Mechanical aspects of CERN GDD 10cmx10cm new PICOSEC detector

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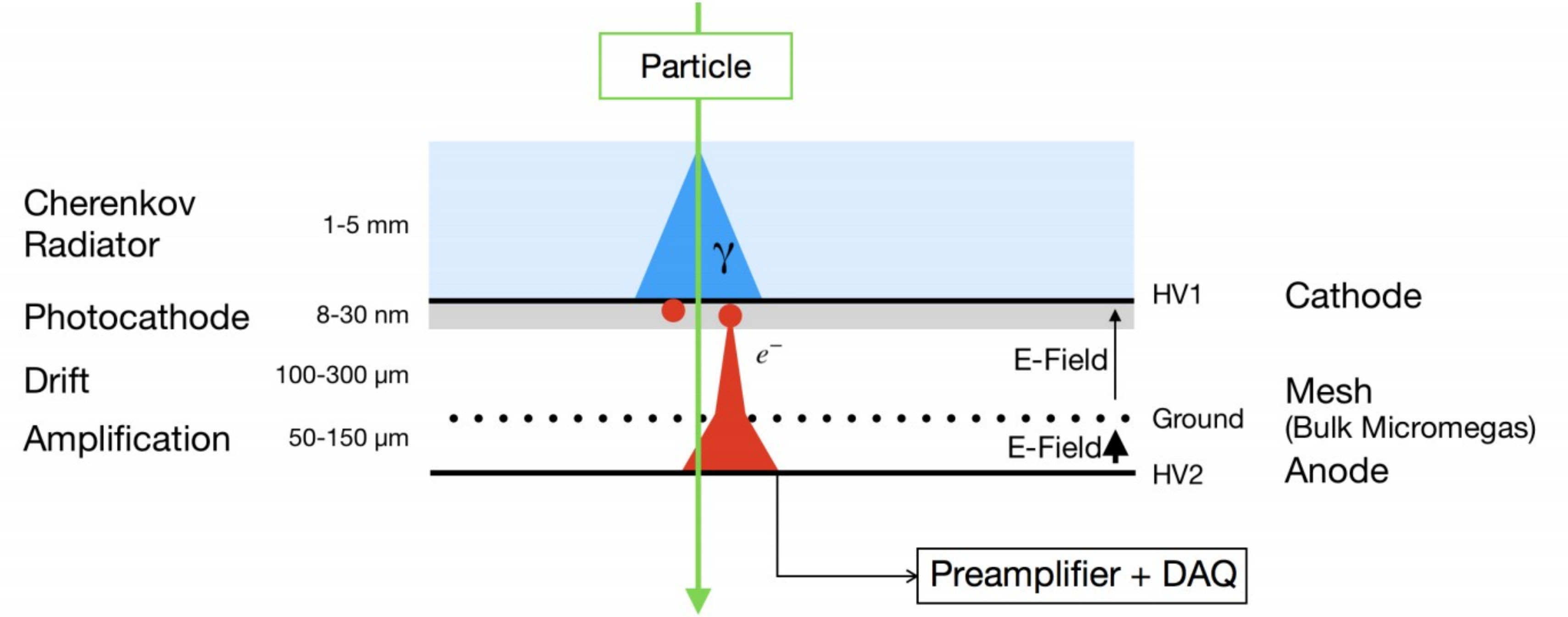
RD51 Collaboration Meeting, 26 June 2020

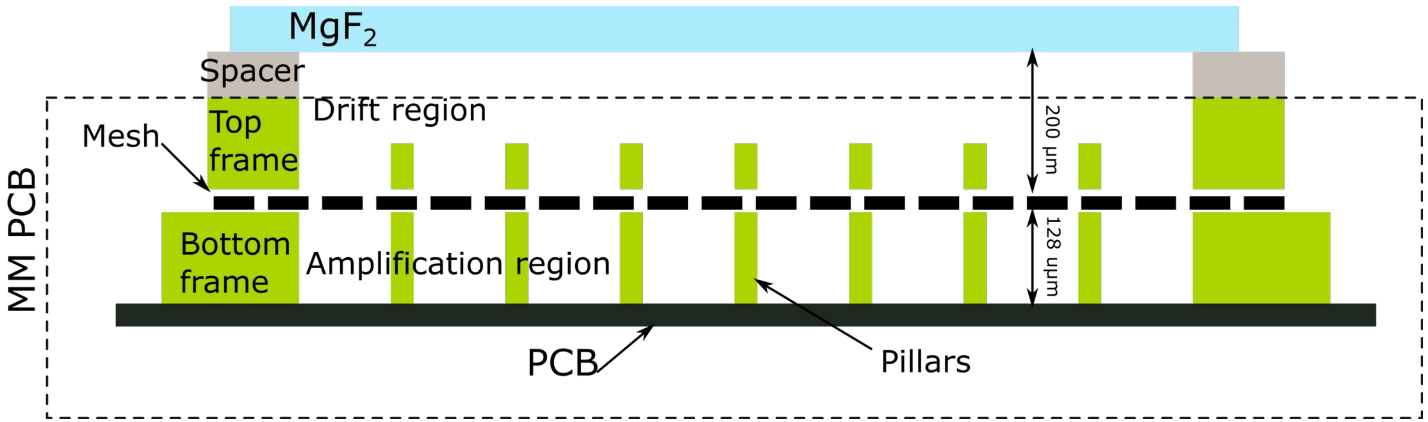
PICOSEC detector concept

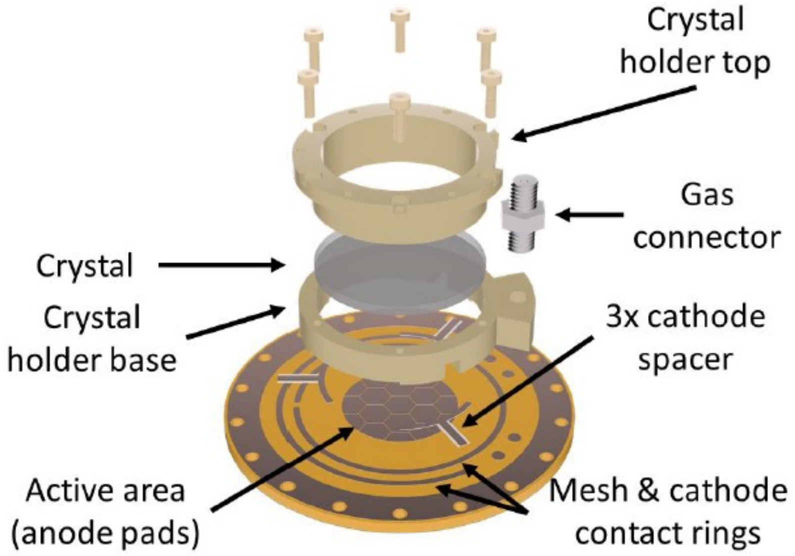


- **Purpose:** give **precise timing** information in the passage of the particle.
- **Cherenkov radiator:** the passage of relativistic charged particle creates UV photons.
- **Photocathode:** conversion of UV photons into electrons.
- **Drift /preamplification region:** Preamplification of electrons in high drift field region (~20 kV/cm)
- **Anode/amplification region:** final electron amplification in high electric field (~40 kV/cm)
- The arrival of the amplified electrons to the anode creates a fast signal (electron peak)+movement of the ions produced in the anode region generate slower component ion-tail

Bortfeldt, J., et al. "PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector." NIM A 903 (2018): 317-325.

PICOSEC geometry and first PICOSEC multipad





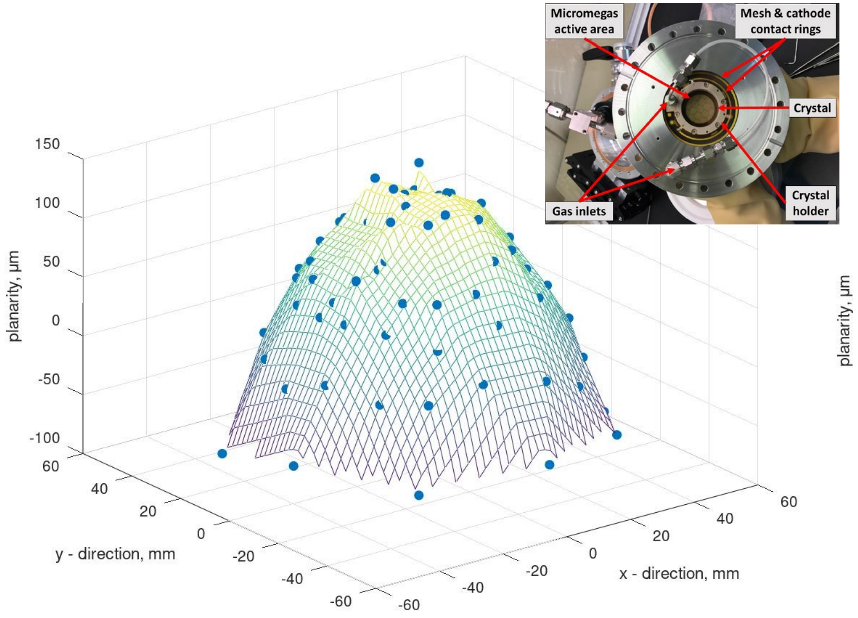
Detector consists of PCB on top of which the mesh (18 µm thin SS steel wire) is stretched over pillars and coverlay frame. The region between the mesh and MM PCB is called amplifcation region.

Region between the mesh and Cherenkov radiator (MgF2) is called the drift region. Spacer placed on top of the mesh stretching frame defines the thickness of the drift region.

