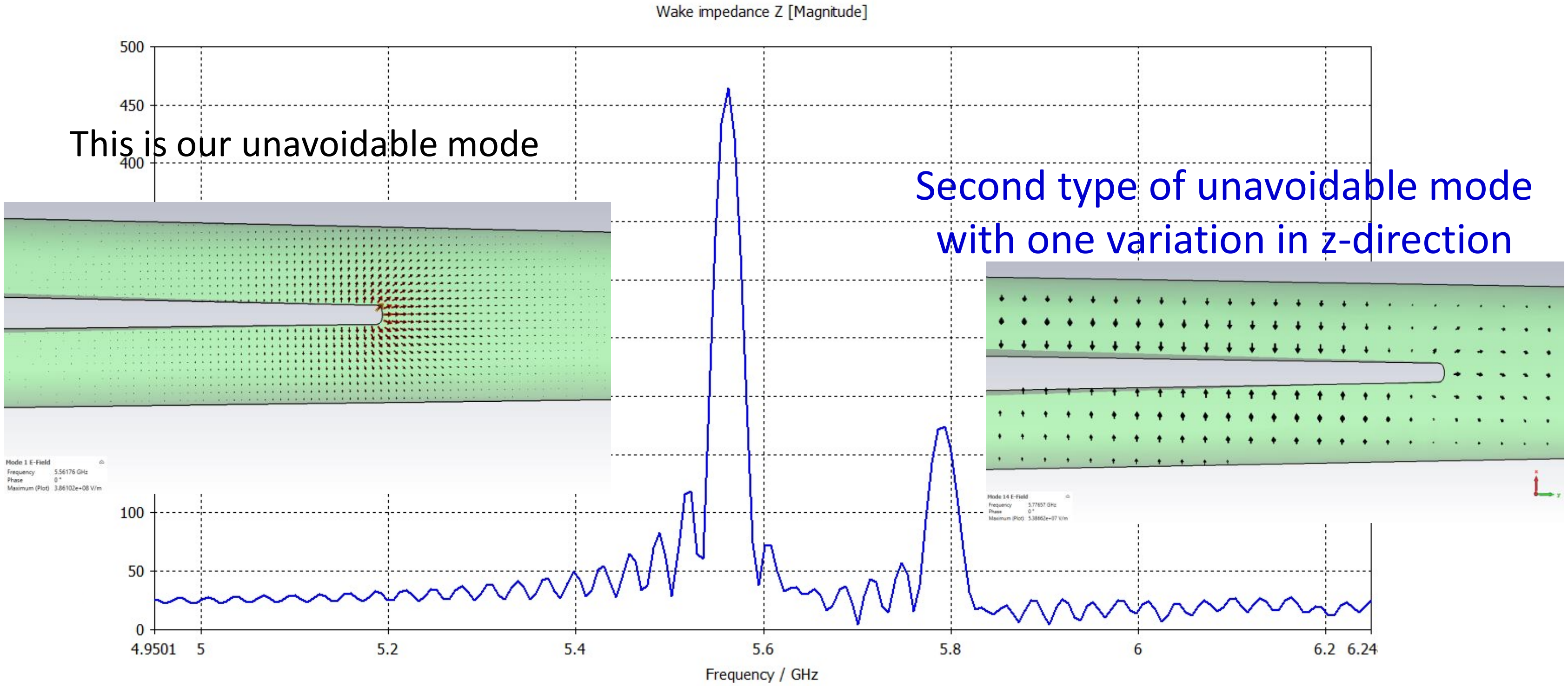


Unfortunately we had to increase the length of the mutual chamber part in order to install these elements

Updated FCC-ee IR vacuum chamber

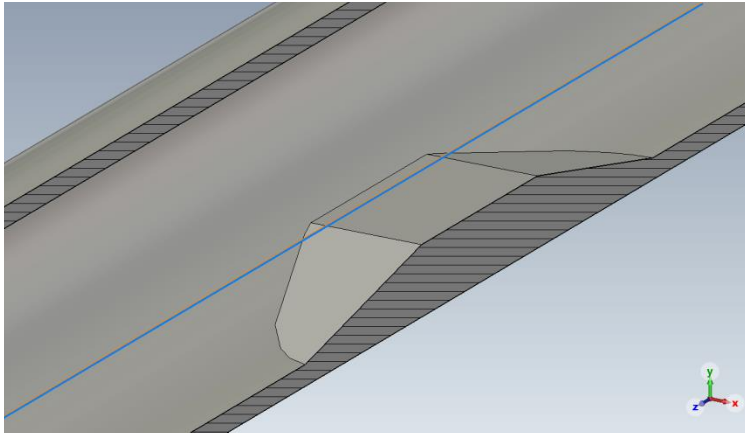
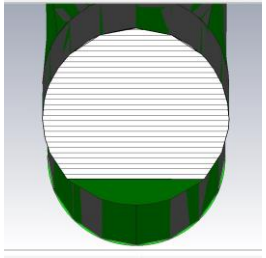


In the new IR chamber we found the second trapped mode

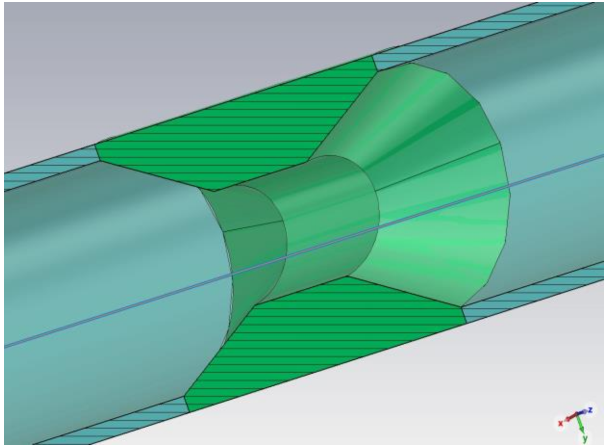
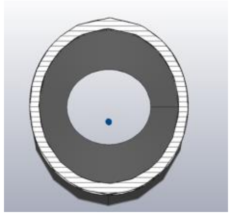


Lengthening the mutual pipe brings more trapped modes

Comparison of synchrotron radiation masks

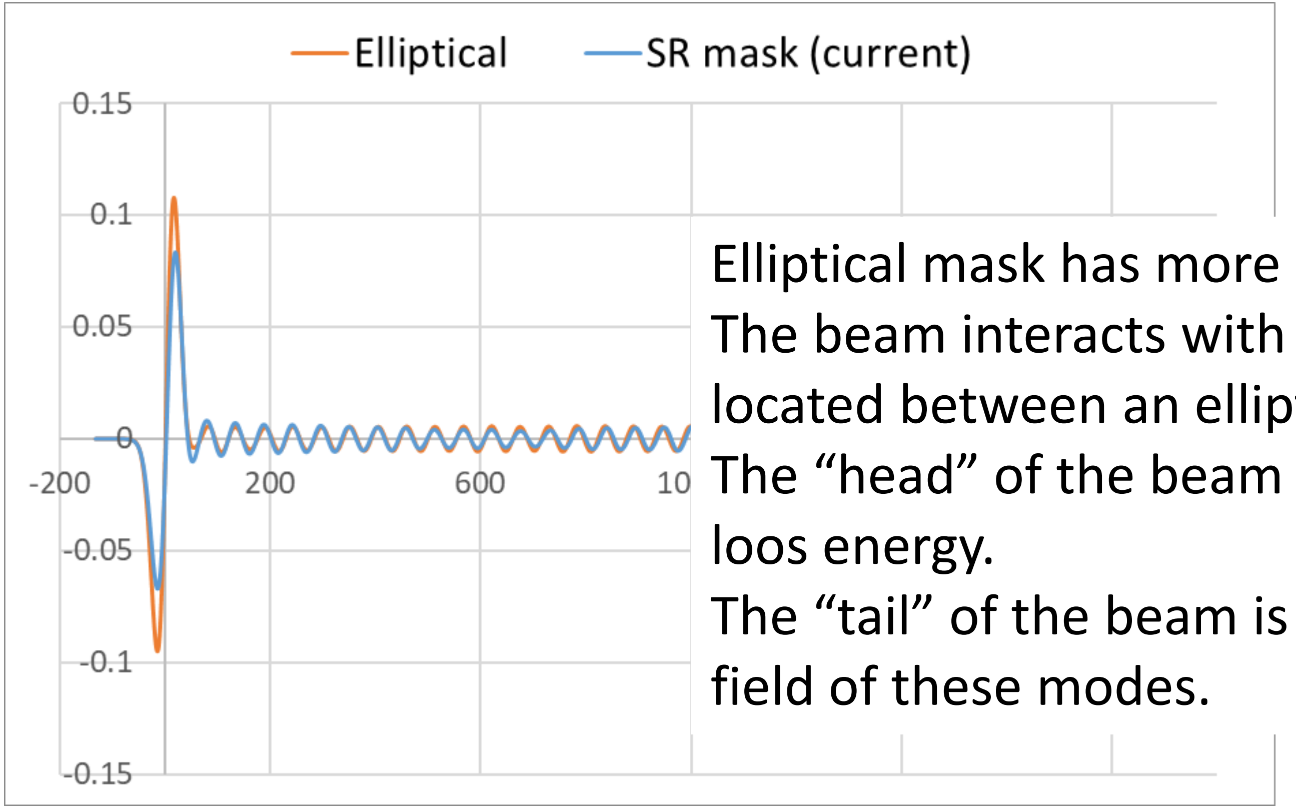



A bump (M. Sullivan)

