Stripline Design for the ThomX tranverse feedback

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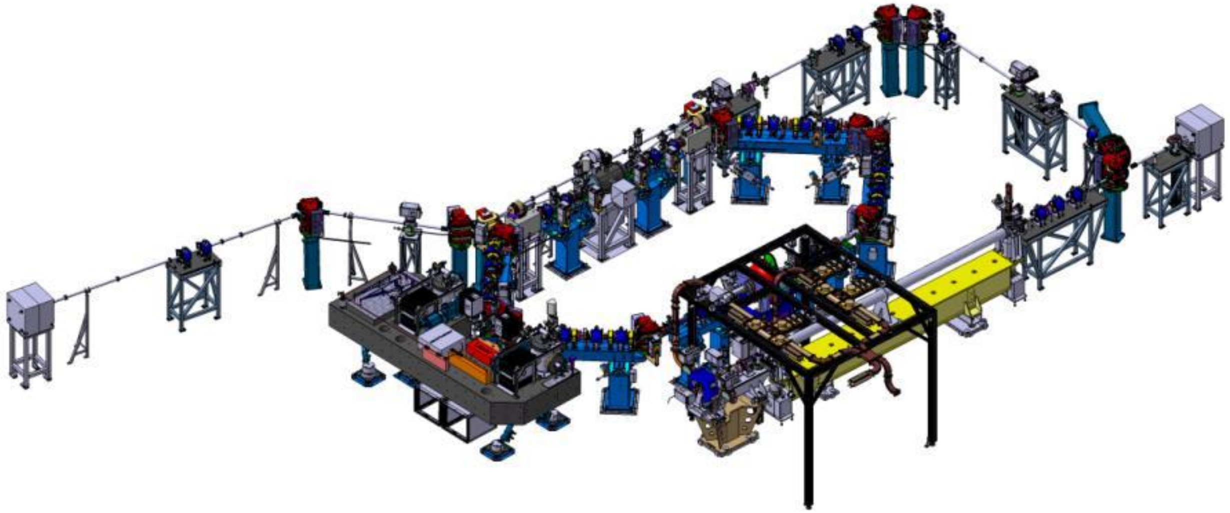
Summary

- ThomX project
- Context for using transverse feedback
- Transverse feedback architecture
- 2D simulation and impedance characterization
- Wakefield simulation and solution to dump longitudinal impedance
- S parameter simulation and final design
- Mechanical conception and design
- Conclusion

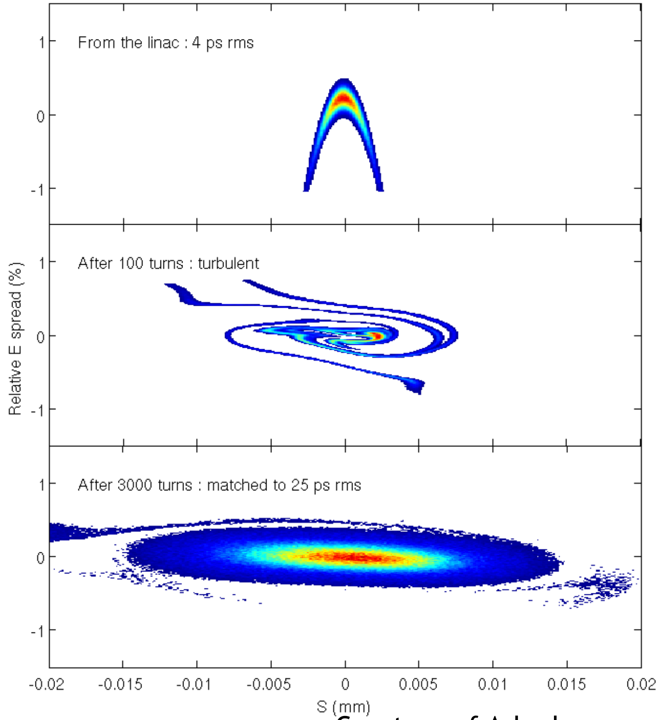
ThomX project

ThomX is a demonstrator for a Compton back-scattering source in the hard X-ray range. A single electron bunch will be accelerated every 20 ms by a 50 MeV LINAC and stored in a 18 m circumference storage ring to interact with a high energy laser.



ThomX transverse feedback context

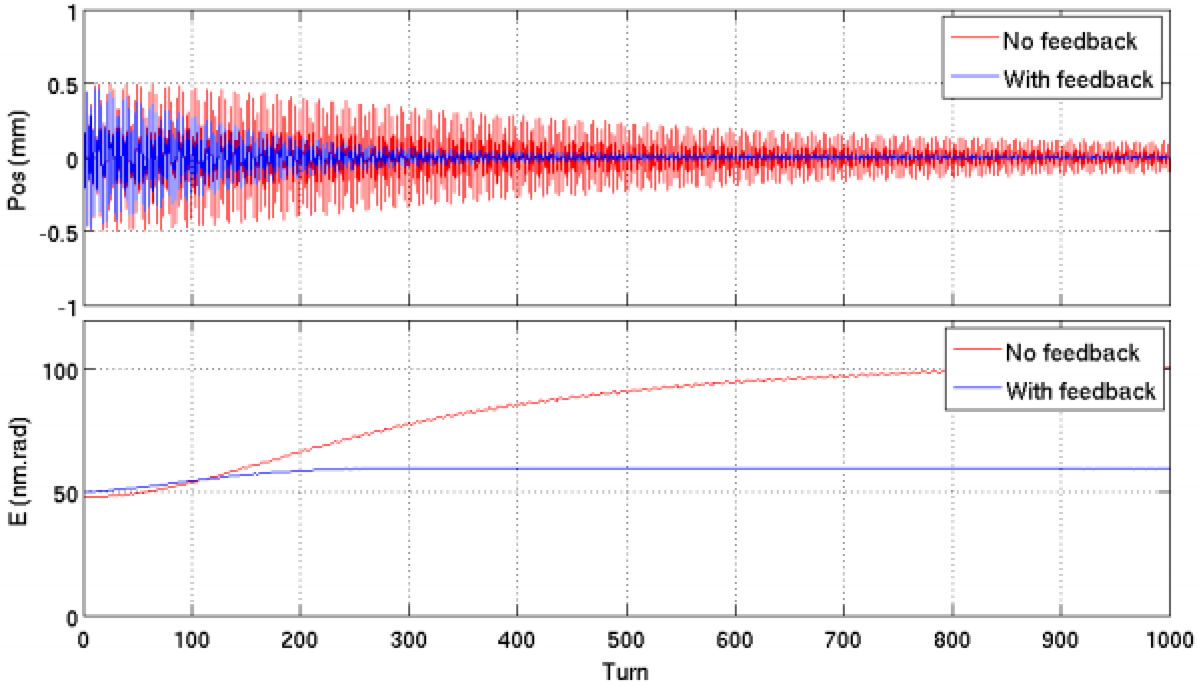
Source of transverse Instabilities	Growing time
Beam pipe Geometries	160µs
Resistive Wall ions	600µs
Ions	< 100 µs
Injection Jitter	5 µs



Courtesy of A.loulergue

- The most critical effect comes from the injection orbit jitter inducing emittance growth at a growth rate of ~5 µs once the bunch stored in the ring

Transverse feedback context

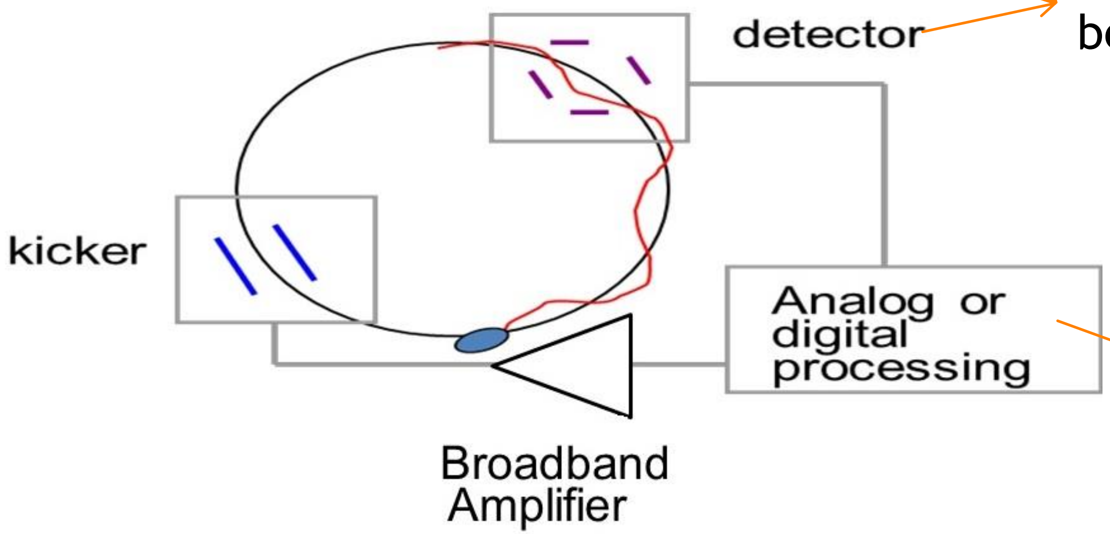


TDR ThomX:
http://hal.in2p3.fr/file/index/docid/971281/filename/TDR_ThomX.pdf

Simulations show that a very fast increase of the transverse emittance can result from steering errors at injection, in about 500 revolutions or 25 µs. To overcome this effect, a fast transverse feedback is needed; it has to damp the oscillation in about 100 revolutions or ~5 µs.