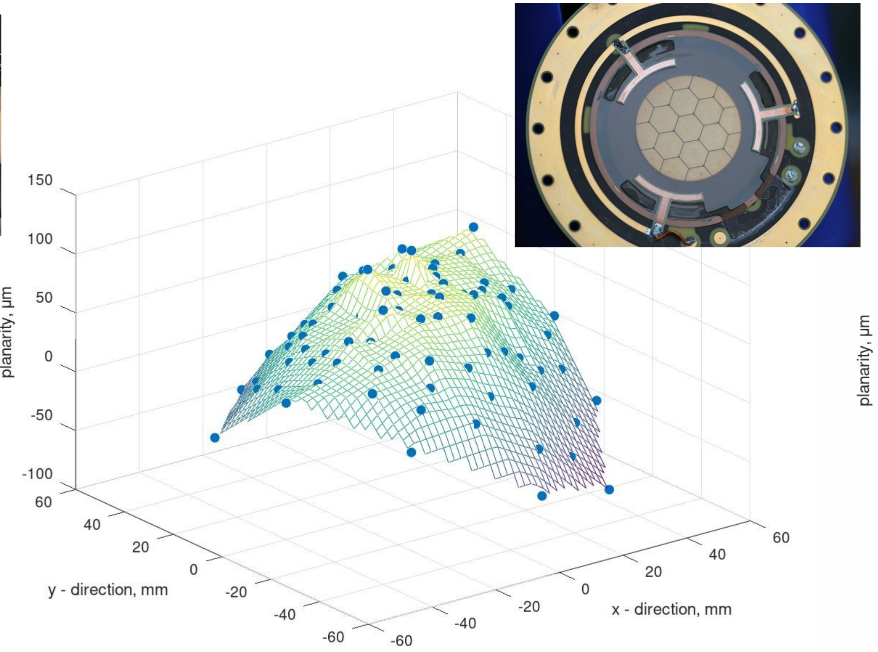
- The thickness of amplifcation region is 128 µm and the thickness of the drift region is 200 µm.
- **The first PICOSEC multipad detector** was a circular shape with 19 channels placed over 36 mm diameter active area. PCB was made of 3.2 mm thick FR4 material.
- Non-uniform detector response suggested on possible deformations in µm range of the MM PCB.

Planarity measurements of first PICOSEC multipad MM PCB

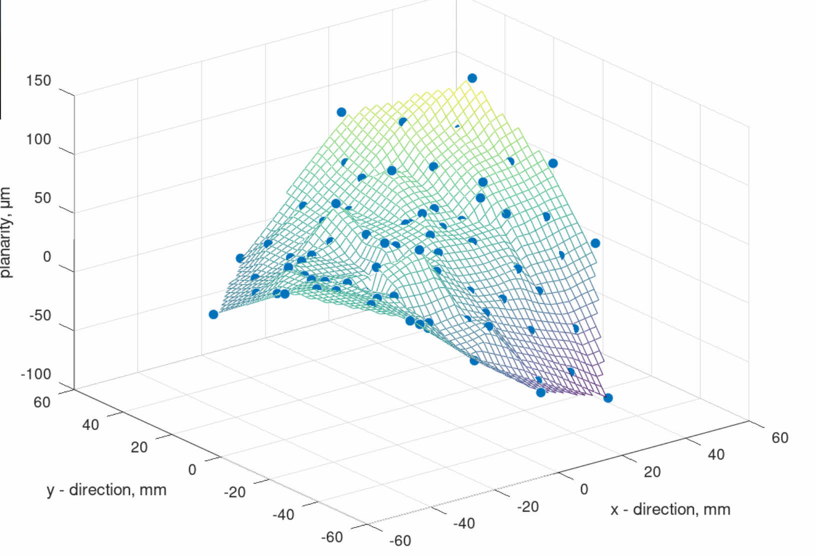
- MM PCB connected to the housing



- MM PCB disconnected from the housing



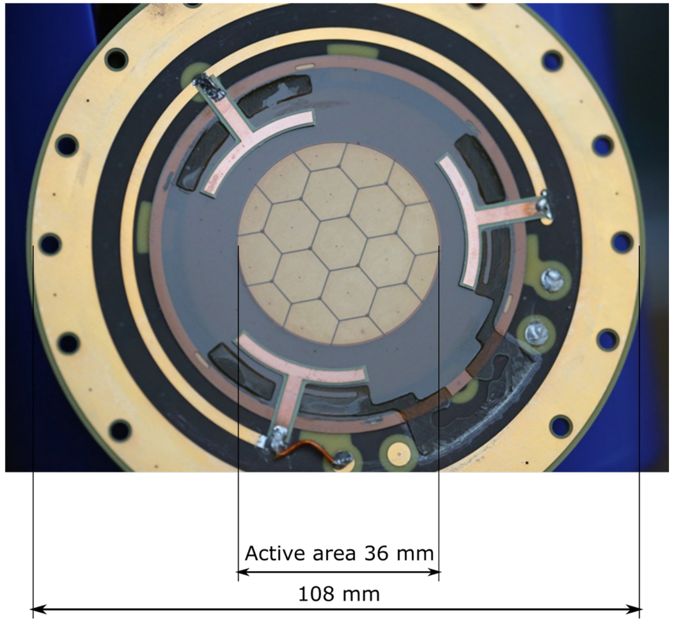
- New never used MM PCB

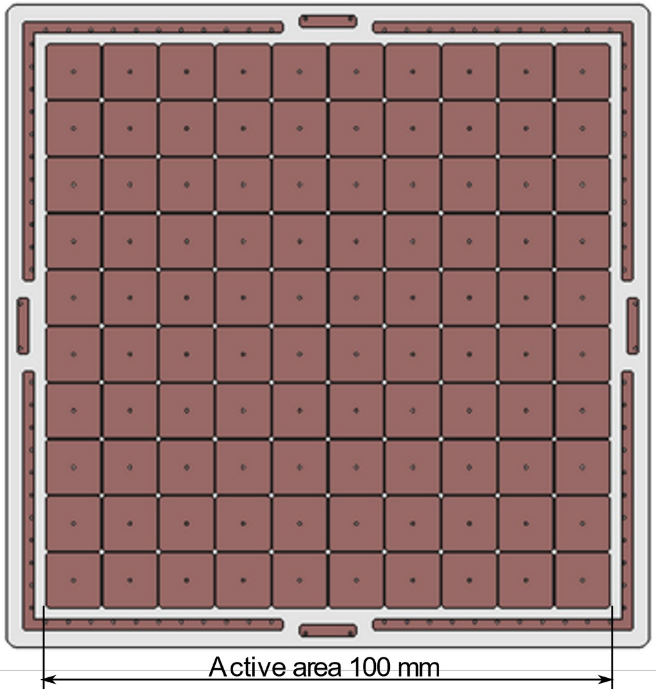


- Tens of µm deformation of the active area due to the:
  - Fixing the PCB to the flange.
  - Nonflatness of PCB itself -> possible deformation coming from the stretching of the mesh on the PCB.

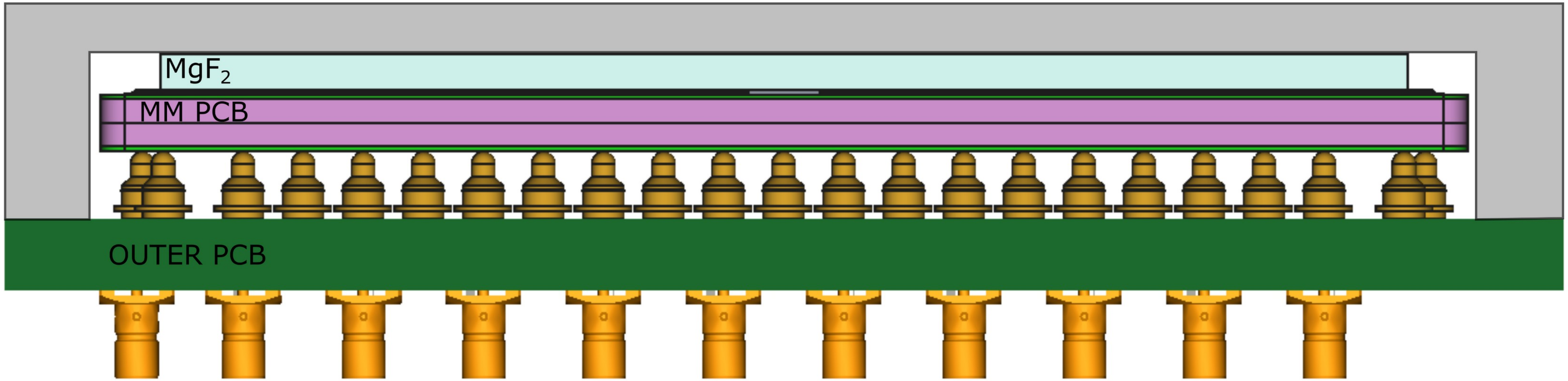
Large area PICOSEC detector concept

- Scaling up to larger-area coverage is crucial to develop an applicable PICOSEC detector.
- Increase in the active area (≈10 times) AND the number of channels (19->100)
- Much larger active area -> deformation will be even more pronounced.
- Crucial to improve in large area design:
    - Avoid the connection of the PCB to the flange.
    - Make a more rigid MM PCB board.