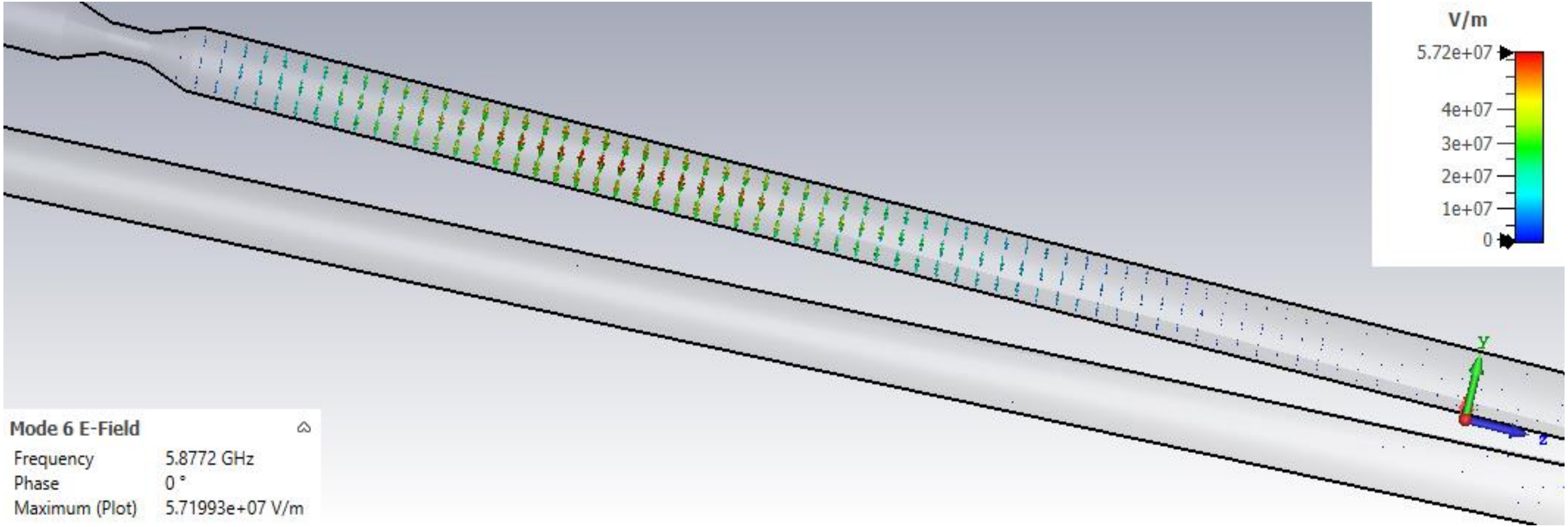
An elliptical shape (K. Andre)

Masks wake potentials comparison



Elliptical mask has more inductive character.
The beam interacts with more trapped modes located between an elliptical mask and IP.
The “head” of the beam excites this modes and loos energy.
The “tail” of the beam is accelerated by the field of these modes.

New mode (due to the elliptical mask) f=5.88 GHz



Do we really need an elliptical mask?

- An elliptical mask produces more trapped modes. Even the interaction with a beam has an inductive character, these modes will interact more when adding other beam pipe elements like bellows and BPMs.
- We believe that upper half part of the elliptical mask does not catch SR but may catch errant beam particles. If we need an elliptical mask only for the time of beam injection, then can we can briefly switch off the detector during beam injection, as we did at PEP-II SLAC B-factory.
- And finally, the mask is situated inside the superconducting cryomodule. The cryomodule can take a limited amount of dipositive power.

Optimization of the BPM geometry

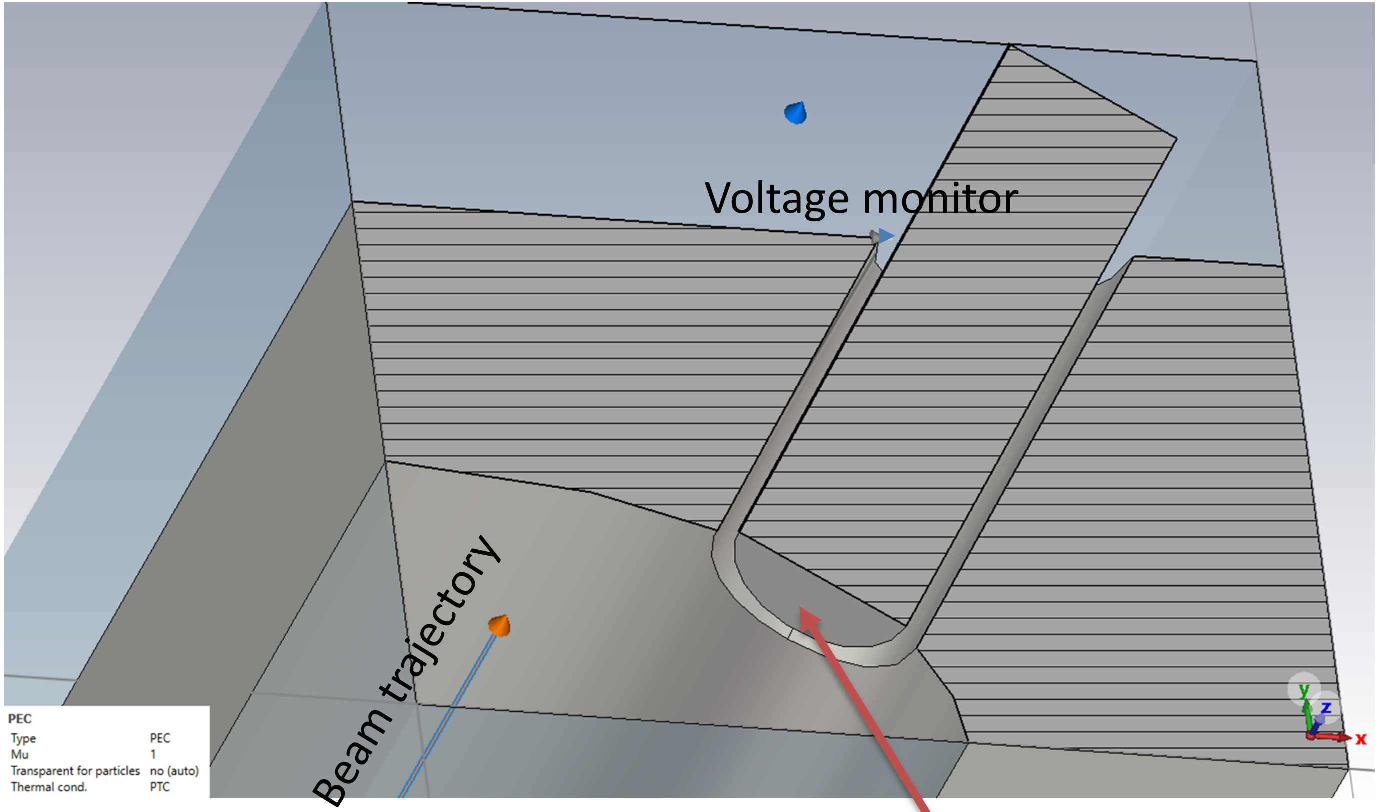
- Based on the Pantaleo Raimondi suggestion we study how the BPM button shape may change the wake field losses. We study the circular and elliptical shape of the button.
- The FCC IR beam pipe, where we plan to install BPMs has an elliptical shape. There is a symmetry in both direction.
- To get a better accuracy in wake field calculation, we use only a quarter of the beam pipe. While using planes of symmetry we need to move the beam trajectory from the BPM center by 5 mm in X and Y direction.
- To avoid to be lost in the complicated transitions of the BMP wire and ceramics we choose a simple geometry, just using the same shape as a button.
- Additionally we made an “antenna” at the end of the BPM wire to decrease the reflected power from the end.
- The gap between a button and the beam pipe body is 1 mm everywhere.