Transverse feedback architecture

- To cope with these instabilities, it was decided to use a digital transverse feedback system, which consists in a wideband detector button beam position monitor a RF front-end, a FPGA based processor, a power amplifier and a stripline kicker. The system is capable of detecting a coherent transverse motion and applying a counter kick to damp it.



the button BPM measure the beam Oscillations

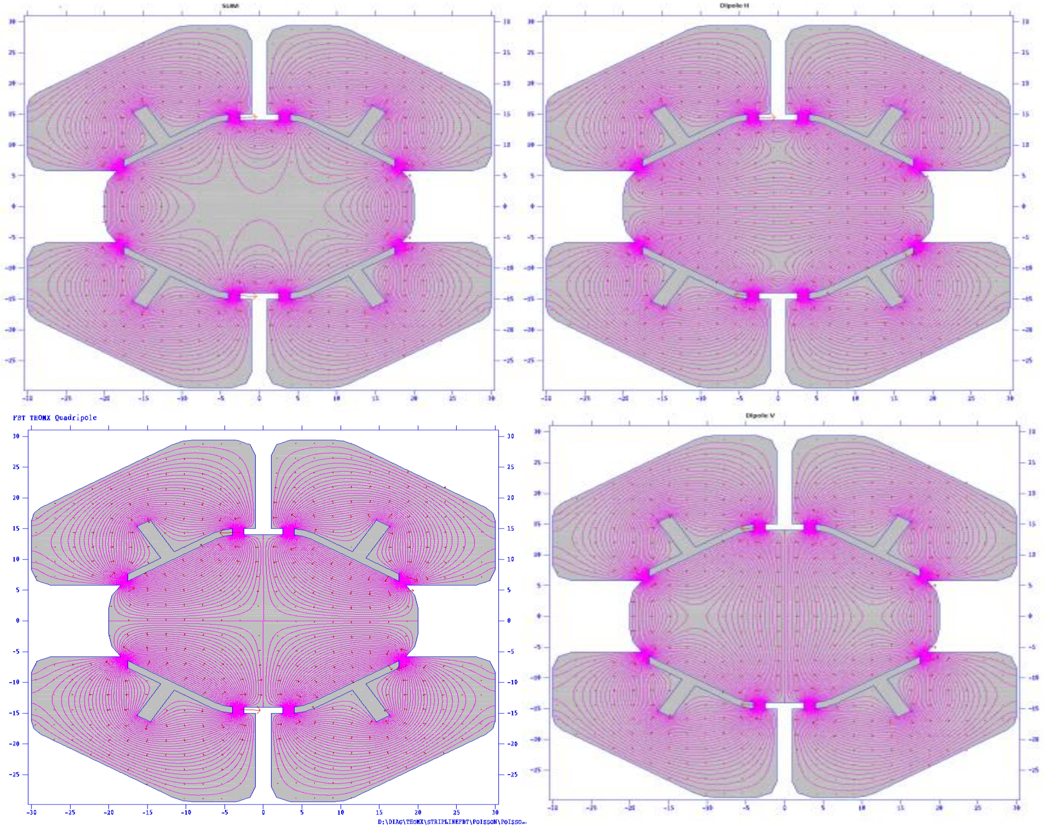
The Kicker generate the electromagnetic field

feedback process generates the correction signal

RF power amplifier amplifies the signal

Impedance matching for the stripline Kicker

- The stripline kicker has 4 electrodes connected to electrical feedthroughs at both ends. The electrodes are 300 mm long that corresponds to λ/2 at RF frequency (500 MHz). To maximize the transmission power, we must adapt the electrode impedance with the external transmission impedance lines (amplifier and cables are 50 ohm).



Poisson electromagnetics 2D software used to calculate the electric field for different dipole, quadrupole and sum mode

$$Zch=\sqrt{Zsum * Zquadrupole}=\sqrt{ZVdipole * ZHdipole}$$

	Sum	V Dipole	H Dipole	Quadrupole
Zmode	54,86Ω	50,07Ω	48,86Ω	47,39Ω

Impedance Shunt

- The shunt impedance Zsh is representative of the stripline efficiency. Higher is the shunt impedance, the better the efficiency of the kicker.
- The shunt impedance *Zsh* is given by the following formula .

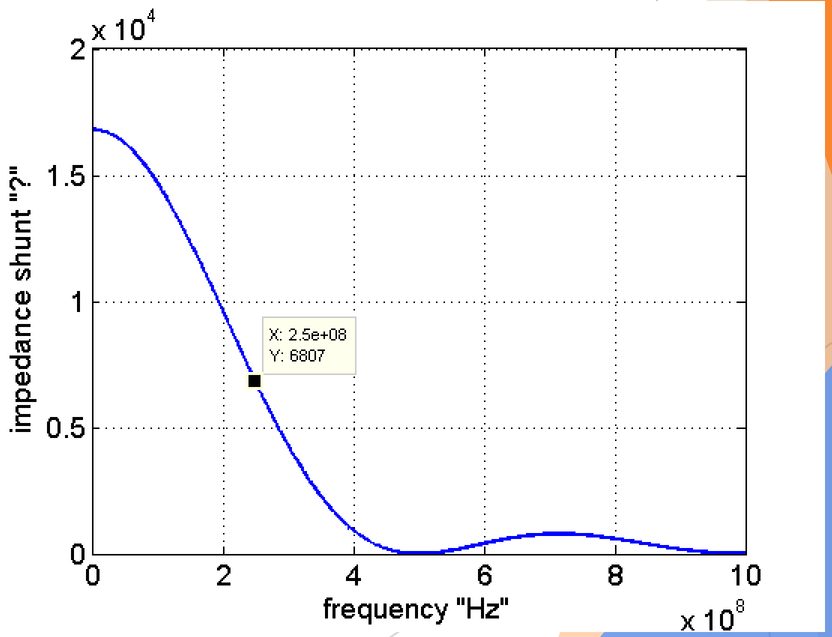
$$Zsh = 2 * Zch\left(\frac{g\perp * c}{2\pi f * R}\right)^2 sin^2\left(\frac{2\pi f * L}{c}\right) \quad [1]$$

where *Zch* is the characteristic impedance, *L* the stripline length, R is the inner radius *c* is the speed of light and *f* frequency.With 2D electrostatic model we determine the transverse geometry factor

$$g\perp = |E_{(x=0;y=0)}| * R \quad [2]$$

where E is the electric field obtained applying unit potential on two diagonal electrodes and R is inner electrodes radius. The transverse geometry factor is about 0.65 for ThomX stripline.

At 250MHz, the shunt impedance is 6.8kΩ



[1] U. Iriso (DESIGN OF THE STRIPLINE AND KICKERS FOR ALBA DIPAC09)
[2] D. Olsson Design of stripline kicker for tune measurements in the MAX IV 3GeV ring

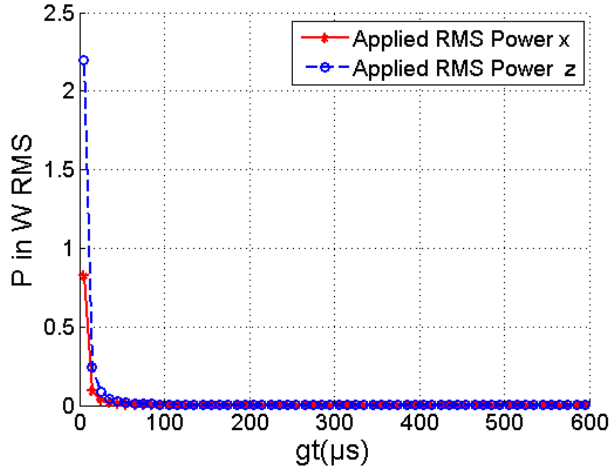
Kicker strength

The computed instability growth time and the corresponding kicker strength requirement for the different types of instabilities

Source	Growing time	Kicker strength Δx	Kicker strength Δz	Applied RMS Power X plan	Applied RMS Power Z plan
Beam pipe Geometries	160μs	66 nrad	108 nrad	<1mW	2mW
Resistive Wall	600μs	18 nrad	28 nrad	<1mW	<1mw
Ions	< 100 μs	10 μrad	17 μrad	2mW	5 mw
Injection Jitter	5 μs	2,6 μrad	3,5 μrad	0,8W	2,2 W

$$1/t_d = \frac{\Delta x}{2\, x_{max}} f_0 \sqrt{\beta_p {}^* \beta_k} \qquad (3)$$