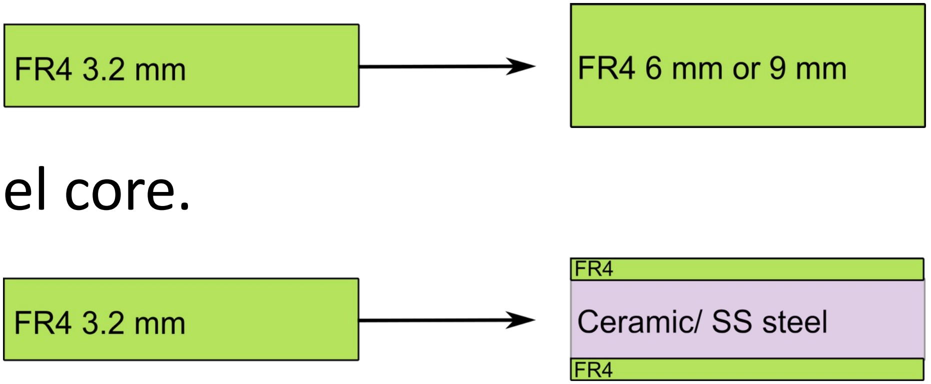
PICOSEC module cross section



- Due to the mechanical stress on the MM PCB, it was necessary to avoid the mechanical connection of the MM PCB with the housing.
- The new design includes 6 mm thick outer PCB that is screwed to the aluminum housing.
- Outer PCB is connected with MM PCB with 136 spring loaded pins (100 for signal + 32 for mesh connection + 4 for cathode connection)

Planarity simulation driven design of MM PCB

- How to improve board rigidity:
  - Use a more thicker FR4 board.
  - Use embedded board with ceramic or SS steel core.



FR4 3.2 mm → FR4 6 mm or 9 mm

FR4 3.2 mm → FR4 / Ceramic/ SS steel / FR4

- CERAMIC or thicker FR4?

- **Structural simulations** of the board deformations under mesh tension.
  - Use the simulation of the MM board deformation in the detector design phase to choose board material and thickness.
  - **Objective:** minimize the deformations if possible below 10 um.

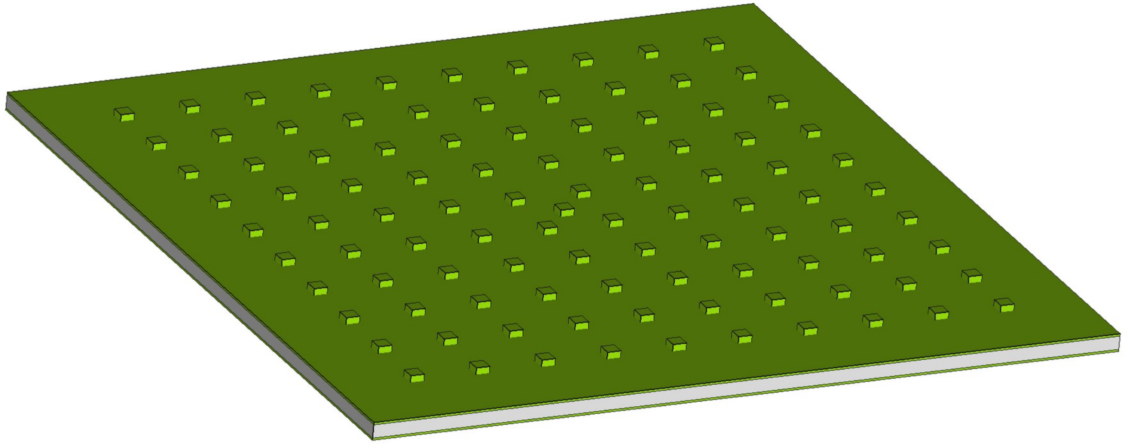
FEM calculation (FreeCAD + Gmsh + CalculiX)

- Objectives:
  - Analysis of mesh tension effect on planarity
  - Analysis of spring-loaded contacts (pogo-pins) pressure on planarity
  - Analysis of both effects on planarity
- Input data:
  - Spring loaded contacts pressure 100 x 35 g (Mill-Max 72 spring)
  - Mesh tension: 15 N/cm
- Material properties:

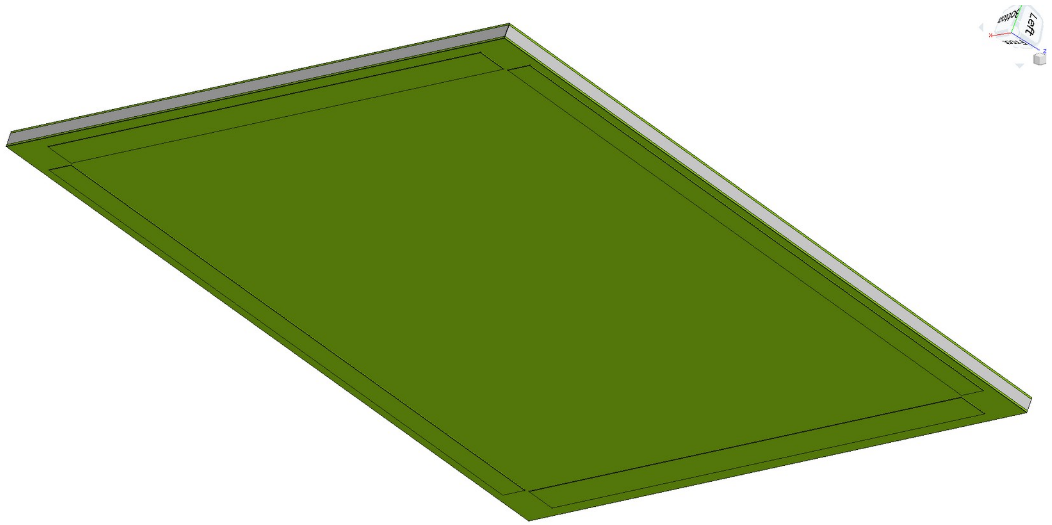
Material	Young's modulus	Poisson's ratio	Tensile strength	Mass density	Source
Al_2O_3 ceramics	**215** – 413 GPa	0,21 – **0,33**	**88** - 165 GPa	3 – **3,98** Mg/m^3	azom.com
FR4 - coverlay	**21** – 24 GPa	0,12 – **0,14**		1,85 Mg/m^3	wikipedia

FEM calculation – model description

- Geometry greatly simplified to sandwich of ceramics and two FR4 layers.
- Influence of via holes neglected.
- 100 rectangular „pressure points” for pogo-pin force application.
- Amplification gap included to introduce shear force of the mesh tension.



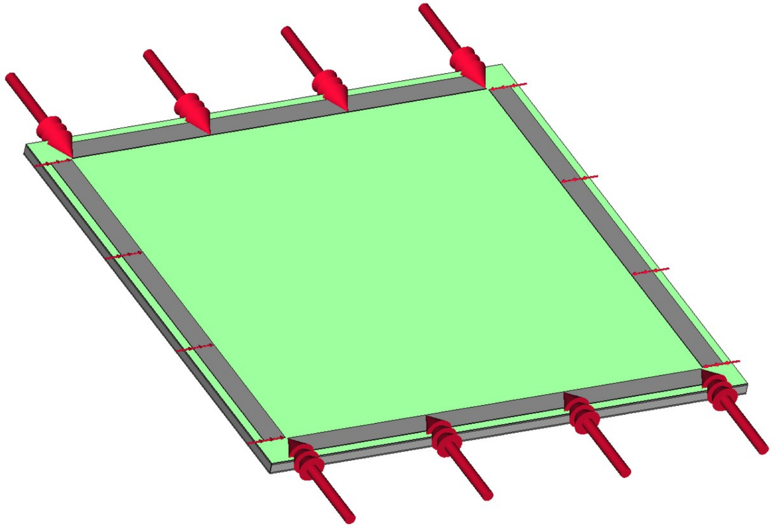
Back side (towards pogo-pins)



Front side (towards radiator)

FEM calculation – mesh tension influence

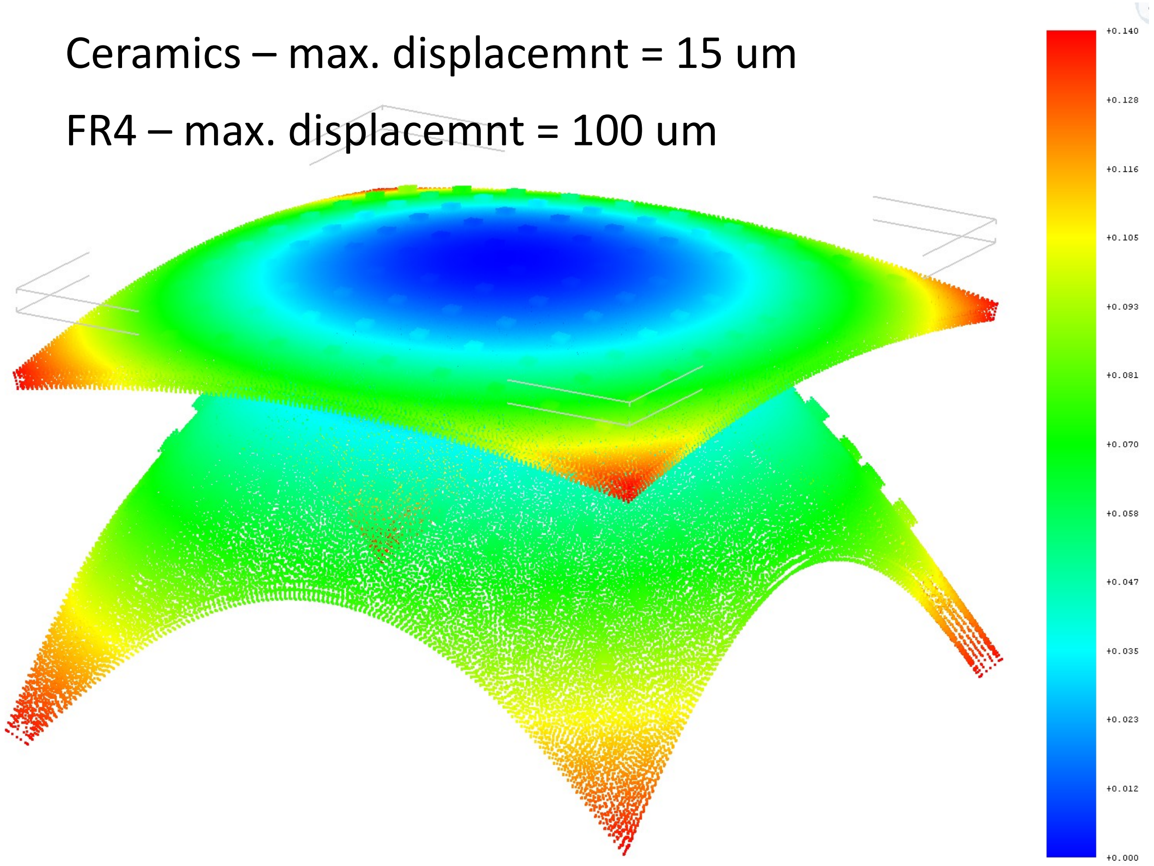
- Shear force of 15 N/cm on coverlay faces directing towards the active area.
- Difference between Al203 hybrid board and standard FR4 investigated.
- Top point of „dome” fixed.