Circular and elliptical shape of a button

- To make comparison of the different button shape we assume that the area of a button must be the same, intuitively thinking that in this case the signal from a button will be the same. Later we check it.
- We choose the area of a button to be 24π mm^2, that means for a circular button the radius will be around 4.9 mm.
- For elliptical shape with *a* and *b* axes we choose

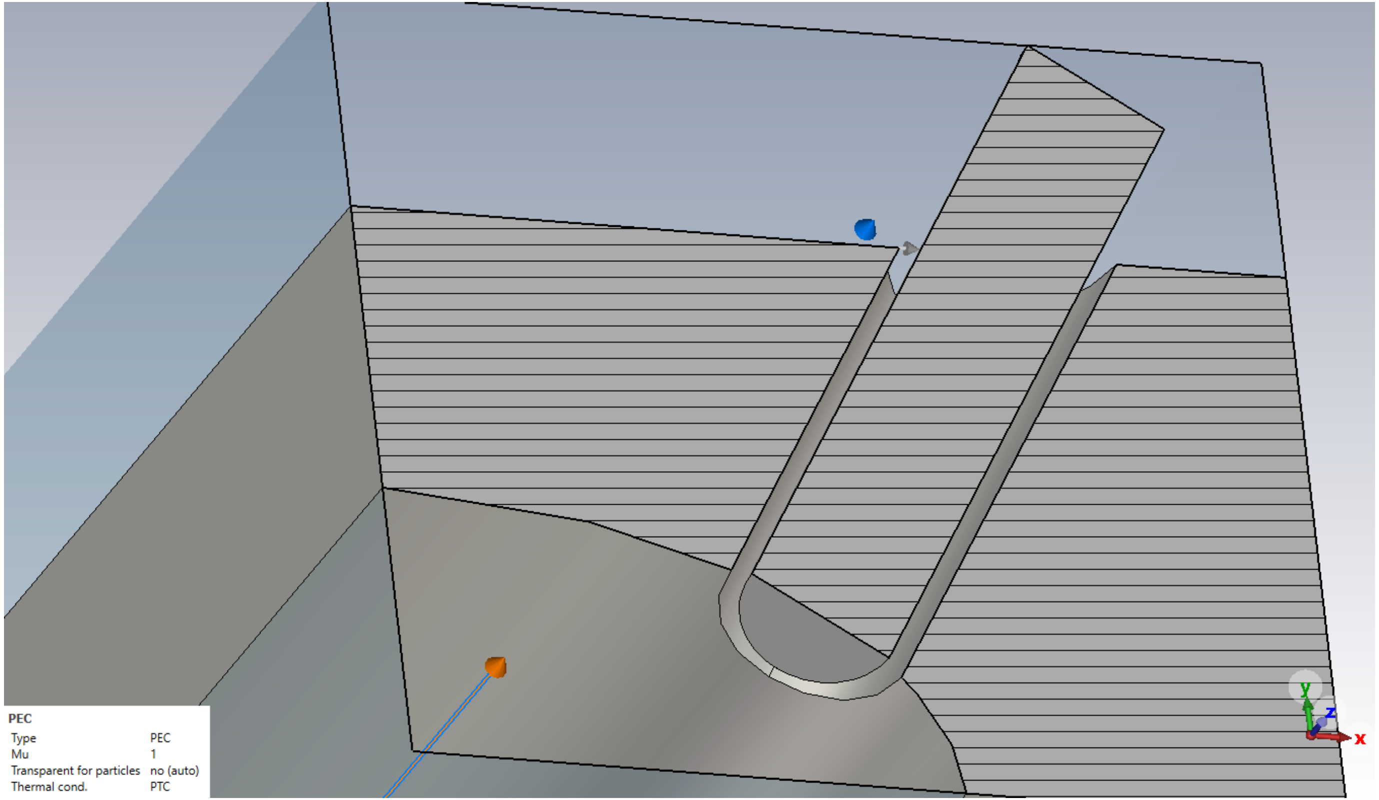
4 mm and 6 mm	a/b=0.67
3 mm and 8 mm	a/b=0.38
2 mm and 12 mm	a/b=0.17
1 mm and 24 mm	a/b=0.04

