Mechanics + Cooling

Julian Becker, Seungyu Rah, Helmut Hirsemann

AGIPD meeting 09.04.13

Overview

- Mechanics
- Integration at SPB instrument
- Cooling concept & plant
- Thermal simulations
- Summary

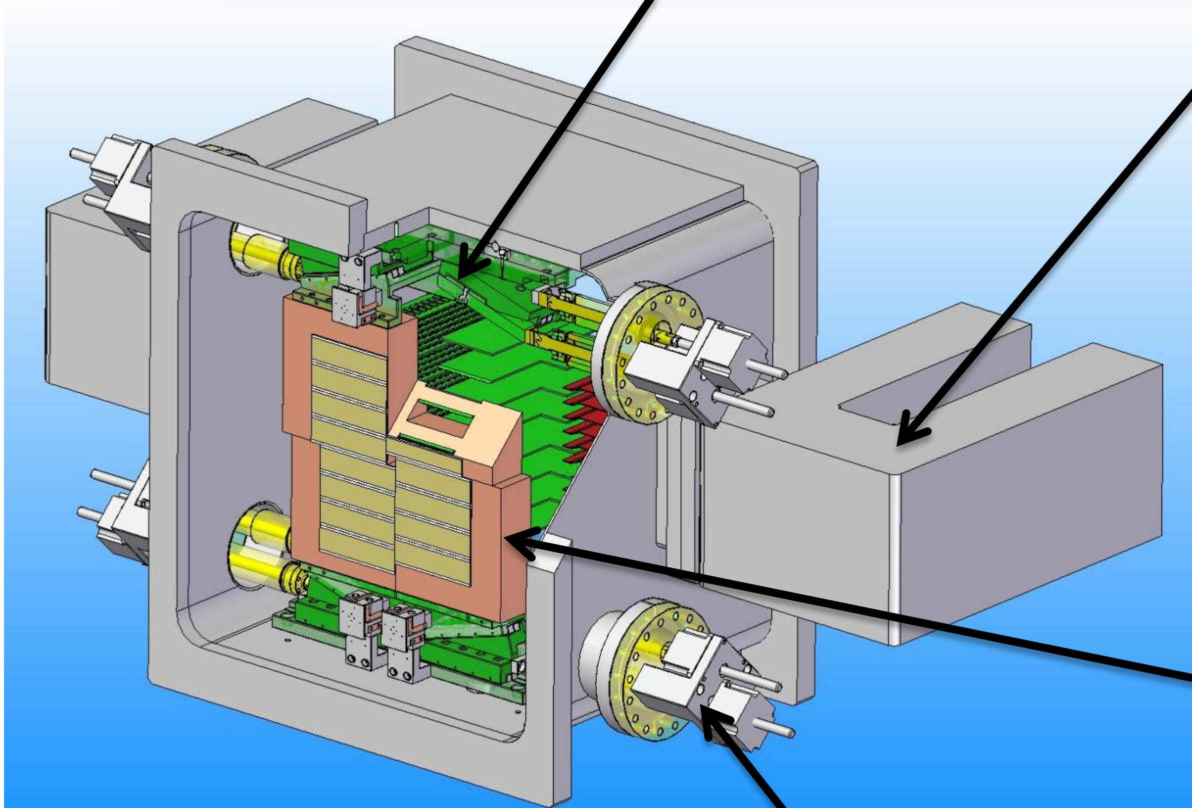
Mechanics

- Global view
- LTCC
- Movement system
- Flexible pipes inside the vacuum
- Assorted other bits & pieces