Front view (towards radiator)

Ceramics – max. displacemnt = 15 um

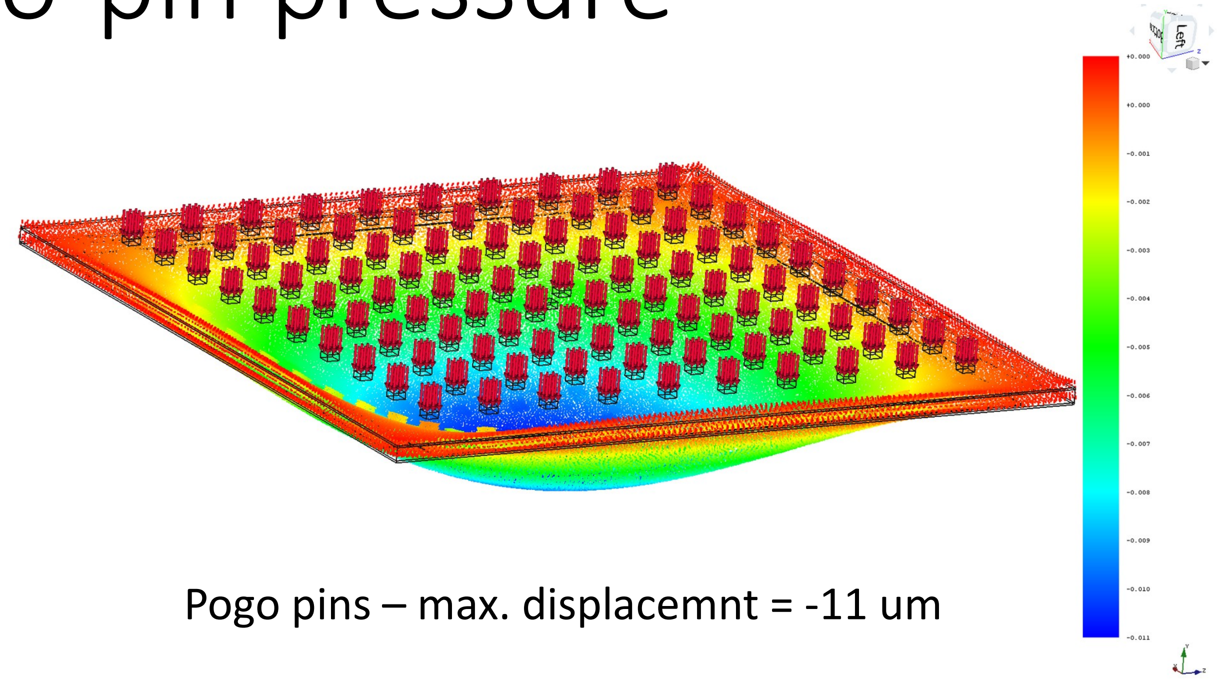
FR4 – max. displacemnt = 100 um



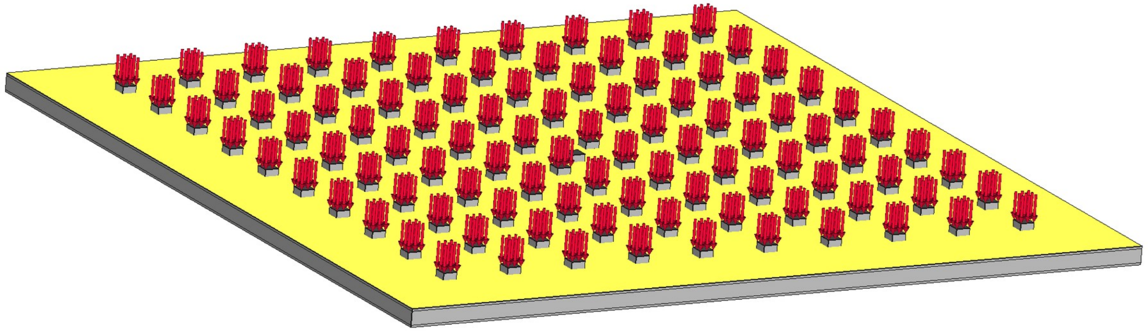
- Increasing thickness of the ceramic core to 3 mm could be considered.
- Simulation greatly depends on boundary conditions, especially mating to the radiator which is not taken into account here.

FEM calculation – pogo-pin pressure

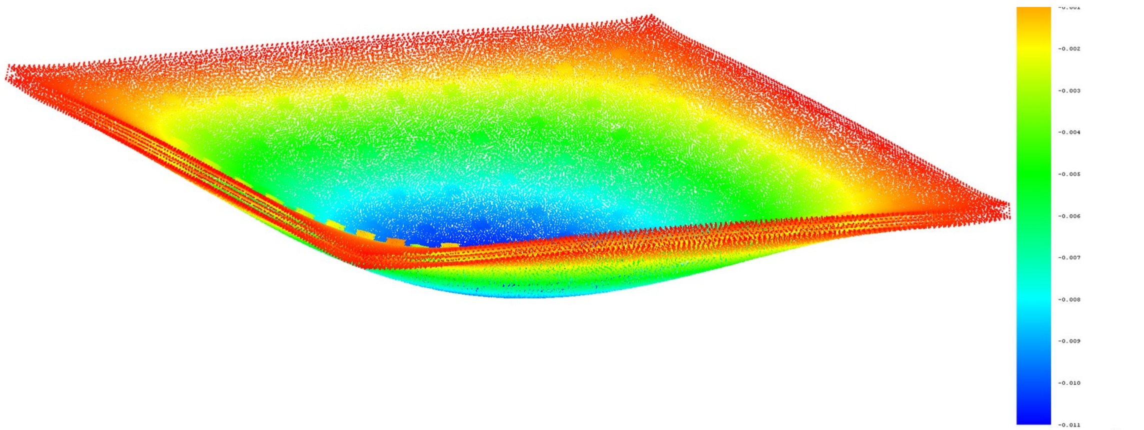
- Force of 35 g applied to 100 pressing points.
- Mesh tension force disabled.
- Dome to other direction appears
- Deformation numbers similar as the mesh tension, but other direction
- Could both effects counteract?



Pogo pins – max. displacemnt = -11 um

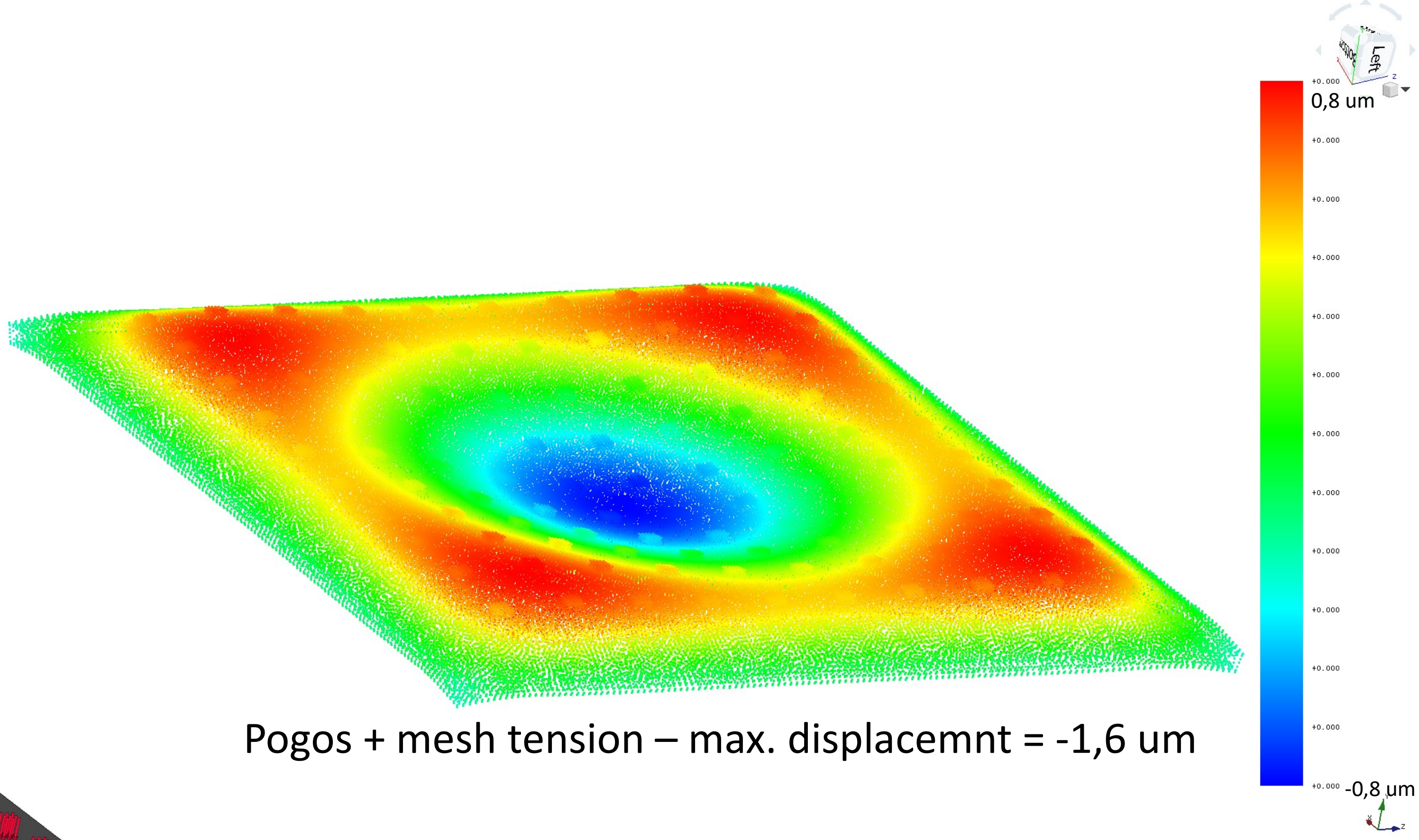


Top view (towards pogo-pins)