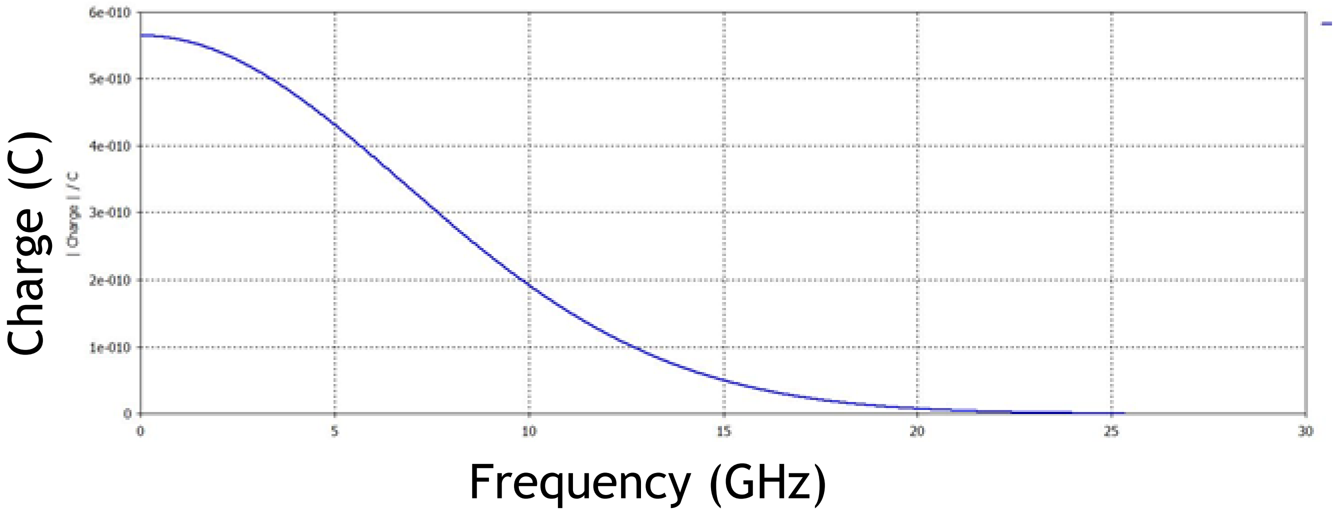
$$\Delta x = \frac{e\sqrt{2P\, Zsh}}{E} \qquad (4)$$



(3) (4) U. Iriso (DESIGN OF THE STRIPLINE AND KICKERS FOR ALBA , DIPAC09)

Wake impedance simulation

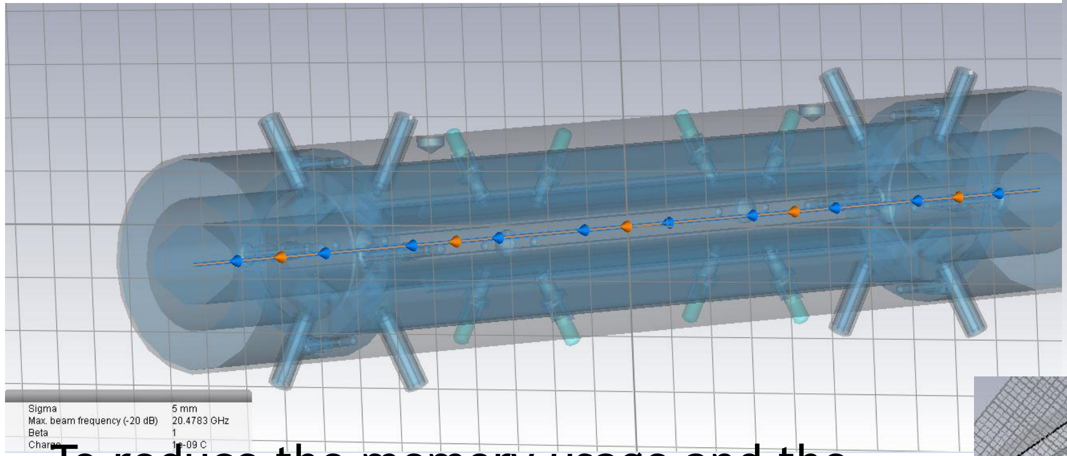
- Due to the short storage time (20ns) and low energy 50MeV , the electron dynamics is not damped and the beam stability becomes a crucial matter.
- To achieve ThomX expected performances , we must determine the possible sources of beam instability
- An important source of longitudinal and transverse instability may be the beam coupling impedance of the storage ring elements. As the beam is only 5 ps long at the injection it is necessary to consider the impedance up to high frequencies.

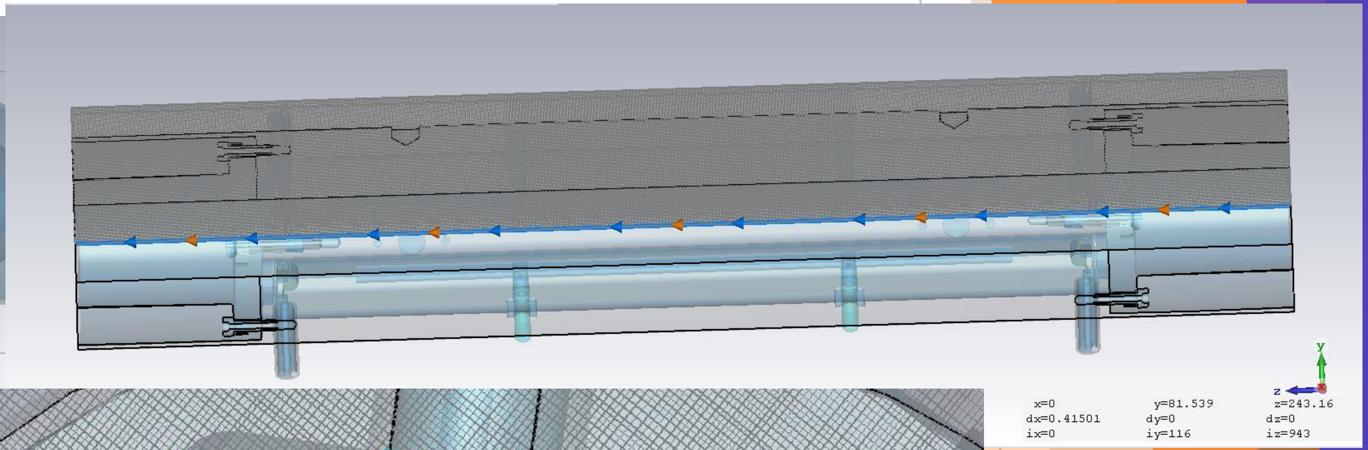


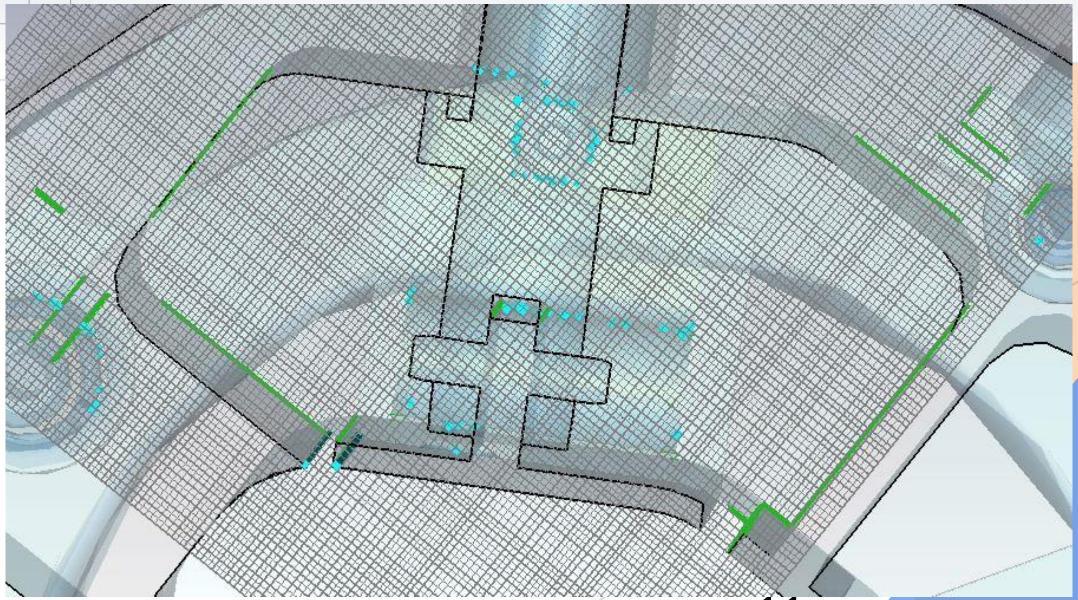
Charge distribution amplitude spectrum

3D Simulation

Wakefield simulations are performed with the wakefield solver of CST Particle Studio