Mechanical concept of AGIPD

Motion system

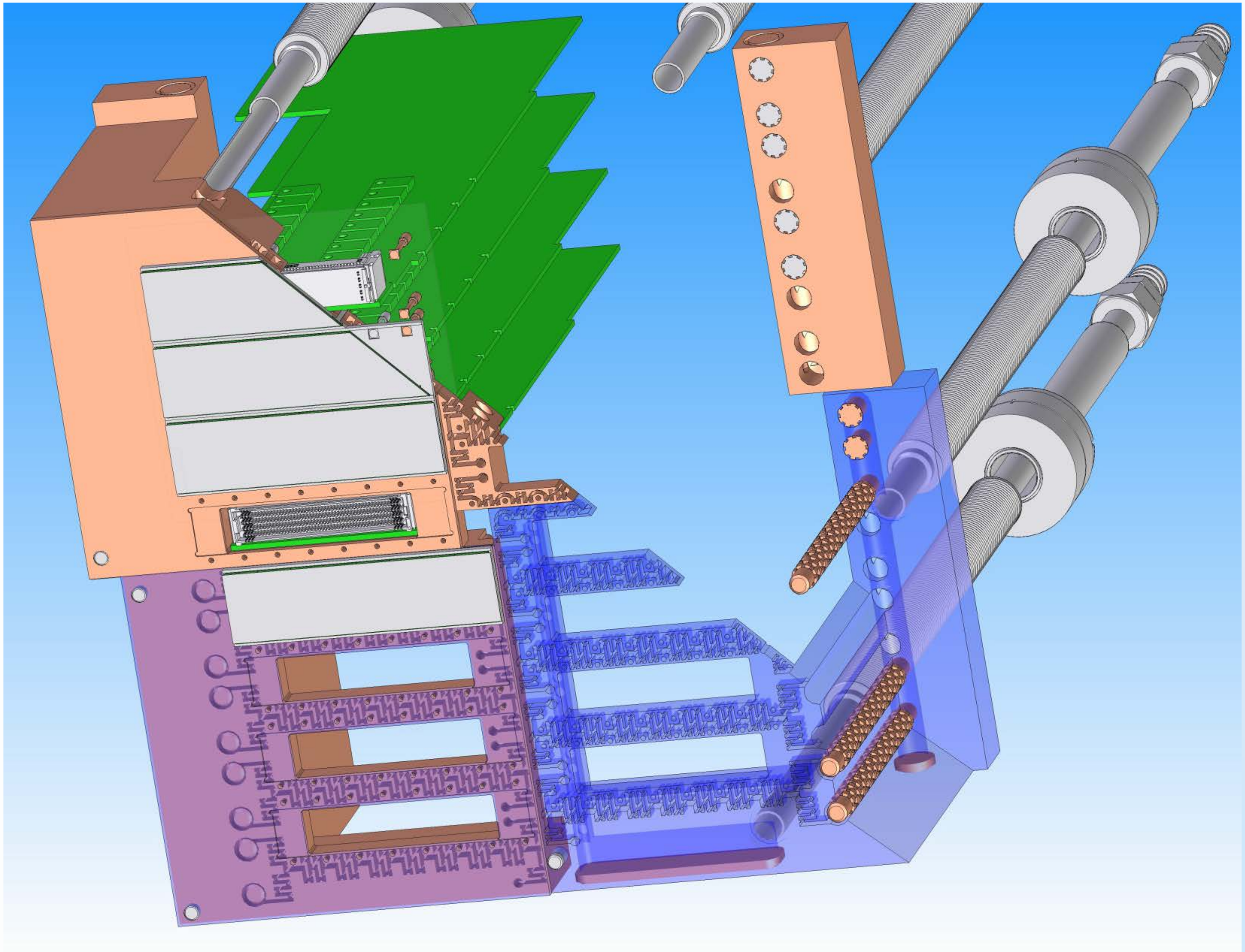
Closed air loop
around electronics



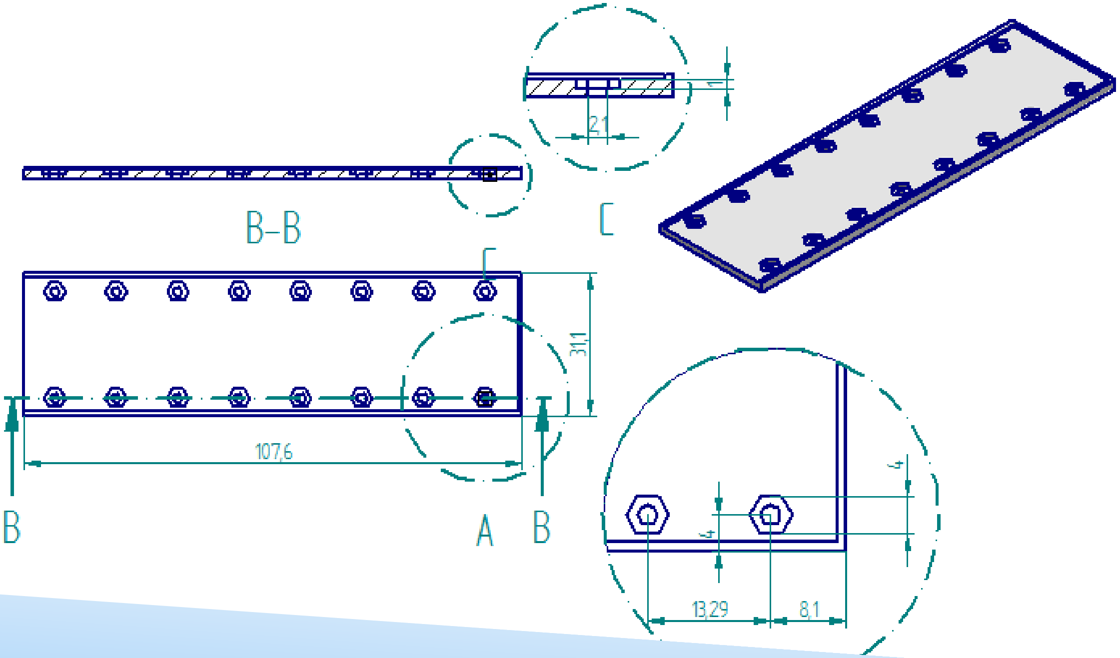
Cooling block

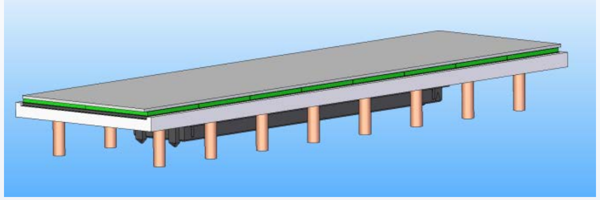
External motors ~ 6W each
Easy to service