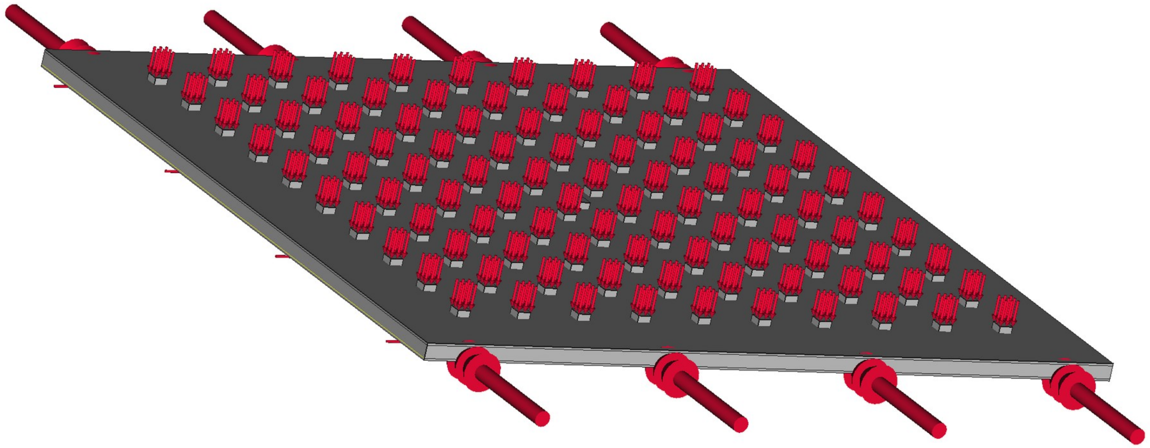


FEM calculation – pogo-pin + mesh tension

- Effects seem to counteract, but this is a dangerous conclusion.
- Pogo-pin pressure is greatly influenced by the geometry and tolerances and cannot be taken as accurate.

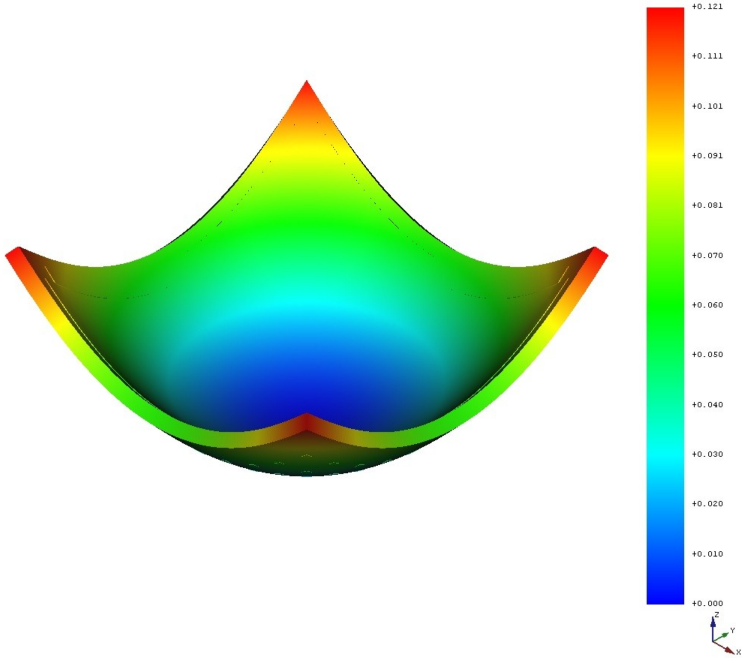


Pogos + mesh tension – max. displacemnt = -1,6 um

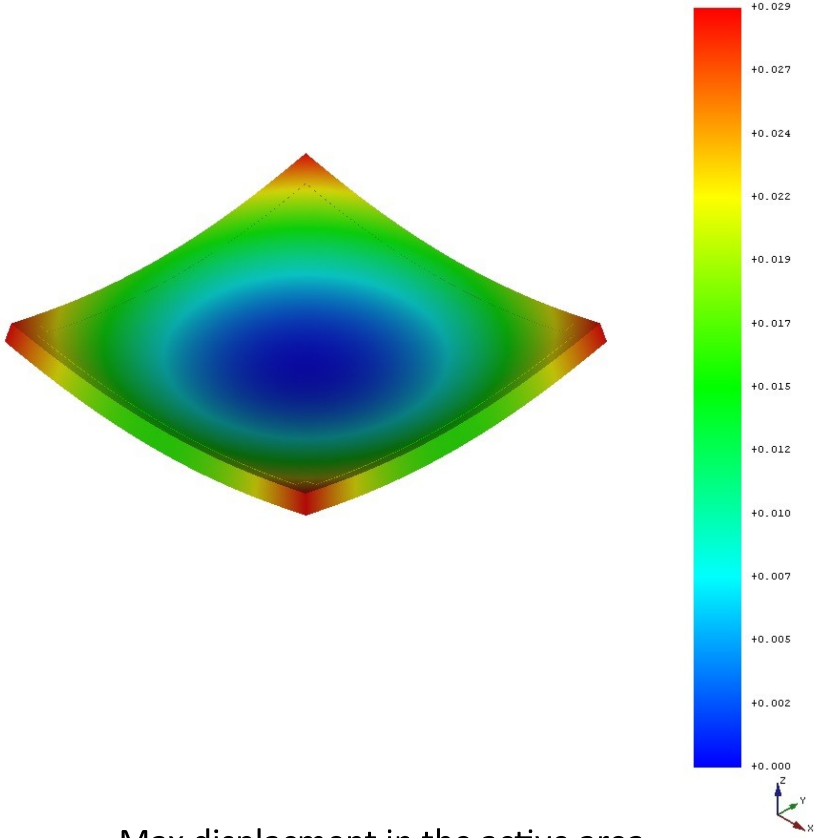


Top view (towards pogo-pins)

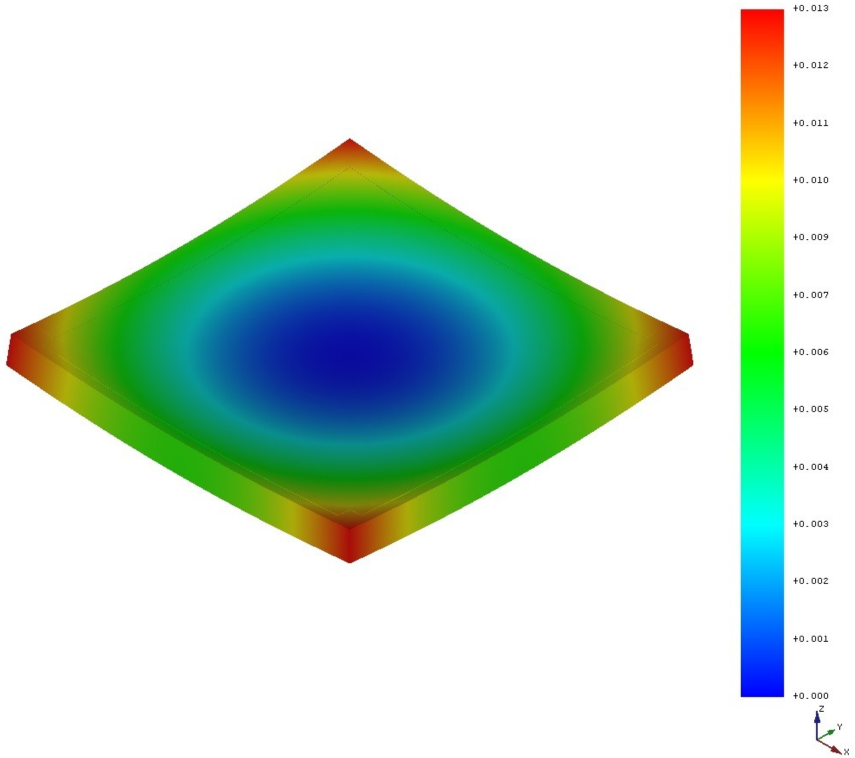
Simulation of the mesh tension influnce for 3, 6 and 9 mm FR4 board.



Max displacment in the active area
is around 100 um.