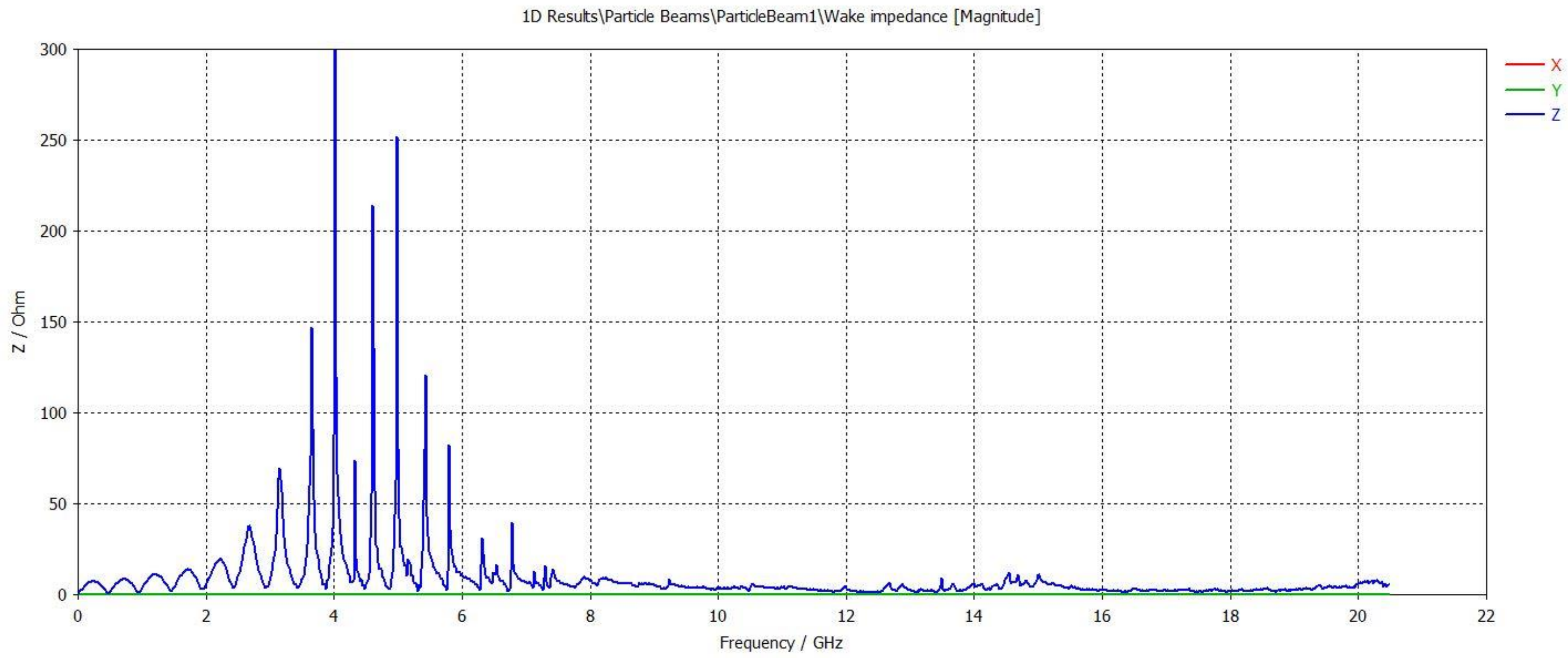






To reduce the memory usage and the computation time, we simulate a quarter of the structure.
22 million mesh cells and 48 hours of calculation.
Special care have been taken to improve the mesh quality and to check that the results do not change with the mesh..

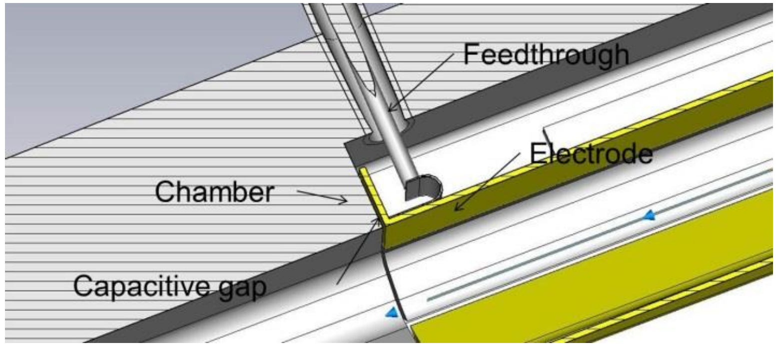
Initial result

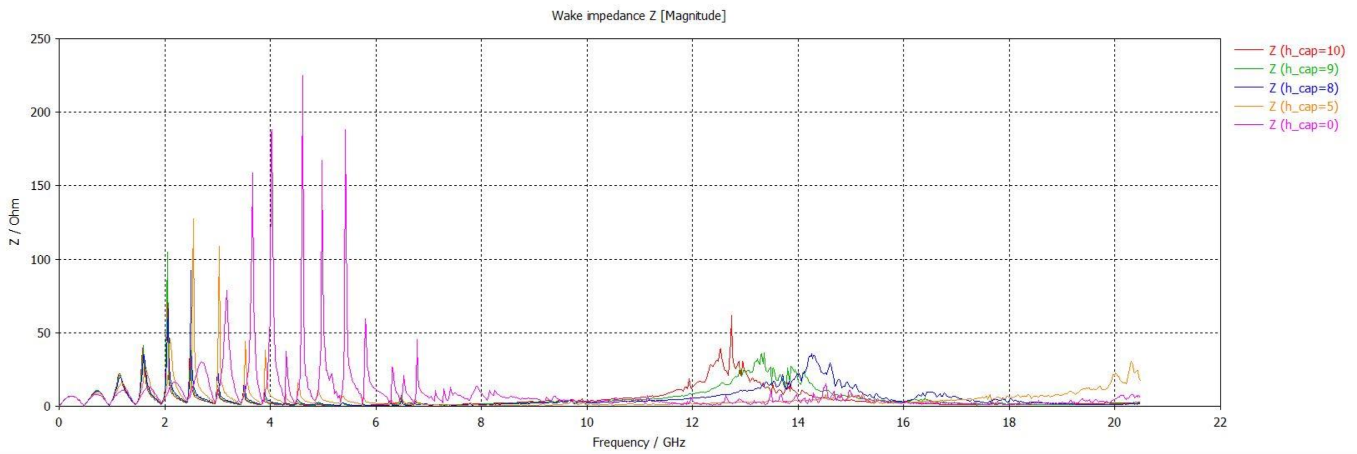


shows the real part of the longitudinal impedance, Impedance peaks are present between 3 and 6 GHz with high values which can disturb the beam.

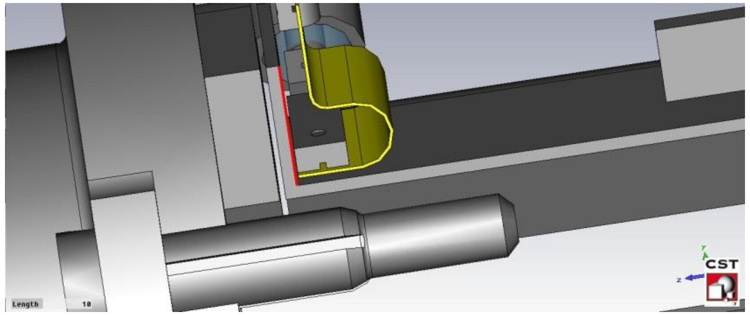
Longitudinal impedance optimization

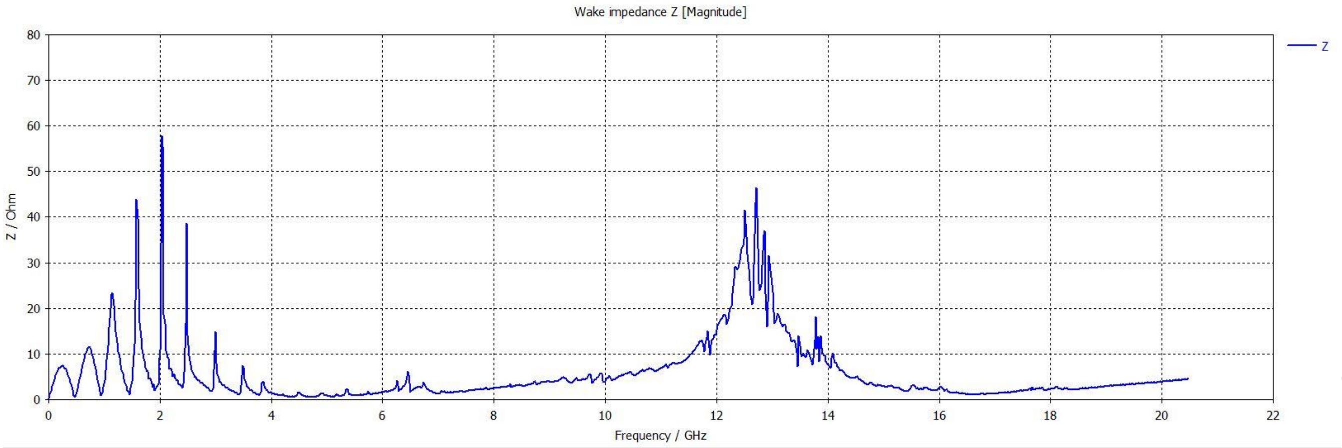
- Longitudinal impedance has been optimized adding (as it had been done for SOLEIL striplines) 0.5 mm capacitive gaps at each side of the electrodes. This capacitive gap, combined with the inductance of the feedthroughs and metal foil, and 50 ohms impedance of electrodes, creates a low pass filter. The cutoff frequency of this filter depends on the height of the capacitive section.