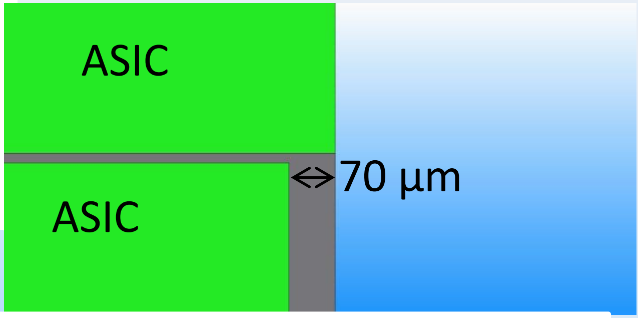
Cross section



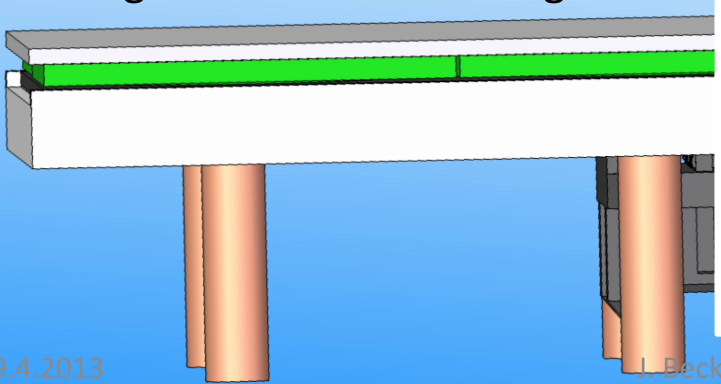
Preliminary dimensions







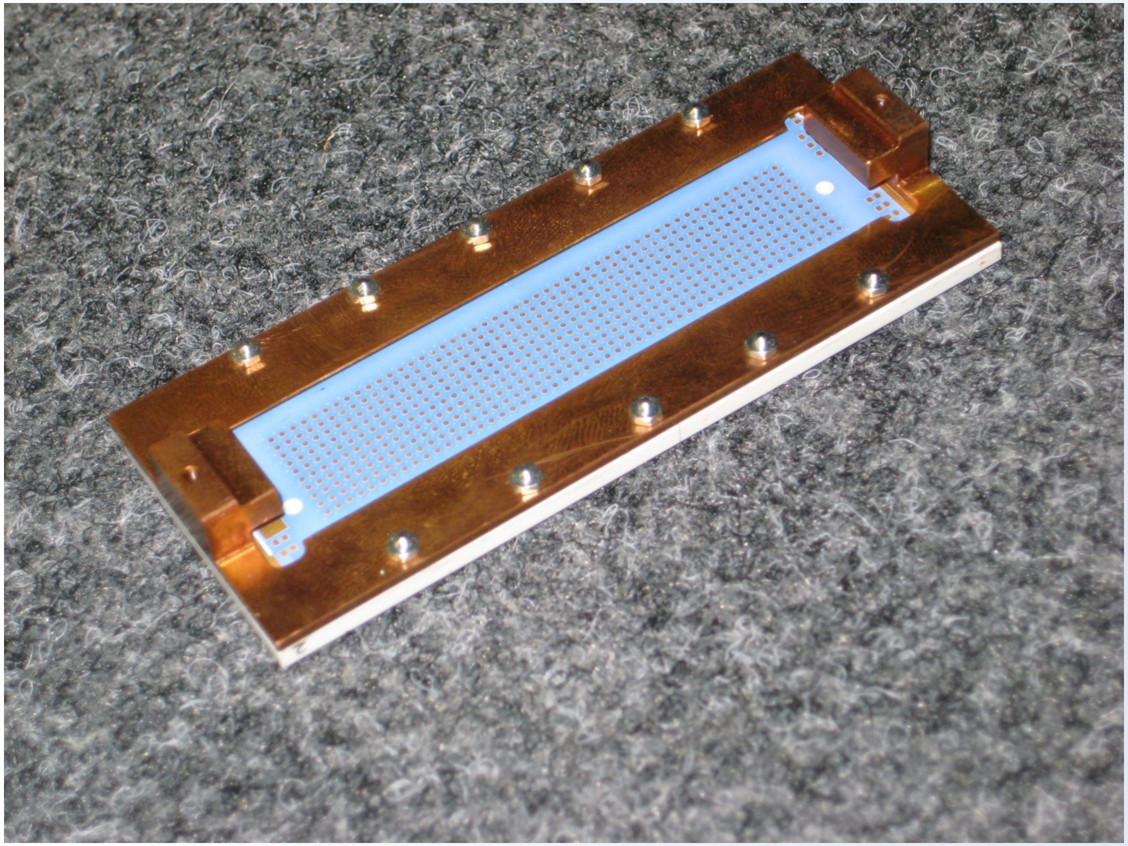
Matching LTCC and sensor length



IF these value become final **AND** 200/100 µm gap on short/long edge are realized
-> 1 pixel less dead space than in spec sheet