Geometry for a circular button

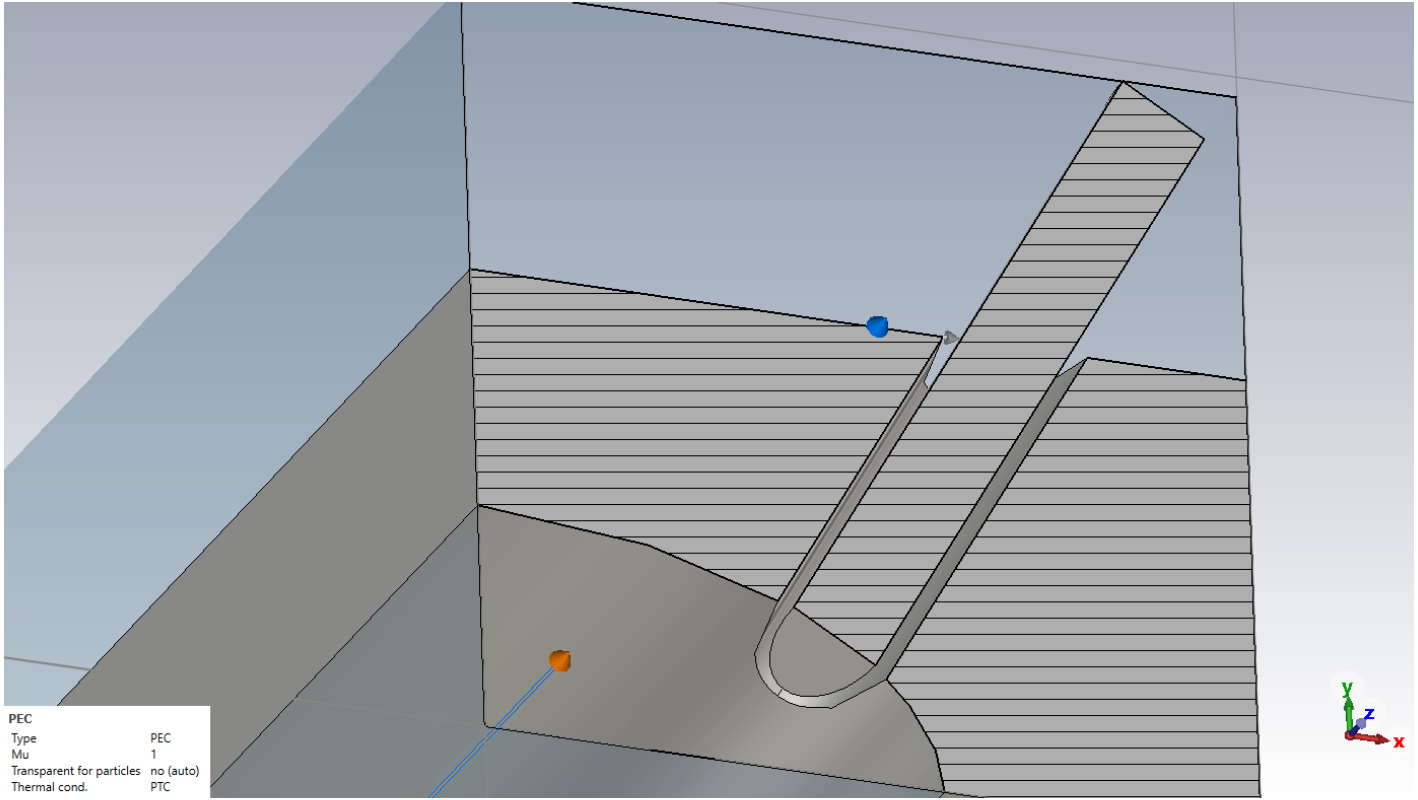


Cross-section of the BPM button

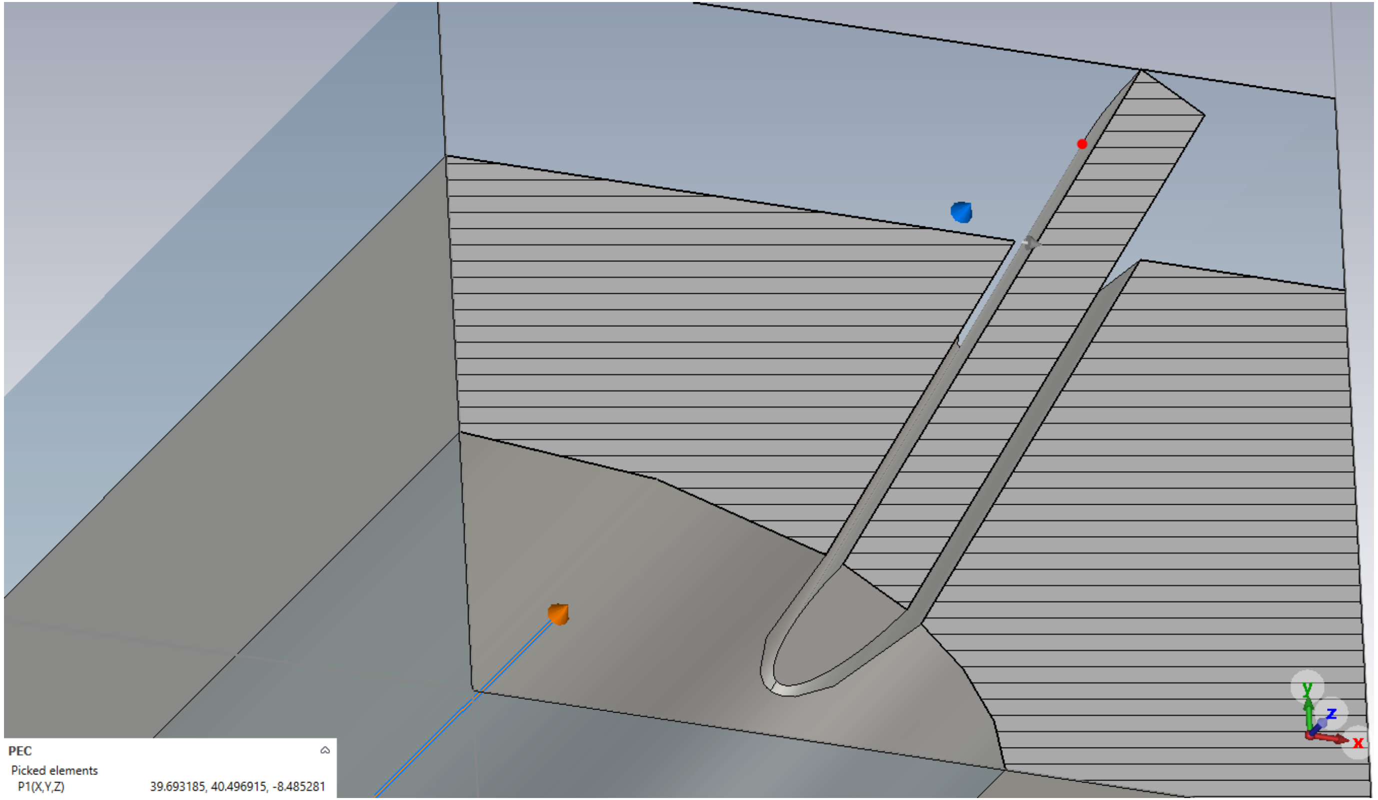
Geometry for the elliptical button 4 by 6



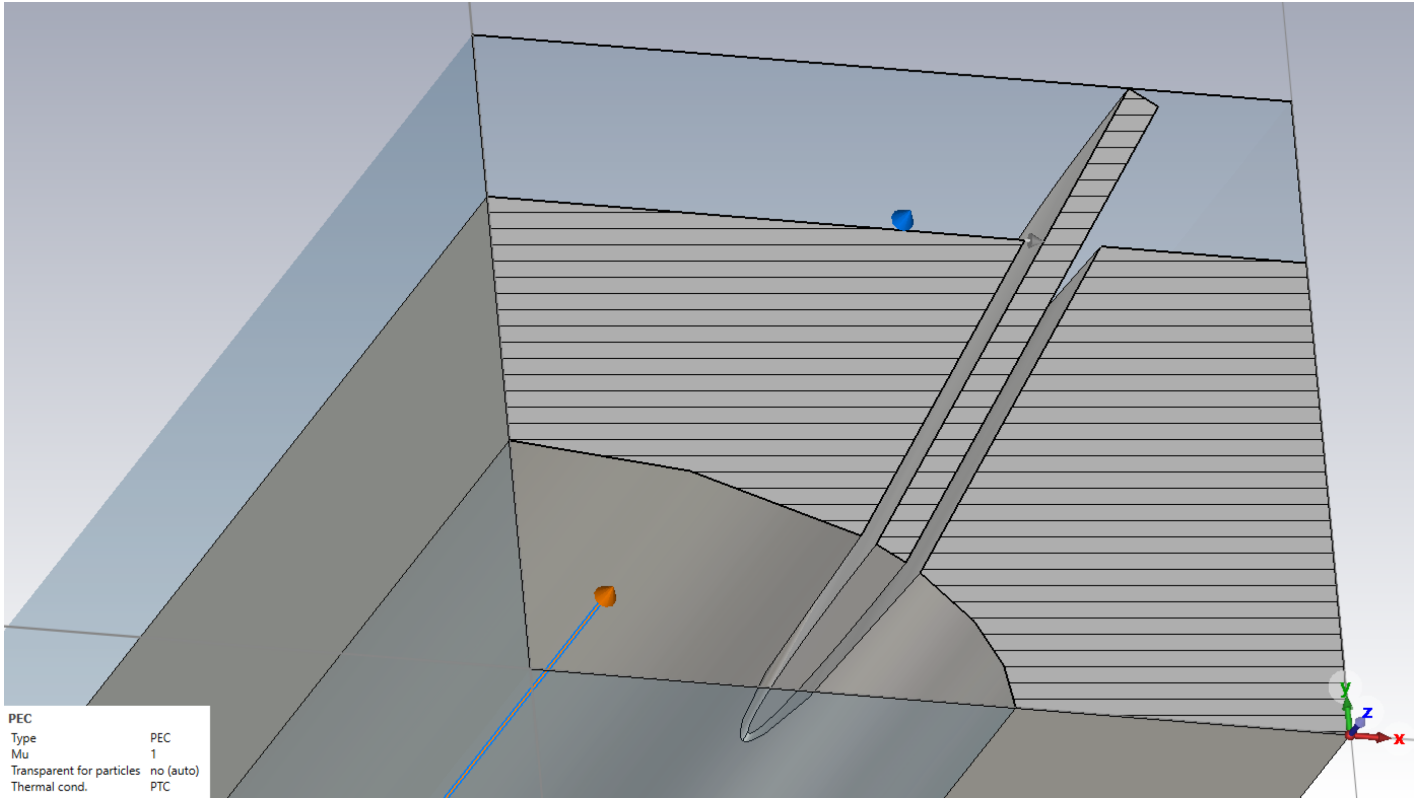
Geometry for the elliptical button 3 by 8



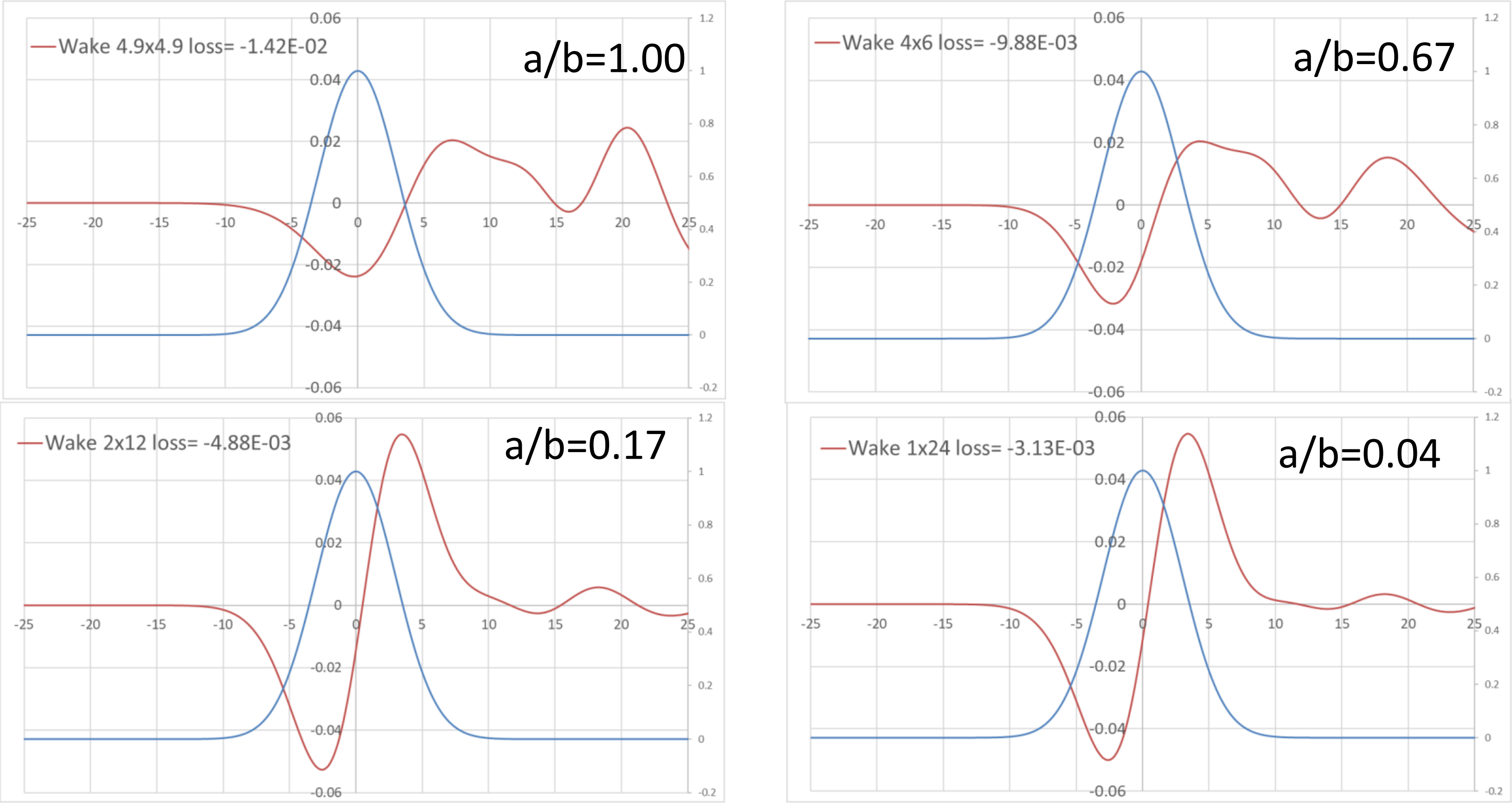
Geometry for the elliptical button 2 by 12