- The longitudinal impedance is significantly reduced, at high-frequency, peak appears but with a low amplitude.



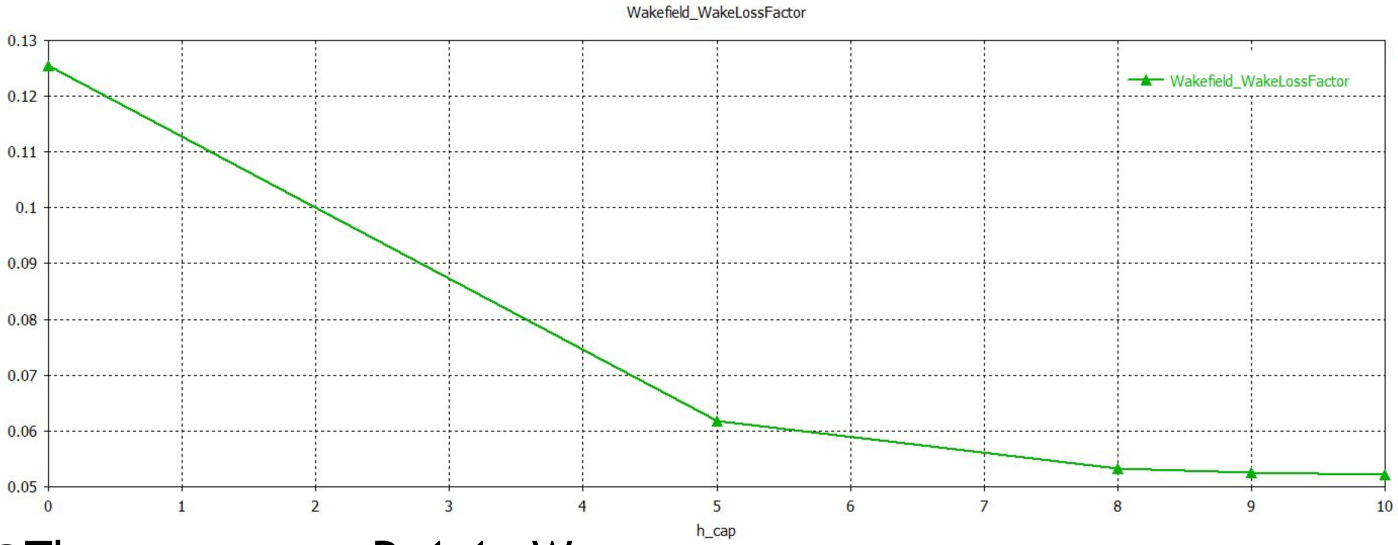


Wake loss factor

particles Beam passes through structures generates wake fields characterized by wake loss factor. Some of the energy deposited will be emitted into the vacuum chamber, some in the ports and a part is absorbed by the materials of the structures. This field must be reduced to avoid interaction with the beam in the following turns.

Power P = I Q kloss
•I is mean beam current
•Q is charge = I Δt
• Δt is bunch distance = t / N
t revolution time

$$P = \frac{I^2 * t * kloss}{N}$$



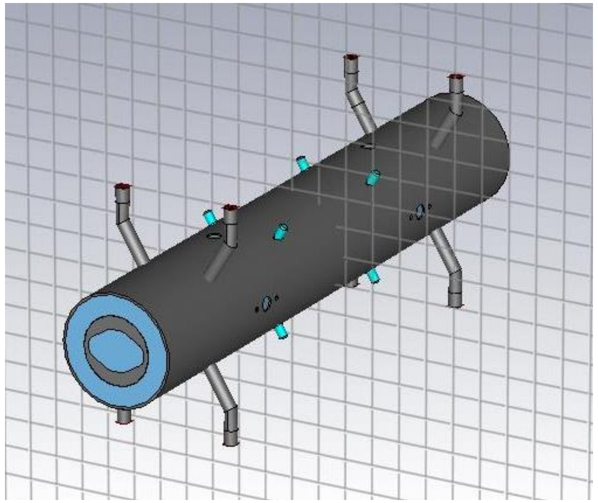
@Thomx P=1,1mW

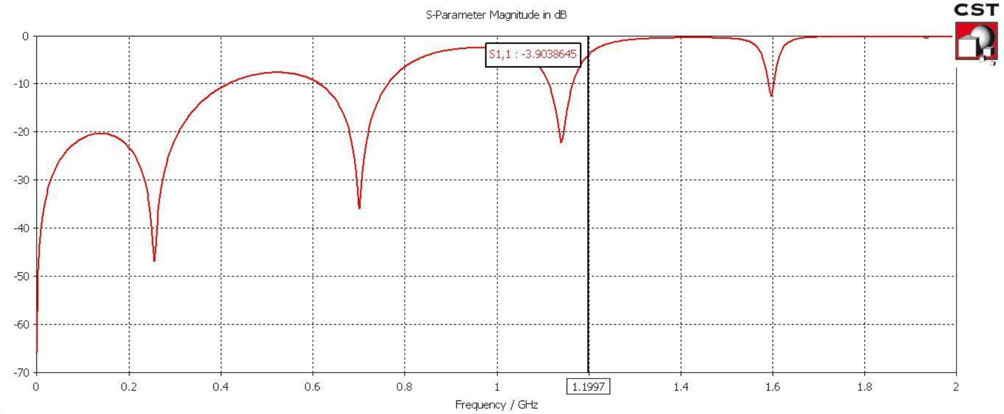
Total longitudinal impedance

Element name	Number in ring	Loss factor of an element (V/pC) for a bunch of σ = 2 mm = 6,6 ps	Total effect in %
BPM4	4	2,5 E-2	1,6 %
BPM6	4	3,7 E-2	2,3 %
BPM8	4	4,9 E-2	3,0 %
Pumping port	13	3,9 E-2	7,9 %
Bellow	18	1,5 E-2	4,2 %
Kicker	2	0,41	12,8 %
Septum	1	1,15	17,9 %
IP chamber	1	1,9 E-2	0,3 %
FBT Stripline	1	7,35 E-2	1,1 %
RF cavity + Tapers	1	3,14	48,9 %
Total		6,42	