Deformation test

LAMBDA ceramics screwed to copper heat sink with 10x M 1.4, without any preparations

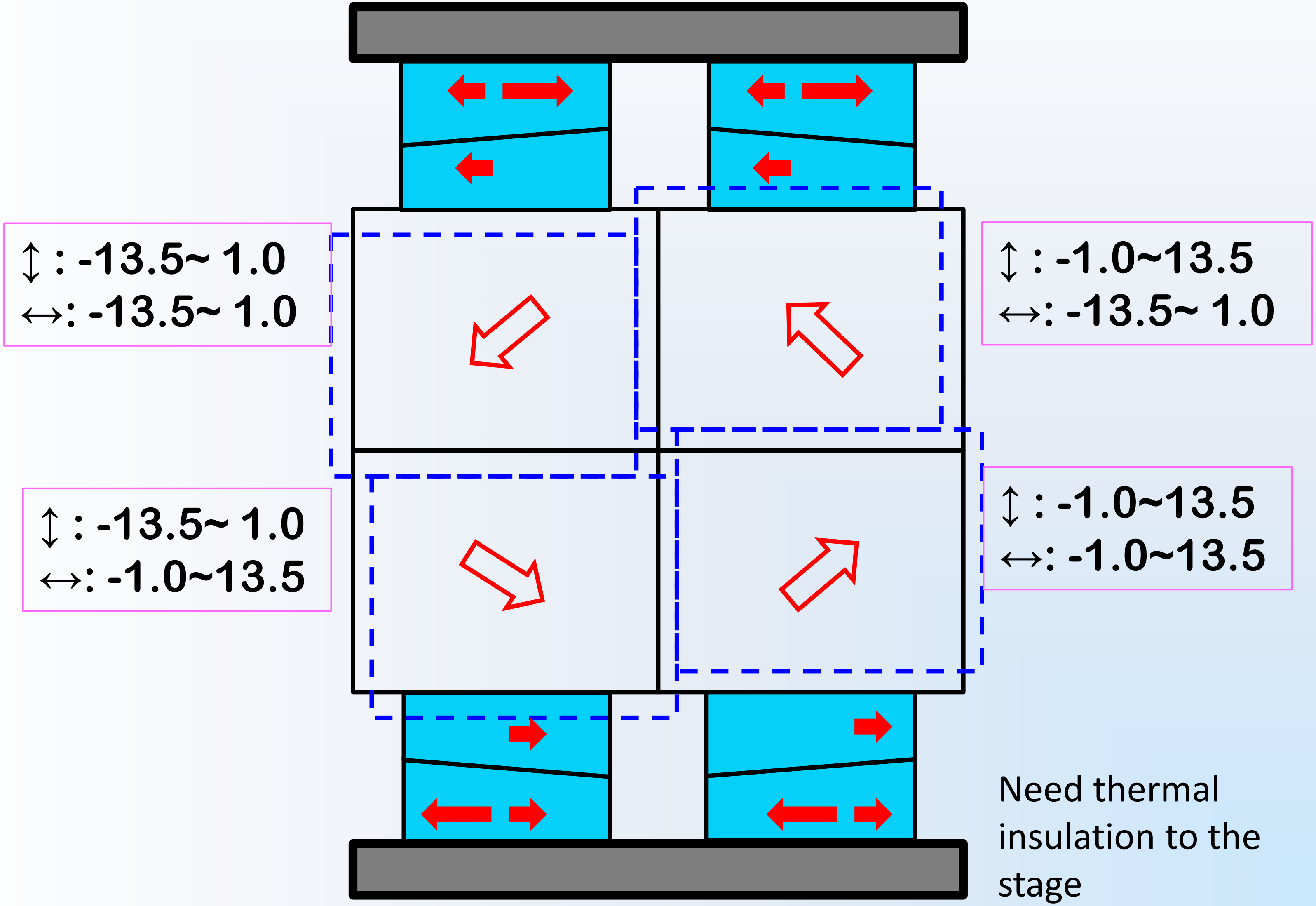


Heatcycle Test:

- Heated up to +50 °C (1h)
- Cooled down to -50°C (1h)
- 50 cycles

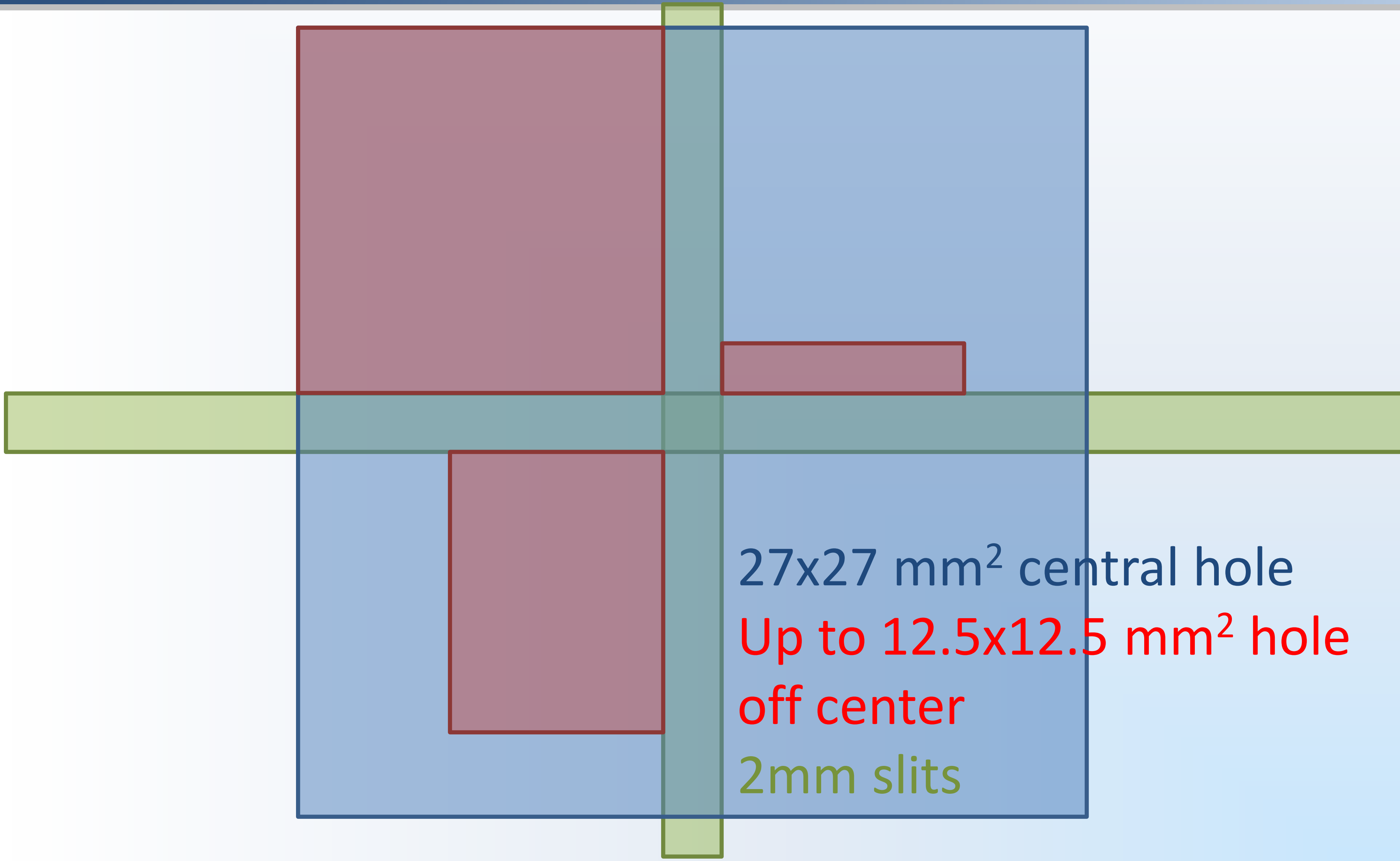
⇒ No visible damages

Image plane movement