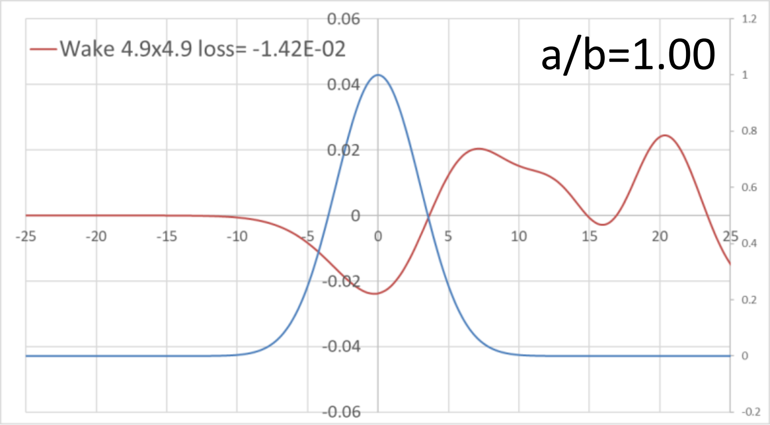
Geometry for the elliptical button 1 by 24

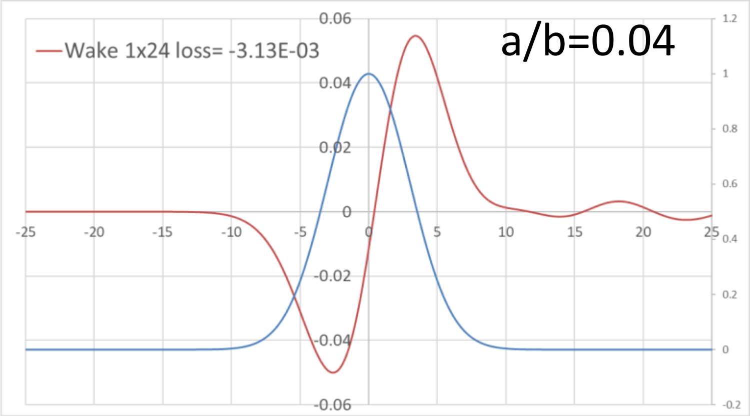


Wake field potentials for a 3 mm bunch



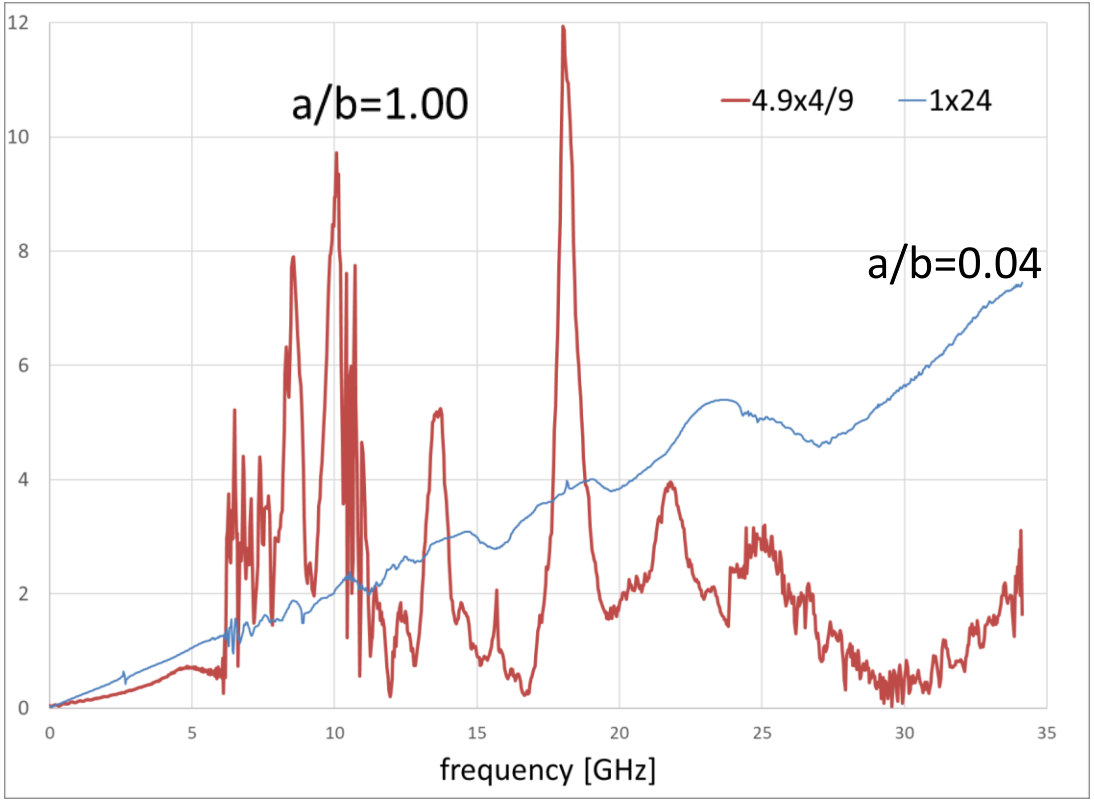
Wake field potentials. Comments





It is clearly seen that with a smaller ration a/b the wake potential becomes more inductive: a bunch “head” is decelerated and a “tail” is accelerated. And the total loss becomes smaller.