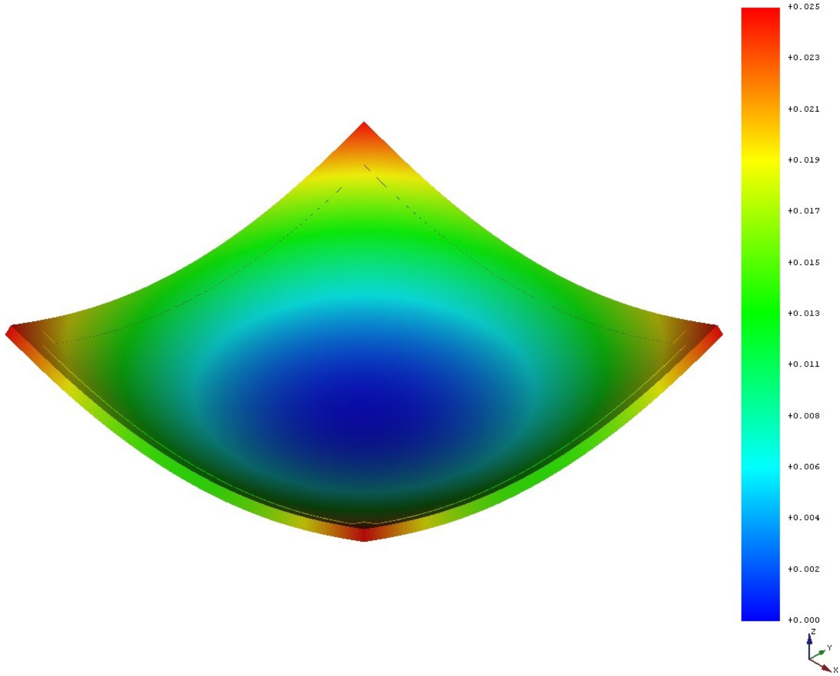


Max displacment in the active area
is around 20 um.

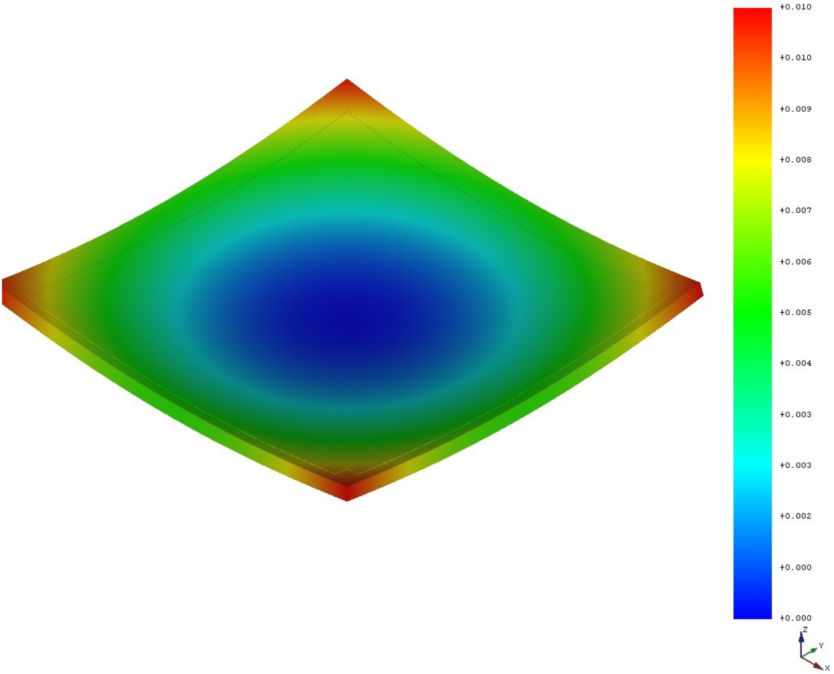


Max displacment in the active area
is around 10 um.

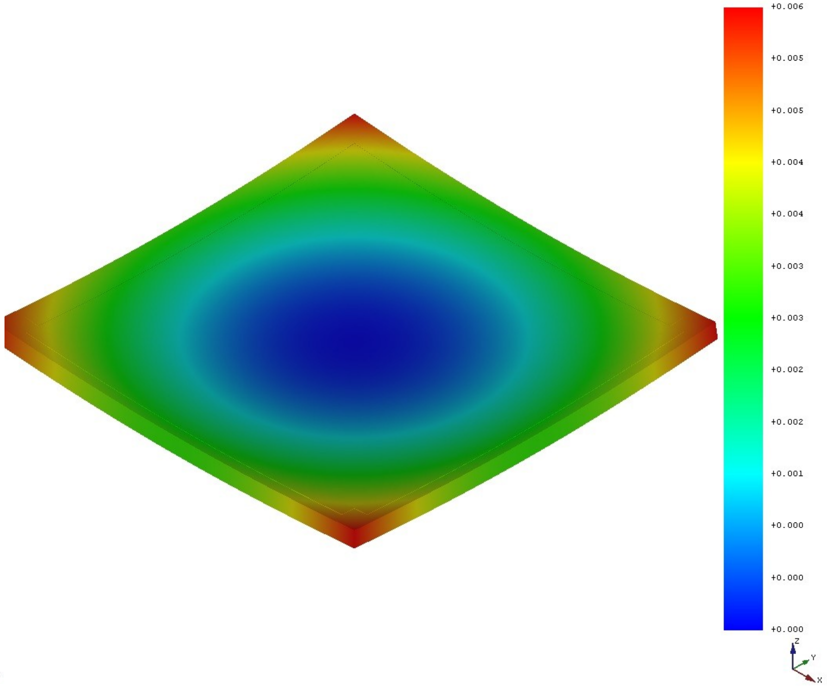
Mesh tension influence for 2, 3 and 4 mm thick ceramic



Max displacment in the active area is around 17 um.



Max displacment in the active area is around 8 um.



Max displacment in the active area is around 4 um.

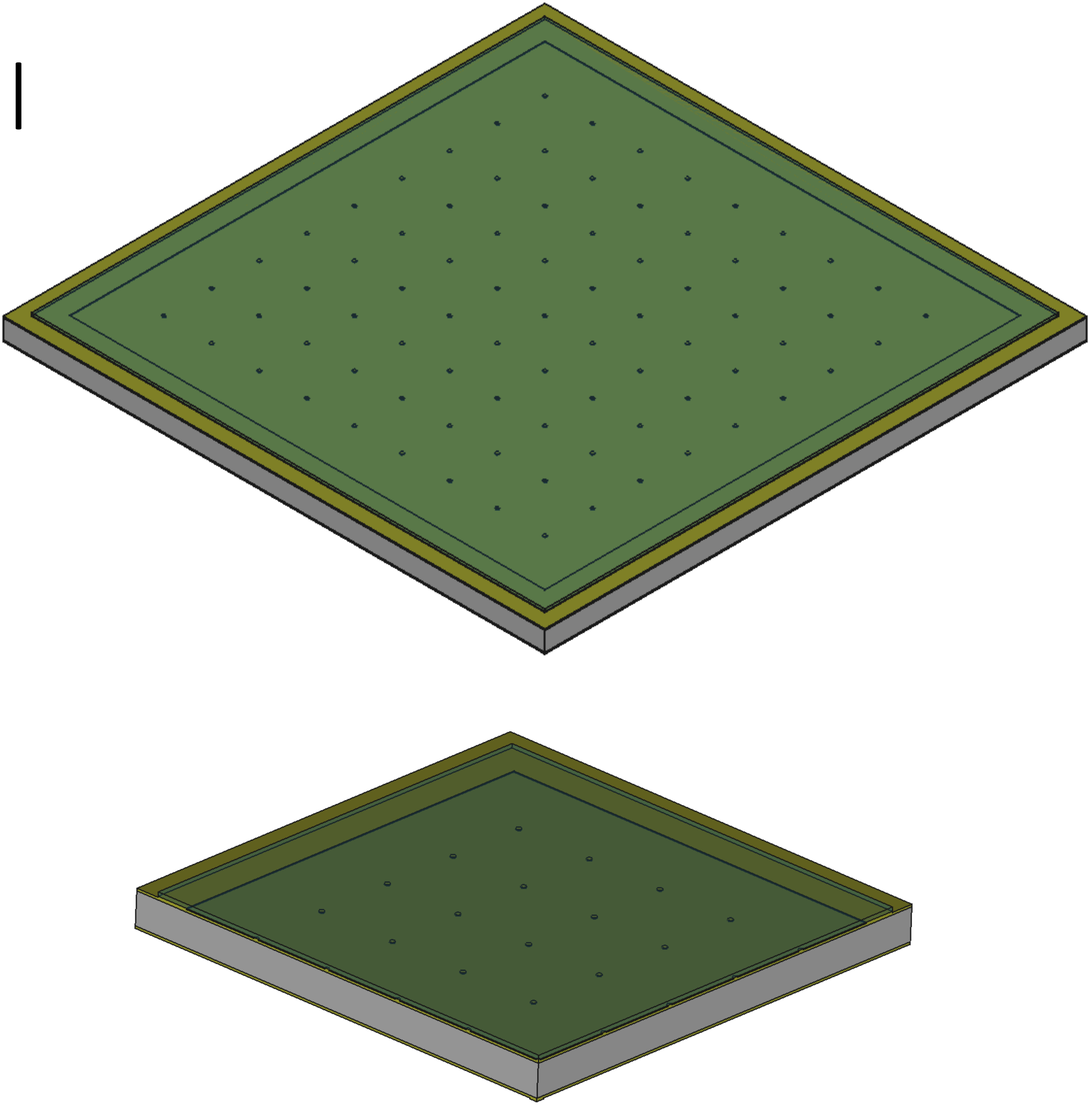
Summary

MM Board type	Thickness	Max. deformation	Max. deformation in active area
FR4	3 mm	121 µm	91 µm
	6 mm	29 µm	20 µm
	9 mm	13 µm	10 µm
Hybrid ceramic FR4 board	2 mm ceramic, 2x0.3 mm FR4	25 µm	17 µm
	3 mm ceramic, 2x0.3 mm FR4	10 µm	8 µm
	4 mm ceramic, 2x0.3 mm FR4	6 µm	4 µm

Usage of the FR4 board results with much thicker board: 2 mm hybrid ceramic board≈ 8 mm FR4.
Big gains in planarity can be seen in small increases of the ceramic thickness.