Need thermal insulation to the stage

Possible holes

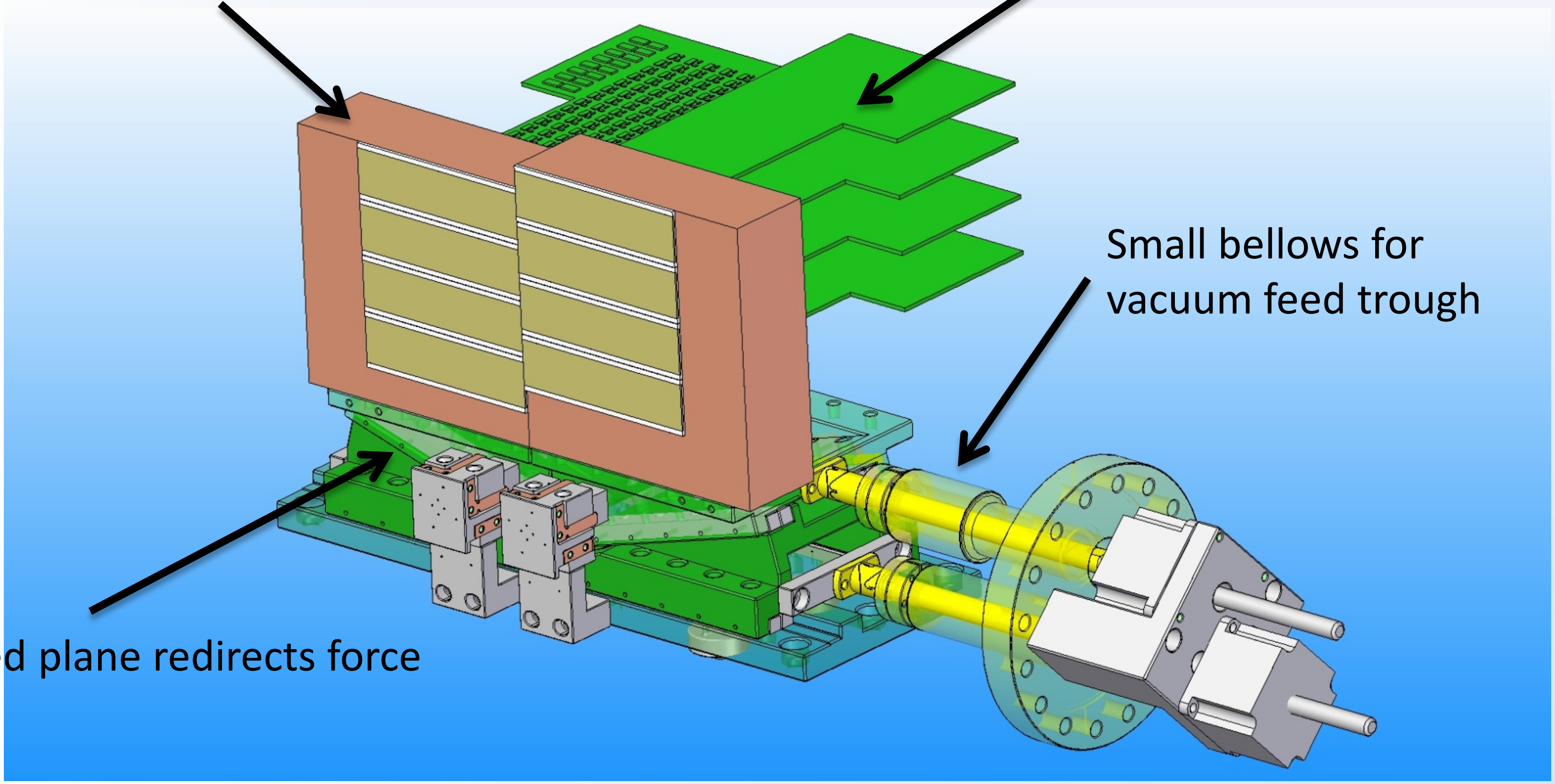


Motors

Quadrant cooling block

Vacuum board