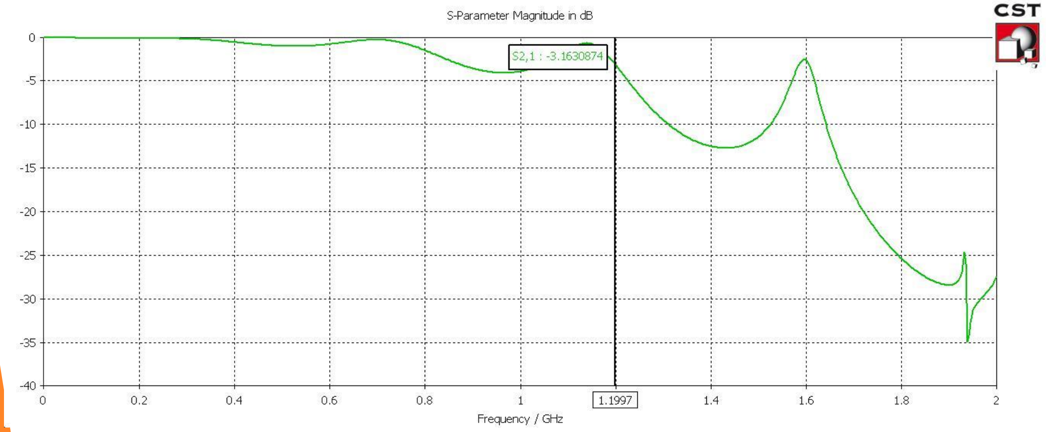
Courtesy of Alexis Gamelin by LAL

S parameter verification

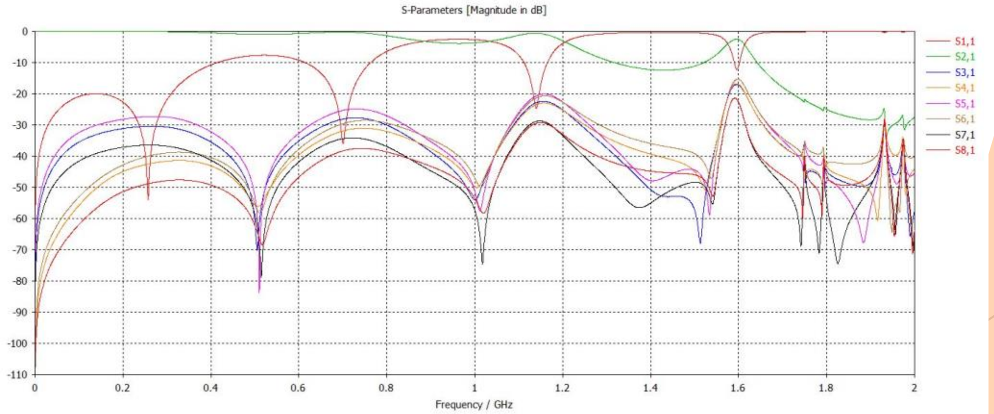




Reflection parameter S11

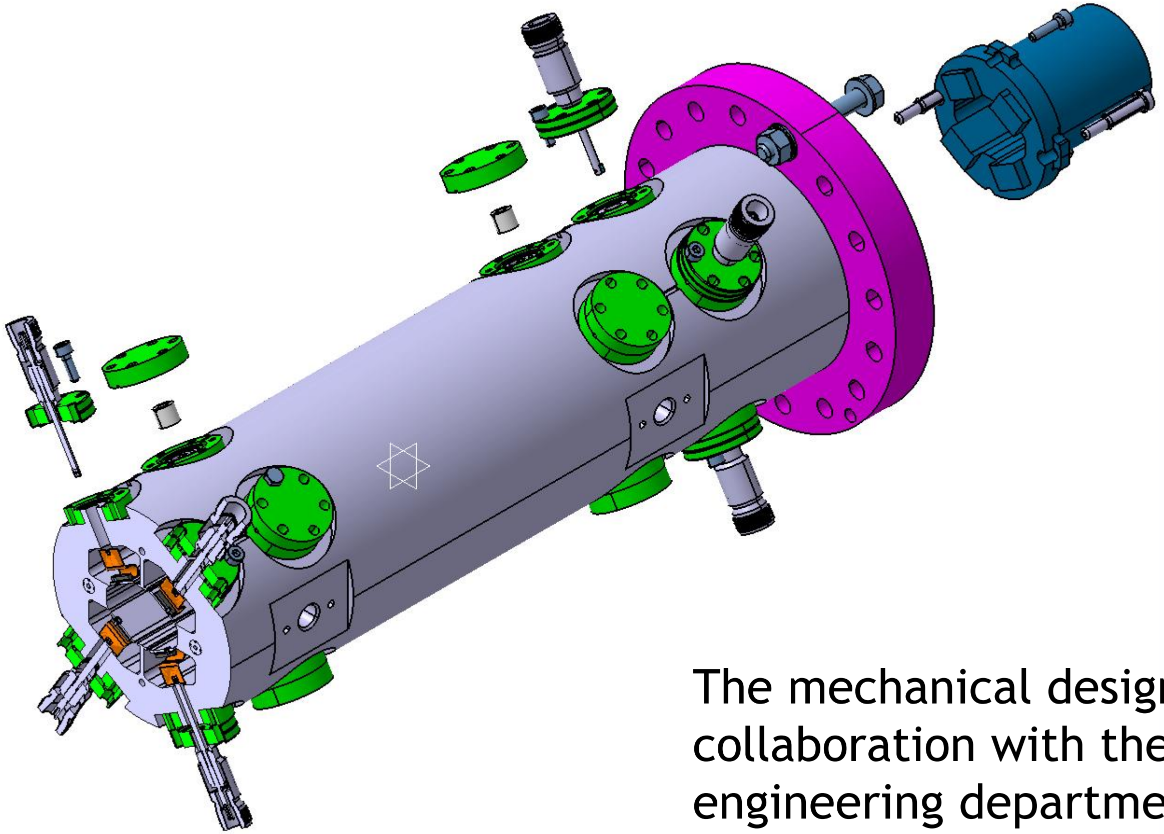


Transmission parameter S21



Coupling between electrodes

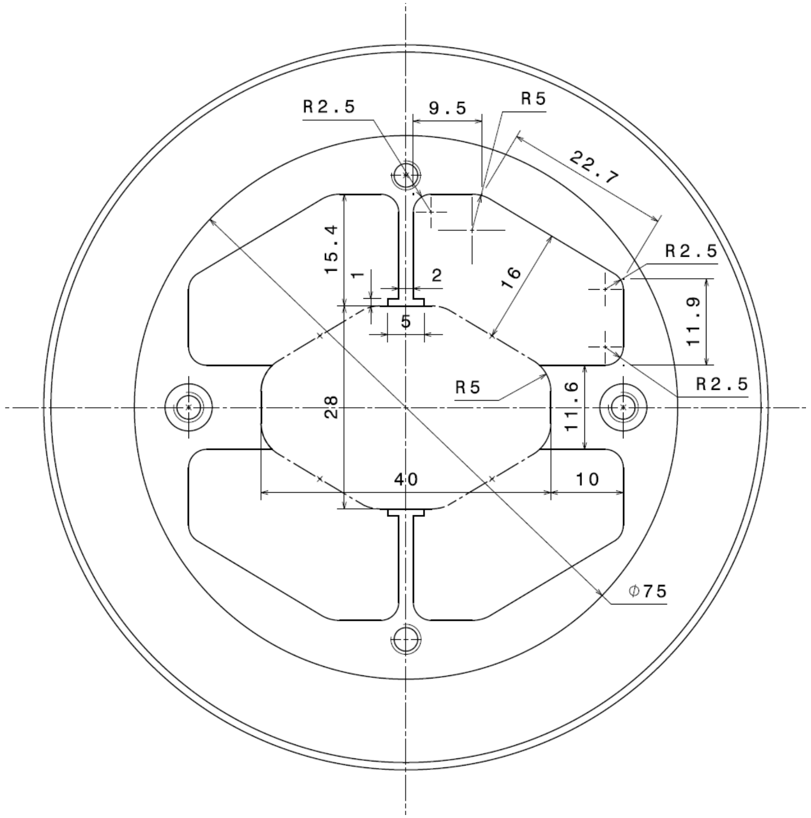
Mechanical design

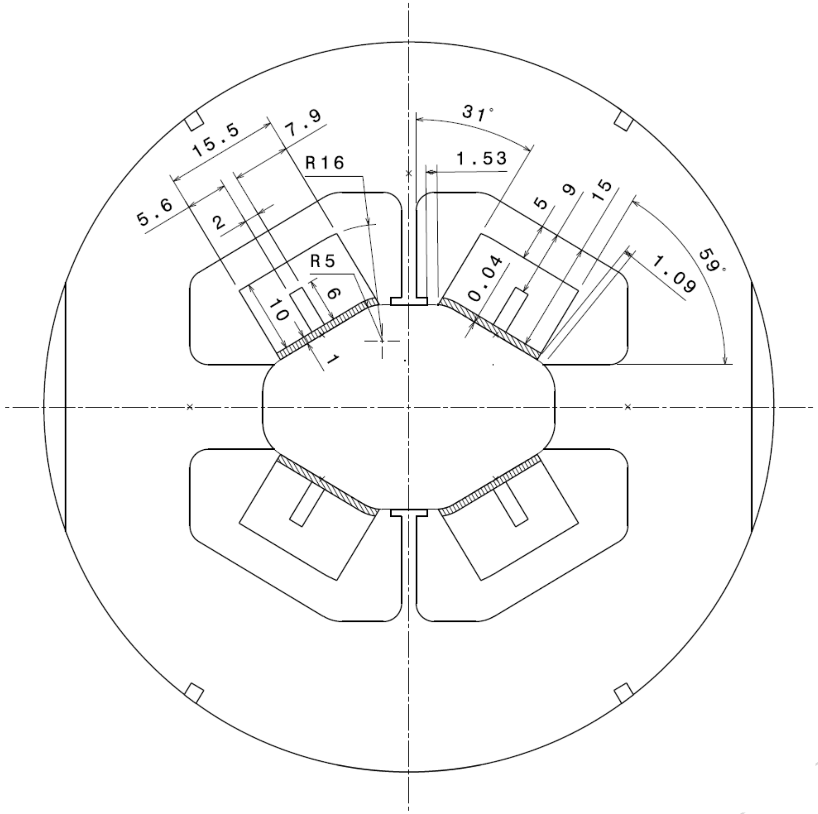


The mechanical design is carried out in collaboration with the LAL Mechanical engineering department