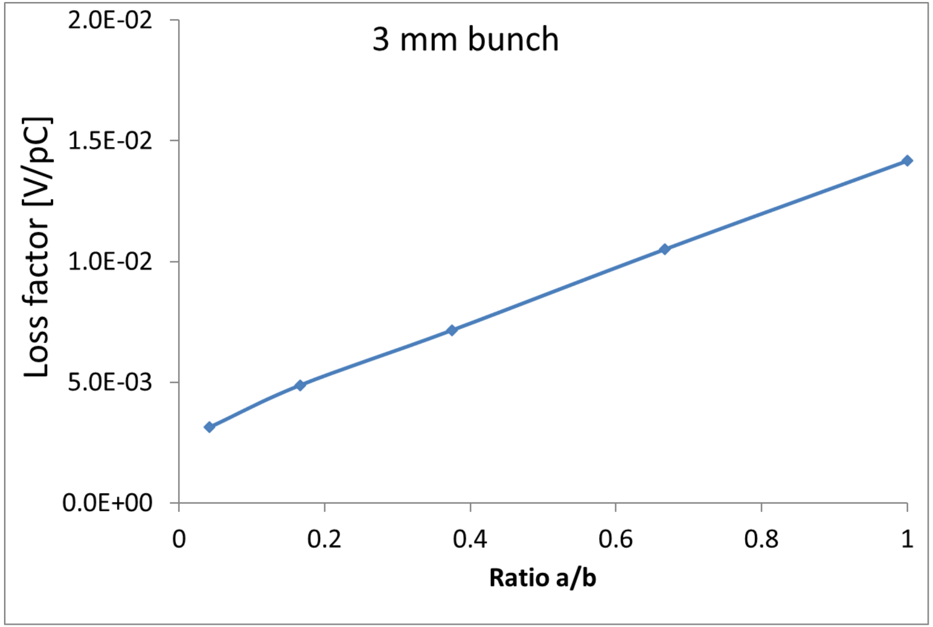
Wake field spectrum

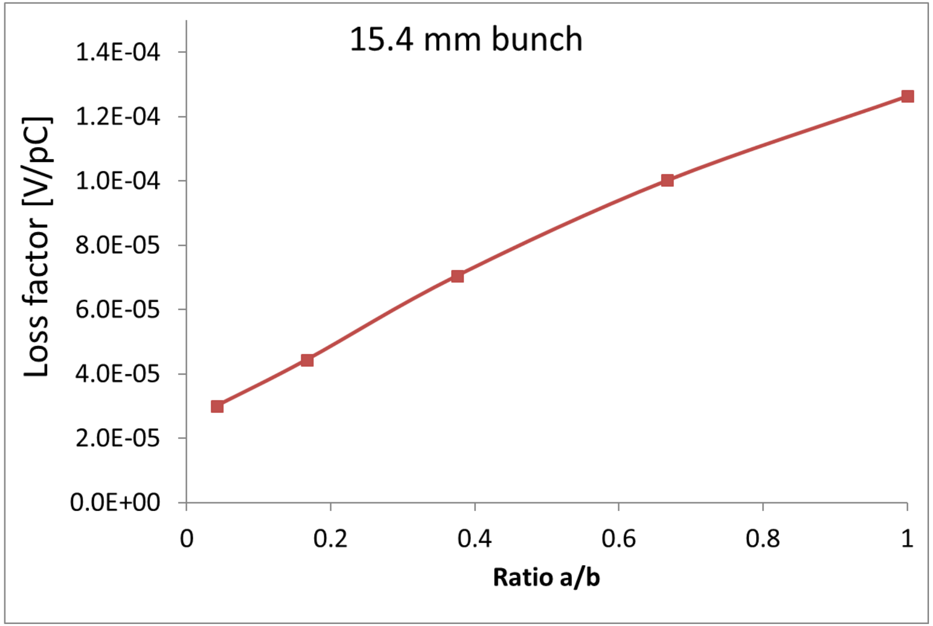


Wake field spectrum confirmed the previous statement: a red line for a round button, a blue line for a longer elliptical button.

There are a lot of resonances for a round button, which are responsible for the wake field losses.

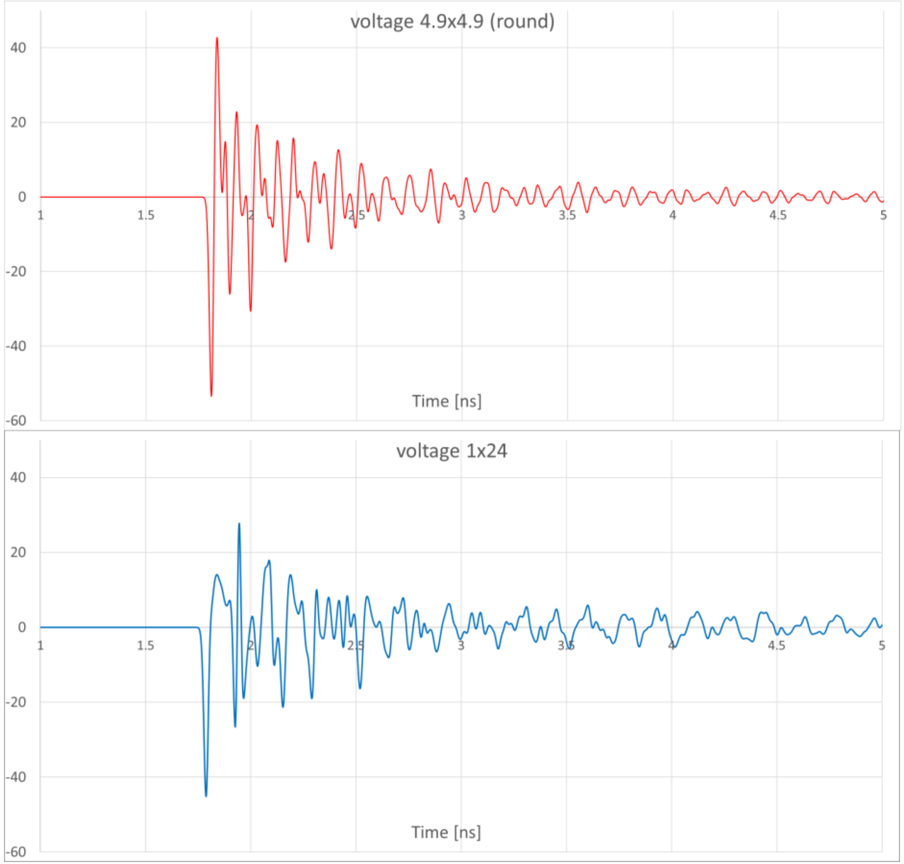
Loss factor





Loss factor goes down with a longer ellipse. It does not go to zero as the beam trajectory is shifted from the beam pipe center

Voltage from a button



Comparison of voltages from a round (red) and an elliptical button (blue).

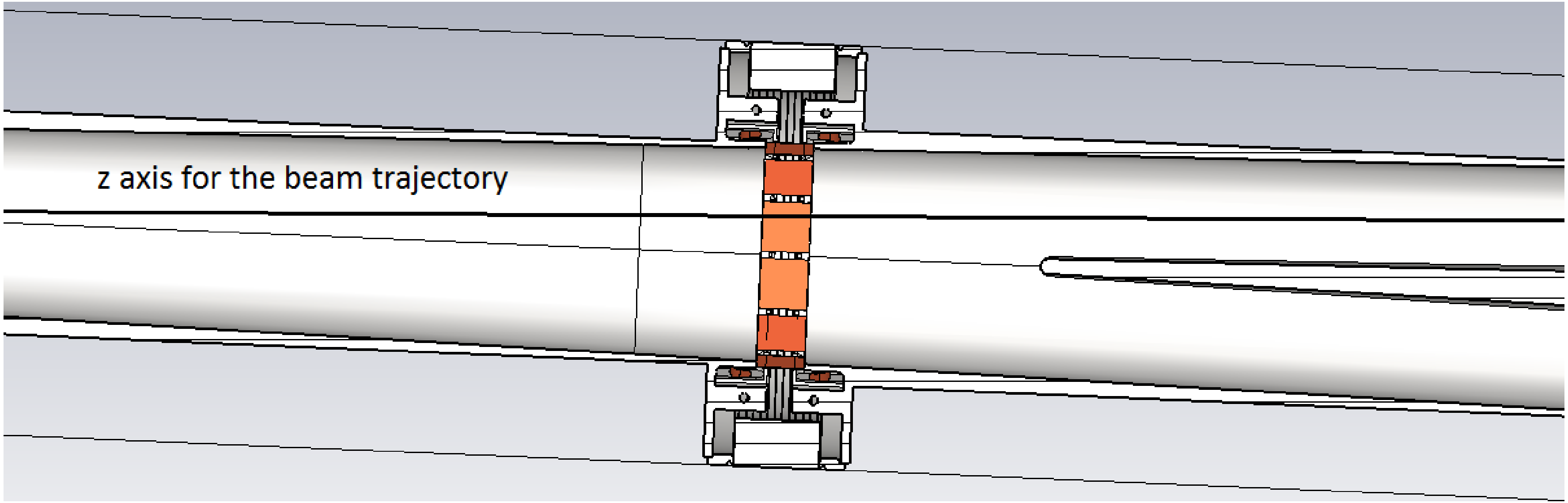
The voltage from the elliptical button is multiplied by the ratio of circumferences.

Voltage from the round button contains more signals from the wake field.