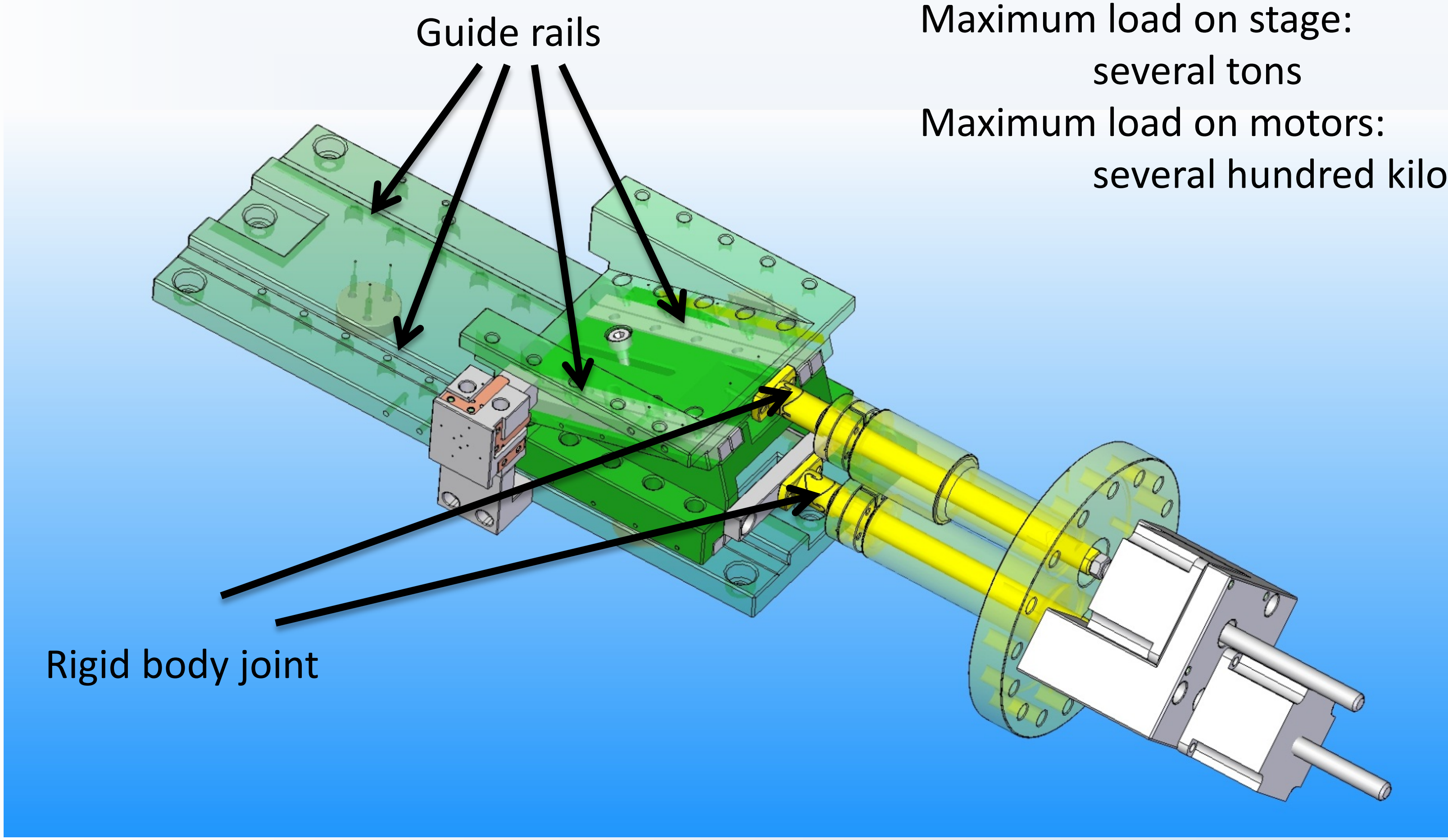
Small bellows for
vacuum feed trough



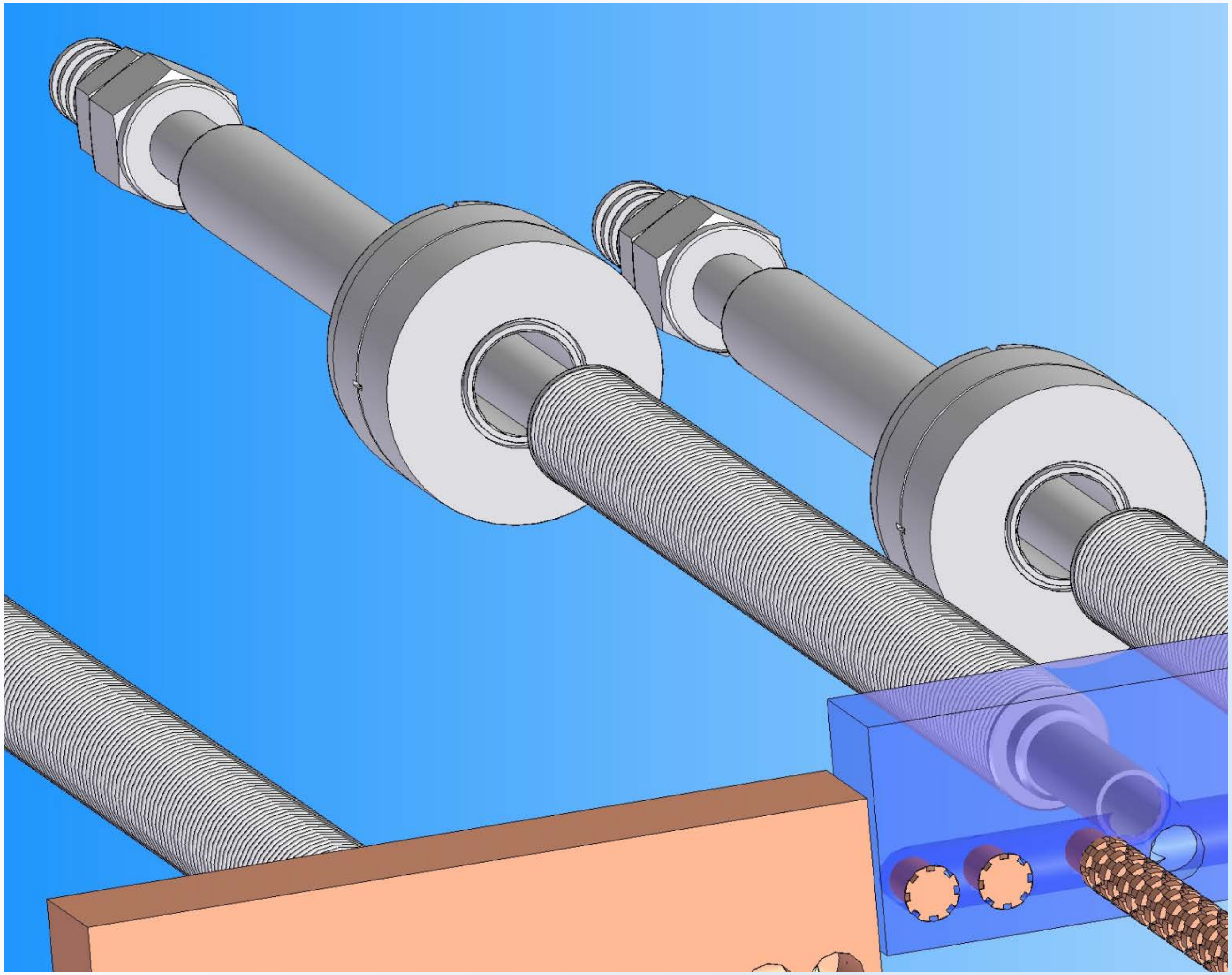
Inclined plane redirects force