Simulations of the final design

- Simulation of mesh and pillars influence on the planarity of 100 cm^2 active area.
- 81 pillars added to the active area.
- Difficult to simulate the entire MM PCB due to the very fine mesh required in the pillars area.
- Only ¼ of the MM PCB used for simulation.
- The symmetry of the PCB board enables the usage of much finer 3D mesh.

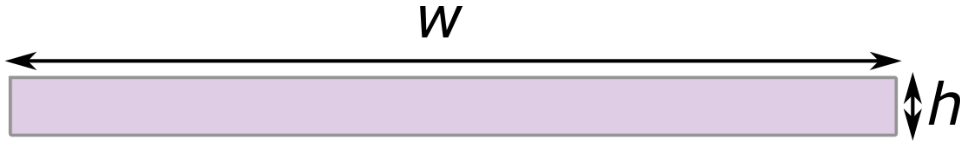


Pseudo-thermal simulation

- Idea: use thermo-mechanical FEM simulation to model the tension of the mesh.
- Calculation of „MESH”/ pseudo-material properties:

$$E=\frac{\sigma}{\varepsilon};\sigma=\frac{F}{A};\varepsilon=\frac{\Delta L}{L}=\alpha\,\Delta T$$

$$E=\frac{F/A}{\alpha\,\Delta T}=\frac{F/w}{\alpha\,\Delta Th}\qquad \Delta T=\frac{\gamma}{E\,\alpha\,h}$$

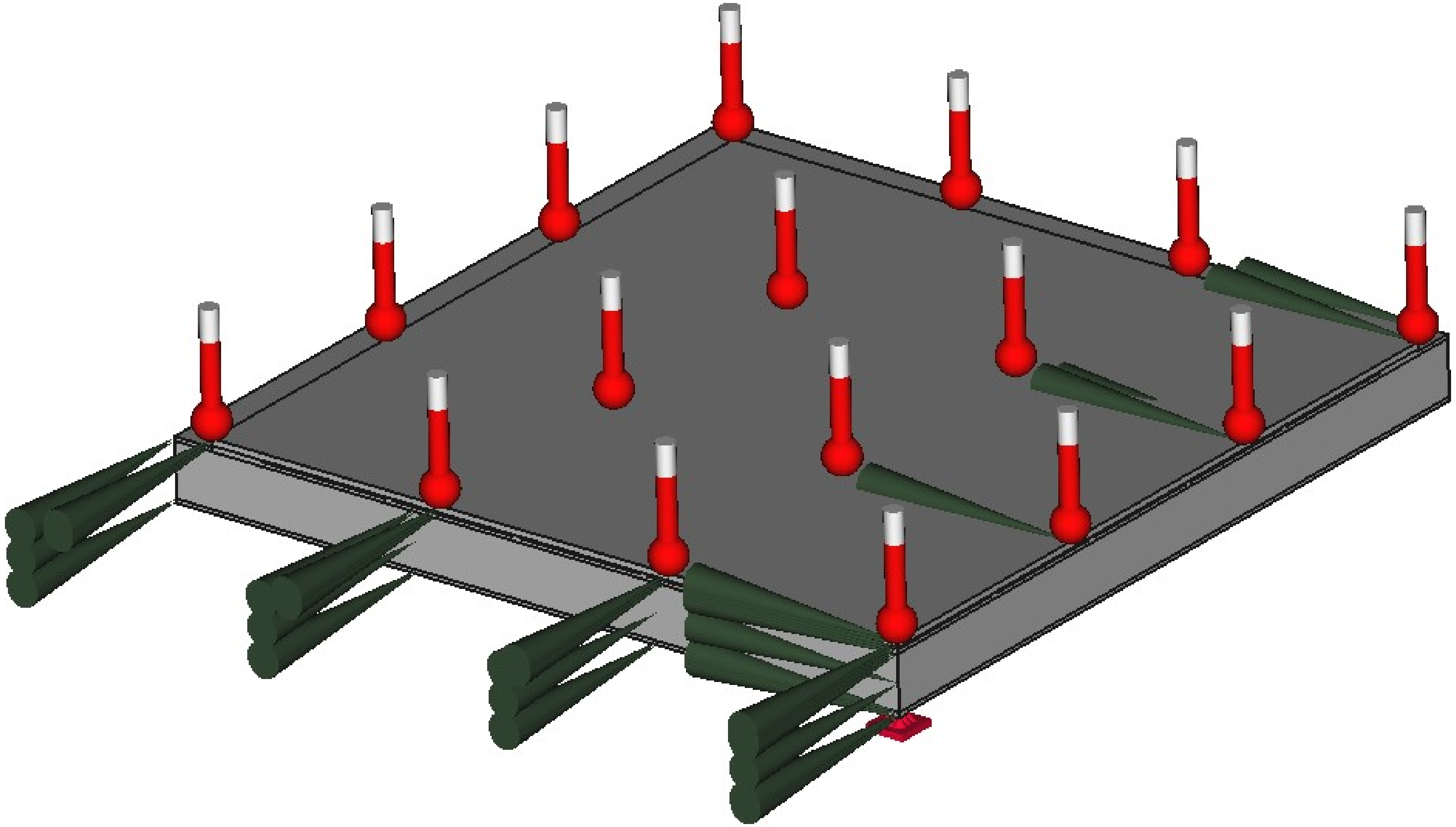


- Youngu’s modul is chose to be 1GPa because it has to be significatly smaller than one for the PCB material in order not to influence overall rigidity.
- γ is 15 N/cm, with chosen *E* = 1 GPa, $\alpha=50*10^{-6}K^{-1}$ and *h* = 0.5 mm .
- This gives ΔT=-60 K
- In order to all of this to work the Poisson’s ratio of the mesh needs to be zero.

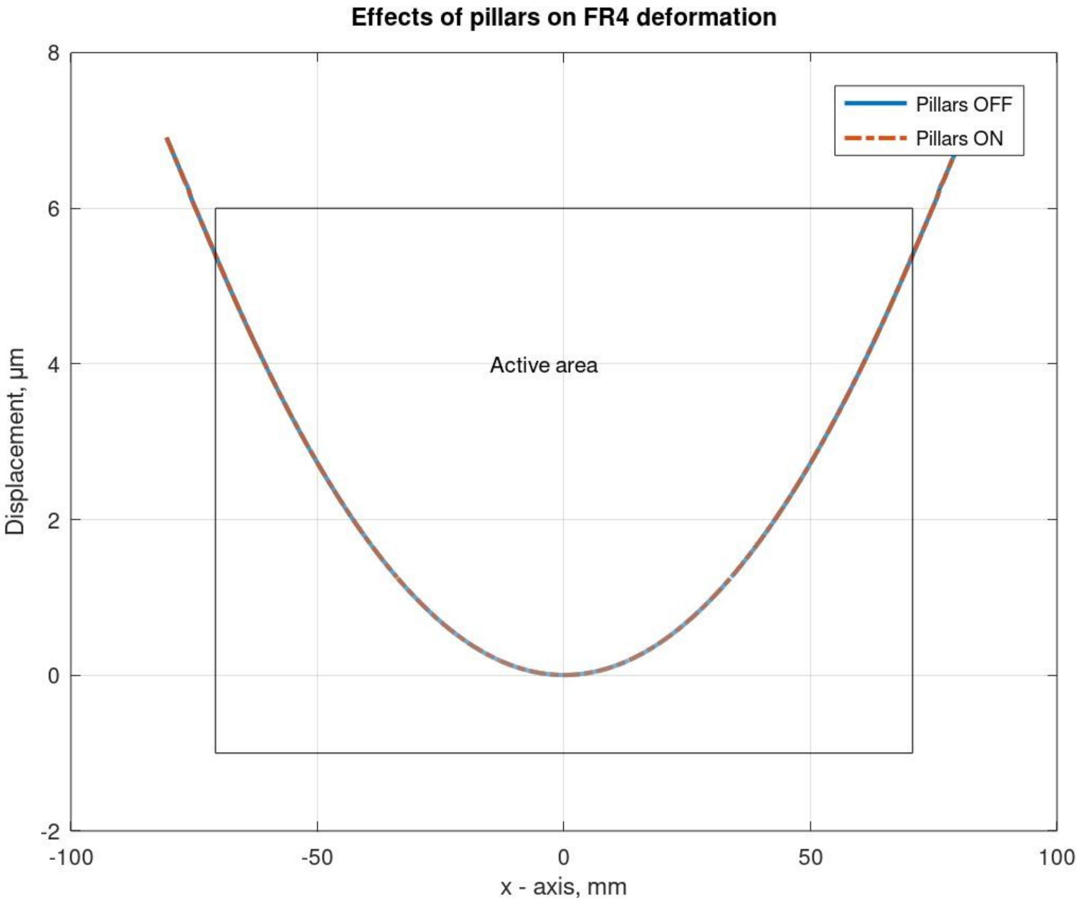
Material	Young’s modulus	Poisson’s ratio	Thermal conductivity	Expansion coefficient
FR4 - coverlay	21 GPa	0,14	1 $Wm^{-1}K^{-1}$	**0 um/m/K**
Mesh	1 GPa	**0**	1 $Wm^{-1}K^{-1}$	**50 um/m/K**