Summary and next steps for BPM design

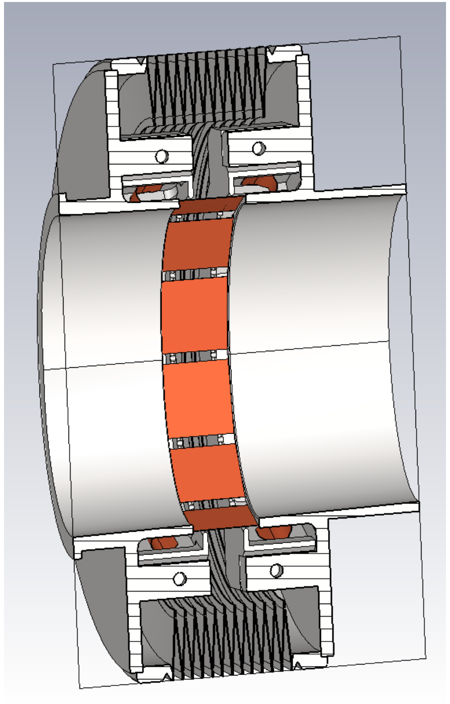
- The loss factor of a BPM button decrease for the longer elliptical button.
  - A beam passing an elliptical button with a ratio 1 x 12, looses 4 times less energy in comparison with a round button.
  - The beam excites less resonance for the longer elliptical button.
- The effective voltage a button is approximately the same if the square surface of a button is the same.
- However the wake field of a long elliptical button has much larger inductive character.
- Nest step can be a comparison of the beam dynamics in the ring for the different shape of the BPM buttons, using the solution of the Vlasov equation for correspondent wake fields (many BPMs in the ring).

Bellows in the chamber

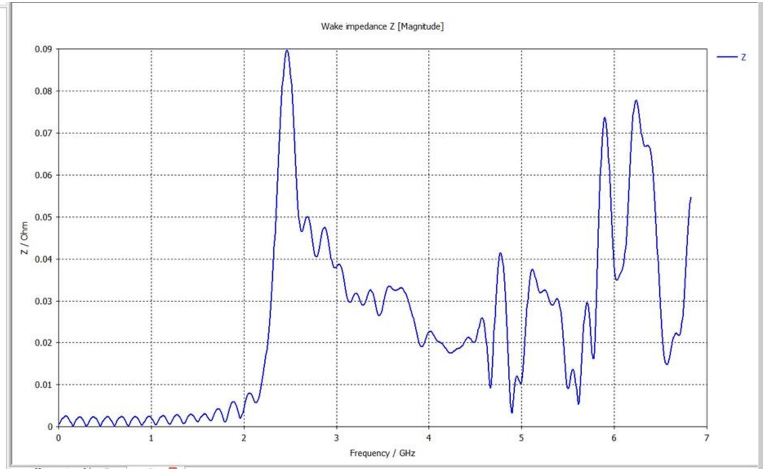


What is important: the beam trajectory is not in the bellows center and the beam can easily excite transverse modes

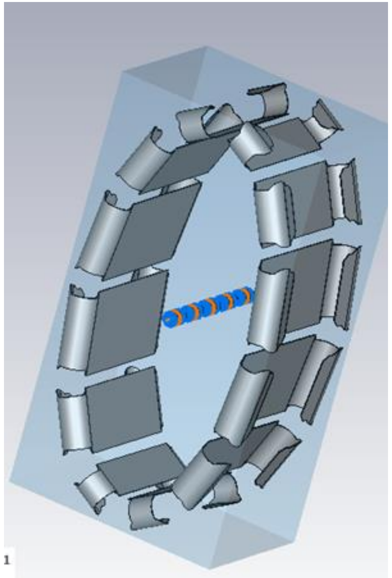
Bellows cavity may capture a lot of power



Bellows is a very delicate device.
It has thing springs and corrugations.



Spectrum of the bellows cavity



The concept of the HOM absorber

In 2017-18 we designed a model of the special HOM absorber for the previous FCC IR vacuum chamber, which has larger diameter of the IP beam pipe.

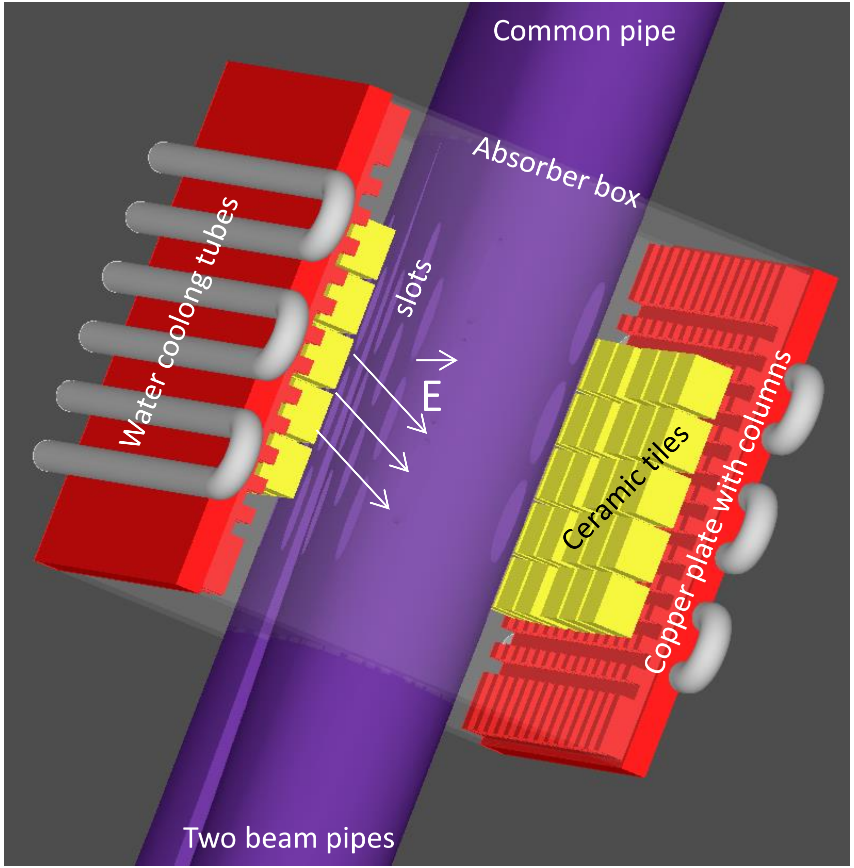
The absorber vacuum box is placed around the beam pipe connection. Inside the box we have ceramic absorbing tiles and copper corrugated plates .

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.

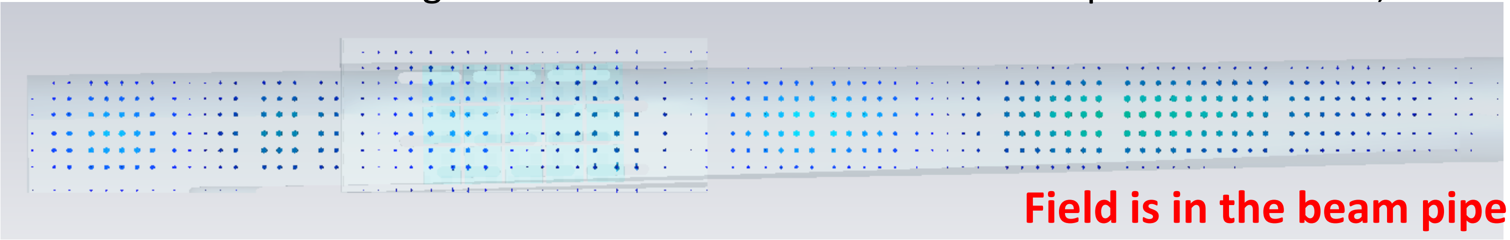
Inside the absorber box these fields are absorbed by ceramic tiles, because they have high value of the loss tangent.

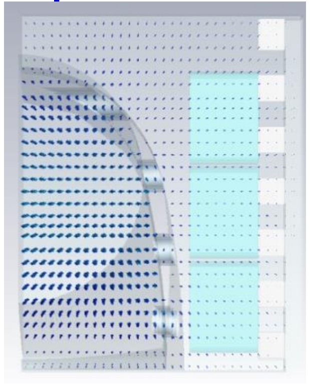
The heat from ceramic tiles is transported through the copper plates to water cooling tubes.



To demonstrate the HOM absorber in action we show two cases when ceramic tiles do not absorb the HOM power (loss tangent is zero) and absorb the power.