mechanical concept

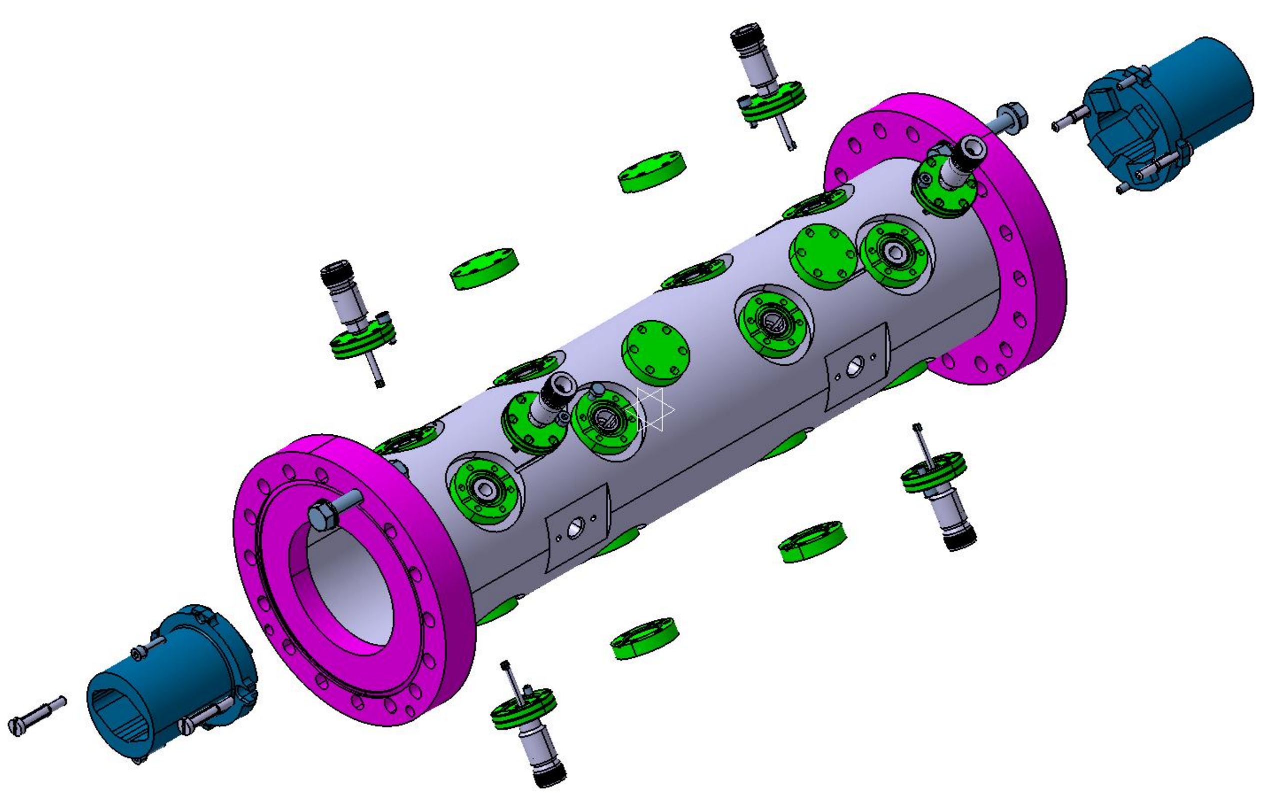
Their shape reproduces the ThomX vacuum chamber inside geometry to minimize variation of chamber cross section seen by the beam and thus the stripline impedance





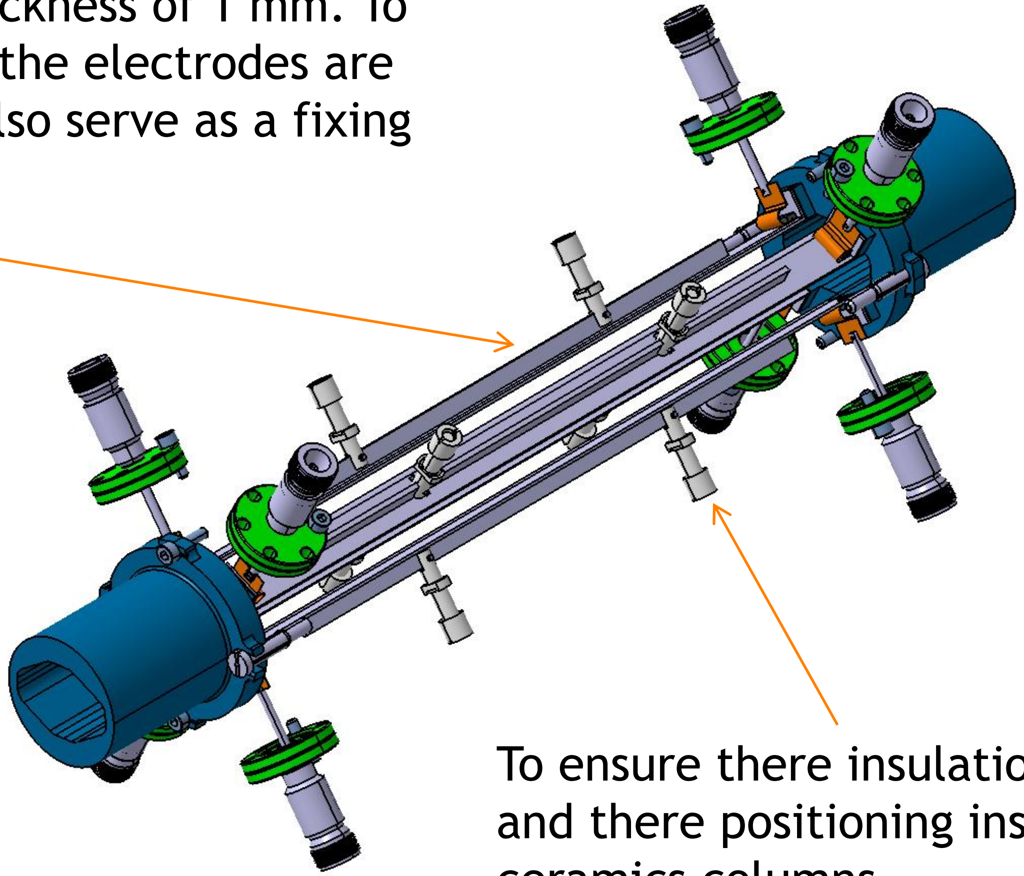
External body

- The Chamber and the Electrodes are made in one part in the same raw material rod.
- The internal section of the FBT Stripline is unbroken all over the Electrode length, without any variation or rupture and with thin mechanical tolerances.
- The chosen material is a AISI 316 LN stainless steel because it magnetic permeability stay under 1.01, even after welding.



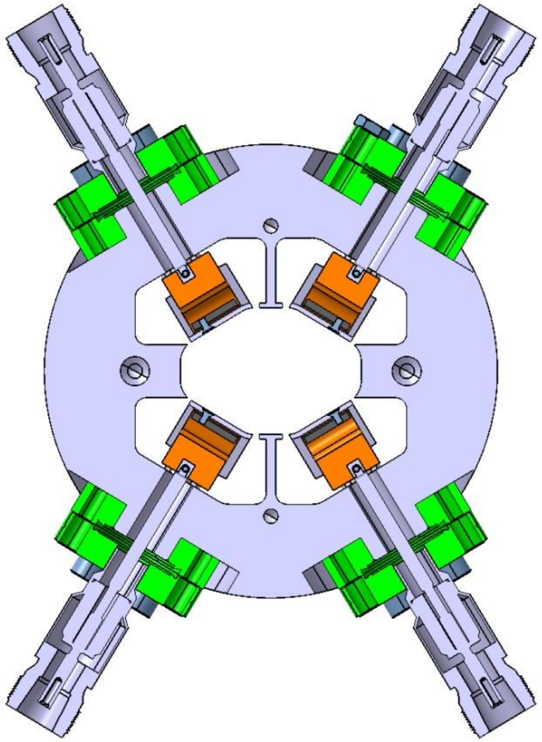
Electrode fixation

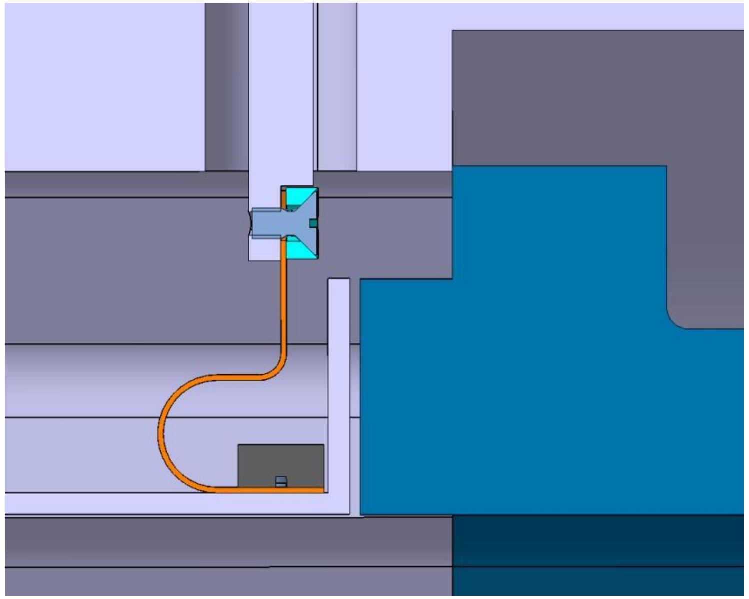
The four electrodes have a thickness of 1 mm. To eliminate the bending effect, the electrodes are designed with a rib that will also serve as a fixing point.