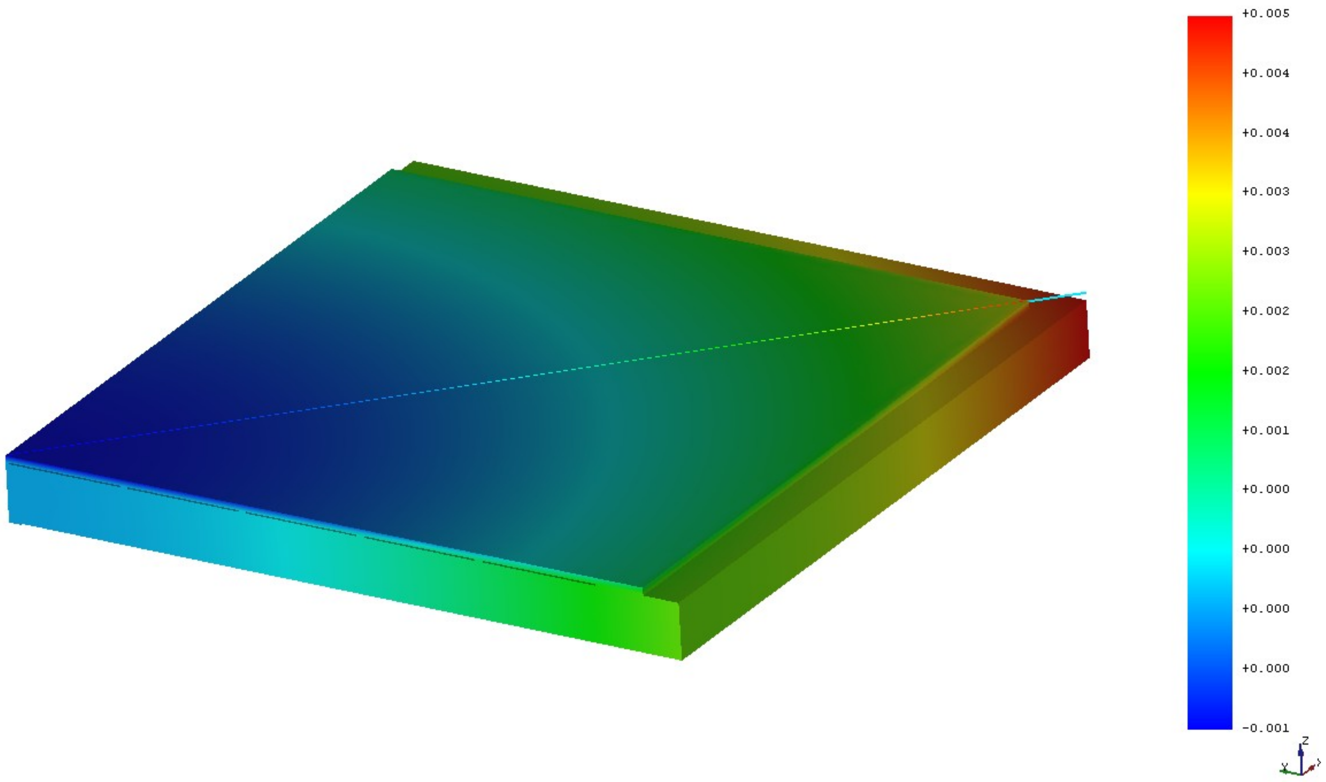
Boundary conditions for cut-out model

- Initial temperature acting on body 300 K (zero strain temperature)
- 240 K temperature acting on the mesh.
- Fixed bottom side center.
- Cutted sides are sliding in *xz* and *yz* planes.



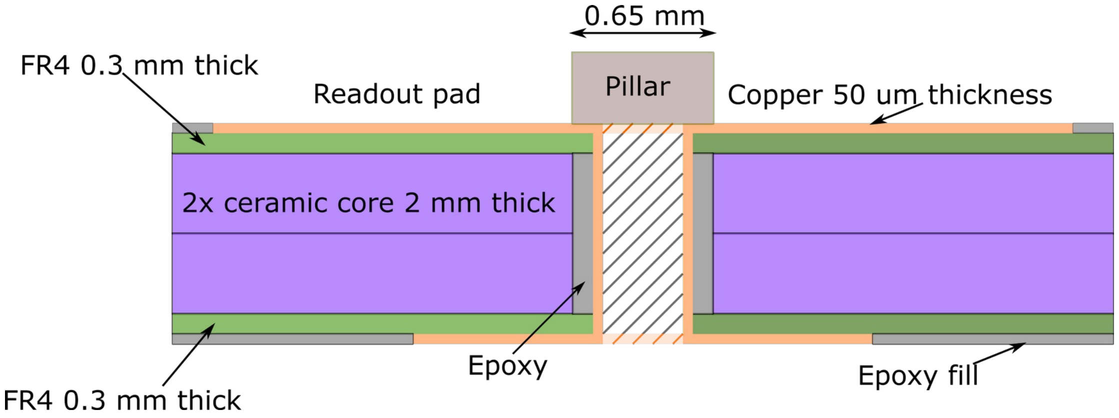
Deformation of the MM board

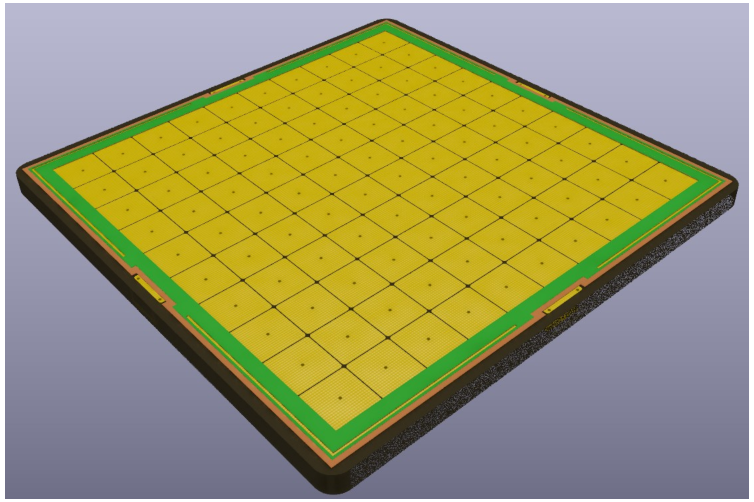

Effects of pillars on FR4 deformation

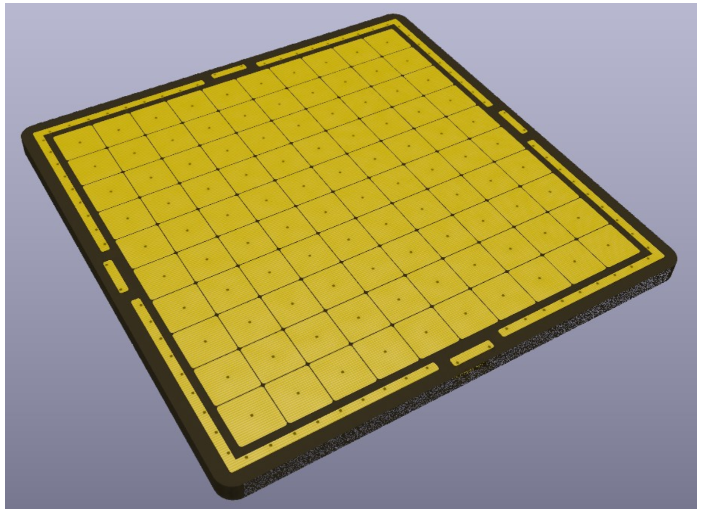


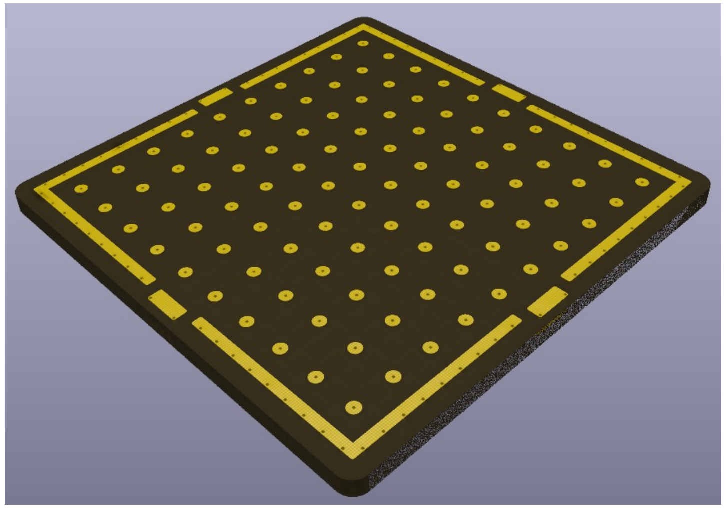
Final design of the MM PCB

- **Ceramic embedded PCB:**
  - **2x 2 mm ceramic core** with 0,35 mm thick top and bottom FR4 layer.
- **Pads:**
  - Square shape (9.82 mm x 9.82 mm) with rounded corners.
  - 0.2 mm distance between the pads.
- **Pillars:**
  - Placed in the center of each pad and in between pads.
  - 0.65 mm in diameter, distance between the pillars ~7.1 mm.
  - Vias in the middle of the pad are closed and plated with copper so pillar can be placed on top.









Conclusion

- Multichannel PICOSEC sets tough requirements on uniformity and thus planarity of used components.
- The planarity issue is addressed by using rigid materials such as hybrid ceramic-FR4 board and avoiding as much as possible mechanical stress to the MM board.
- Initial structural simulations were made using open-source tools to check how the mesh tension and contact pressure influence the planarity.
- Simulation suggest that big gain in planarity can be achieved by small increase in ceramics thickness.
- Safety factor to the calculated deformations has to be applied.
- Other possible source of deformation than the mesh tension (difference in CTE of FR4 and copper, losing mesh tension over time) have to be considered.
- The plan is:
  - to be involved in the manufacturing process of MM PCB and conduct planarity measurements before and after mounting the mesh.
  - make functional test of the detector and think about the optimization of the PCB thickness if the planarity measurements show that PCB is overdesigned.