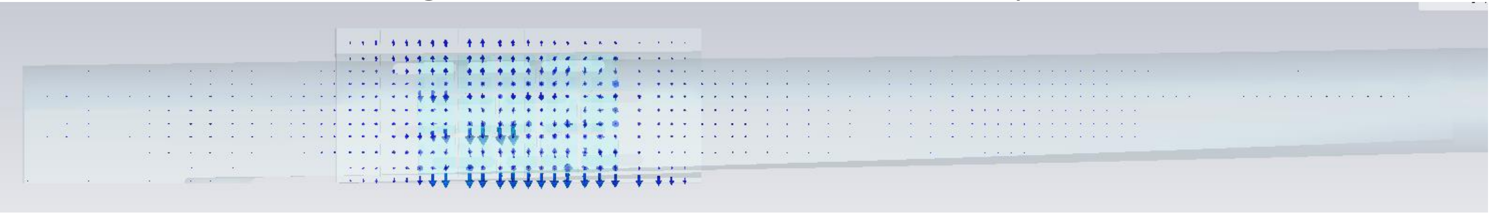
HOM mode in the IR region when ceramic tiles have vacuum parameters : ε=1, δ=0

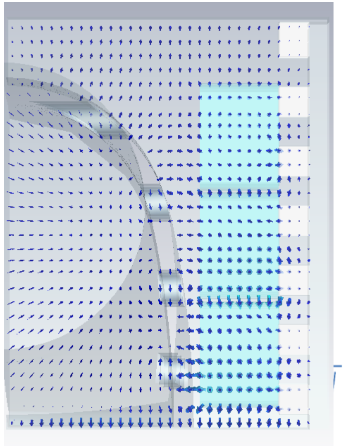




Field is in the beam pipe

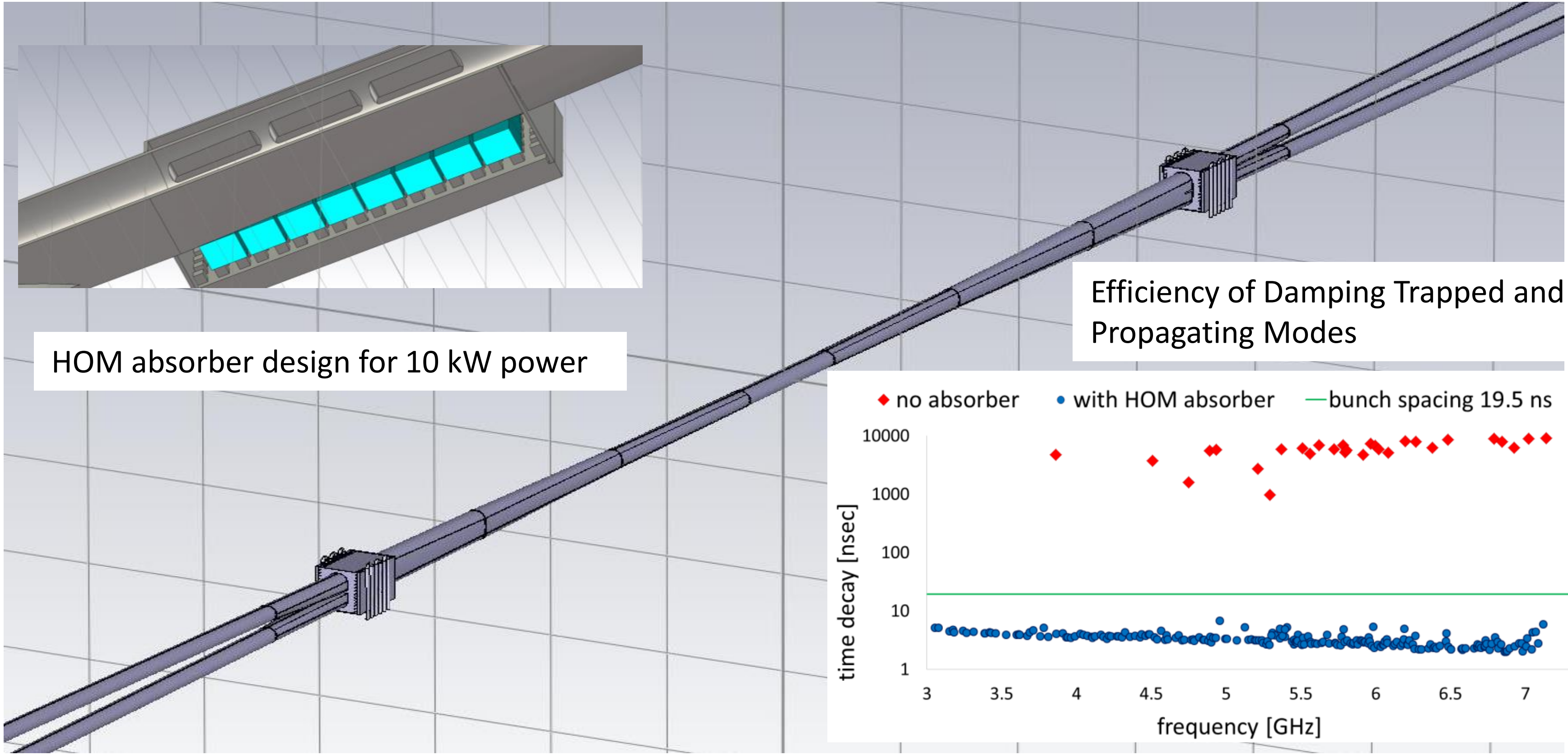
HOM mode in the IR region when ceramic tiles have real parameters : ε=22, δ=0.1





Field is concentrated in the absorber region and in the ceramic tiles

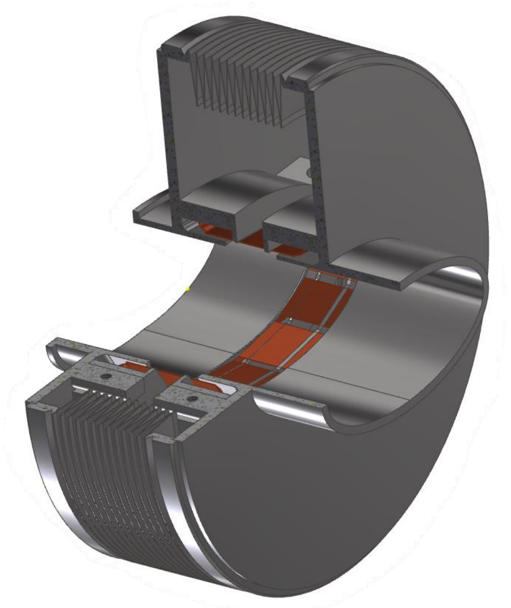
FCC ee IR beam pipe with a water-cooled HOM absorber

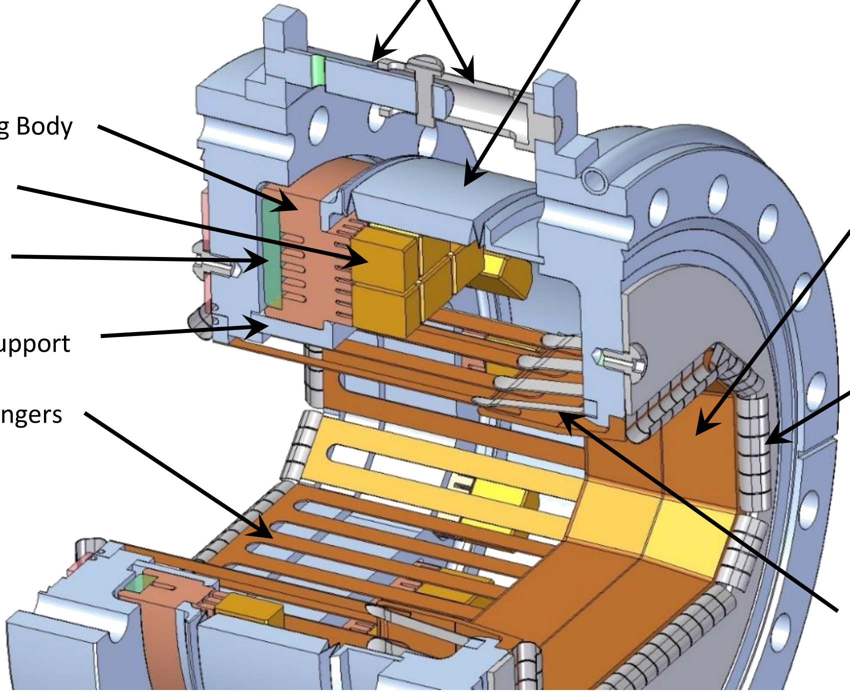


HOM absorber design for 10 kW power

Efficiency of Damping Trapped and Propagating Modes

Transform FCC IR bellows to a HOM absorber like we did at the PEP-II SLAC B-factory





Summary and future steps

- Wake field study of the new chamber with extension of the mutual IR pipe showed that a second trapped mode appeared due to the larger length and size of the mutual beam pipe.
- Study of the new elliptical mask showed that it brings more inductive impedance, which may be important for the beam dynamics (bunch lengthening or instability) and also for the heat load when adding other beam pipe elements.
- Next we will try to do calculations for a full model, which includes bellow, BPMs and SR masks with may be new materials.
- With a cooling of the bellows we will design a special bellows: bellows-HOM absorber to capture increasing HOM power from a complicated IR beam pipe.

Acknowledgement

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Thank you!