To ensure there insulation from the rest of the machine and there positioning inside the Chamber, it are taken by ceramics columns

Feedthroughs

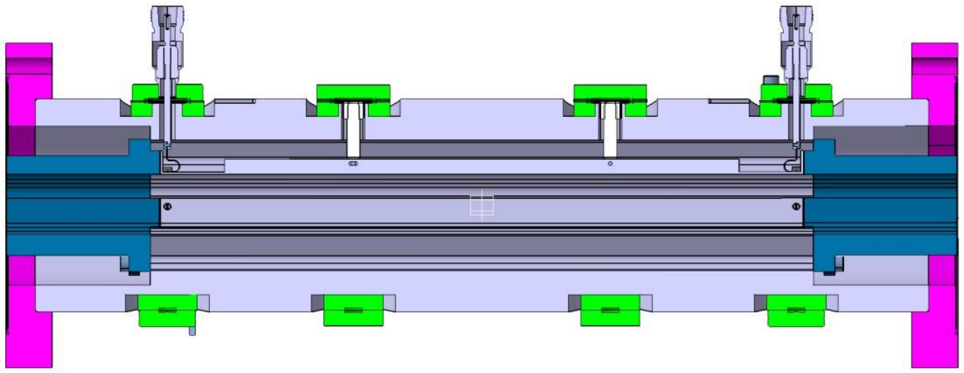


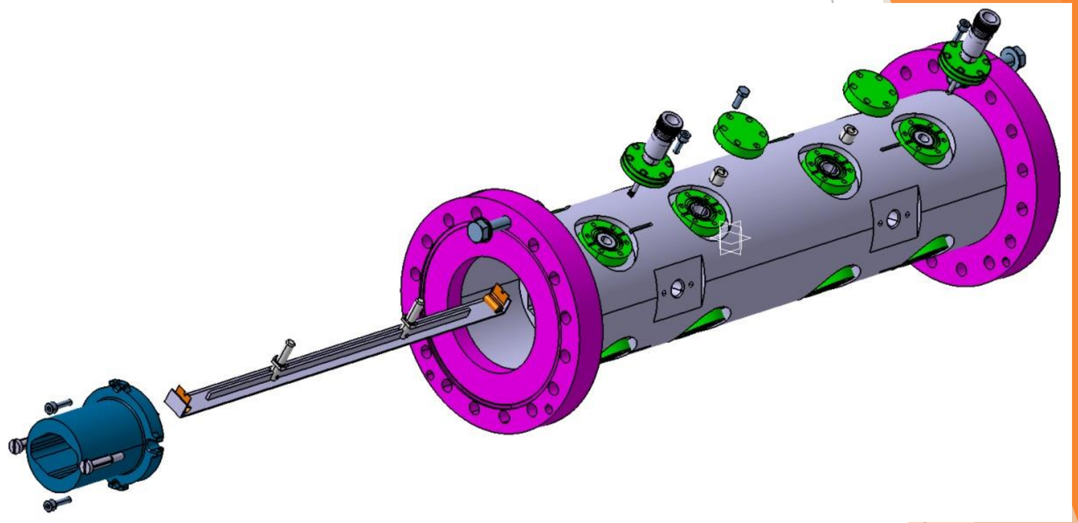


Feedthroughs are the standard CF flange N type adapted to our needs.

Electrical connections at both ends of the electrodes are made through a flexible copper sheet to avoid damage during baking process.

Final assembly



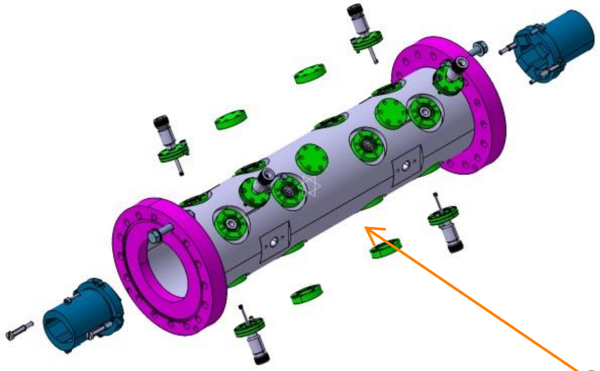


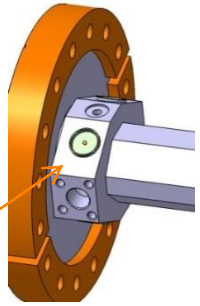
All parts are screwed together, so that the stripline can be fully dismounted for future needs.

Conclusion

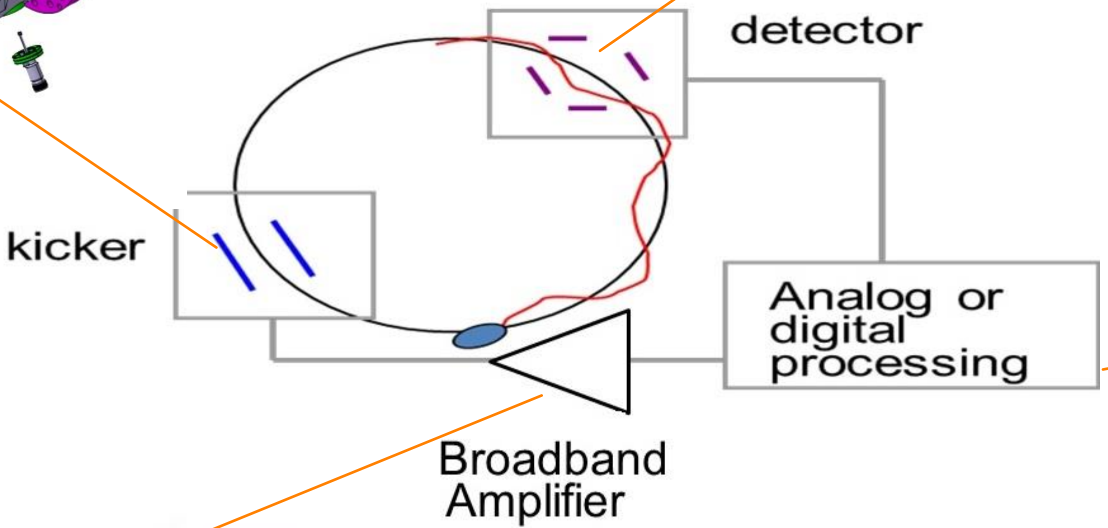
- The selection procedure for the manufacturing company is launched
- Feedback with the manufacturing company for the technical details
- Production should start in the next weeks
- The delivery time is estimated by the manufacturer at 20 weeks

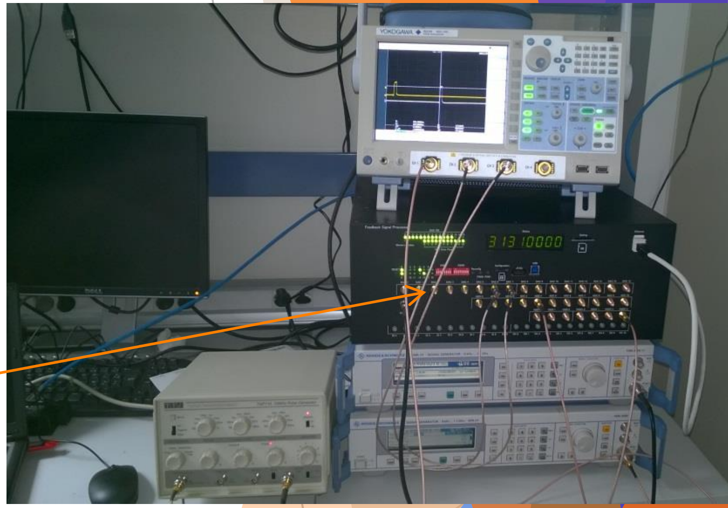
FBT system status





Mechanics and soldering are done by RIAL Vacuum





The 10W RF amplifier and 100 MHz of Bandwidth are ordered from RFPA

Electronic system provided by spring8 and new testing and adapting for Thomx specification in SOLEIL

Thank you for your attention.