Sliding stage

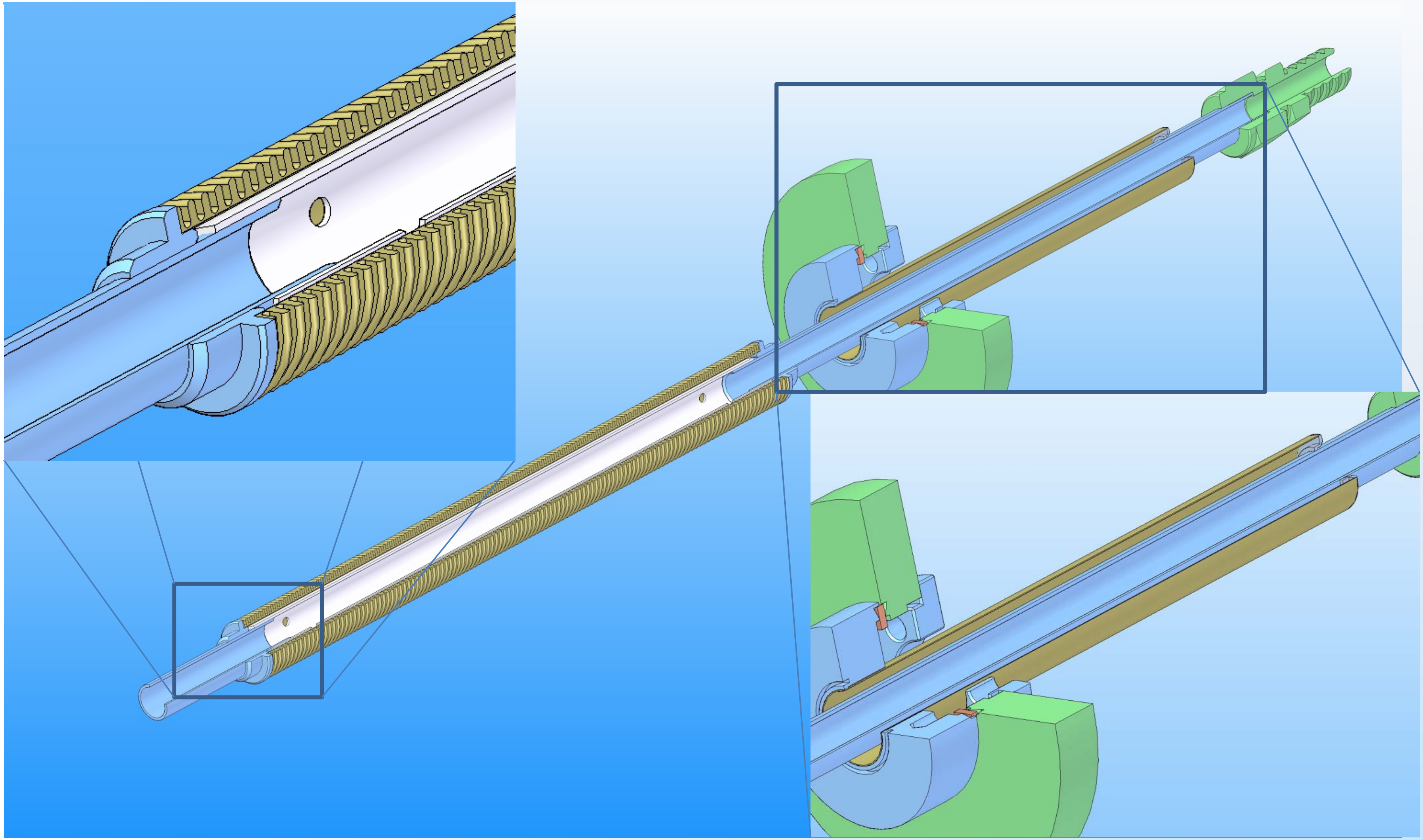
Maximum load on stage:
several tons
Maximum load on motors:
several hundred kilos



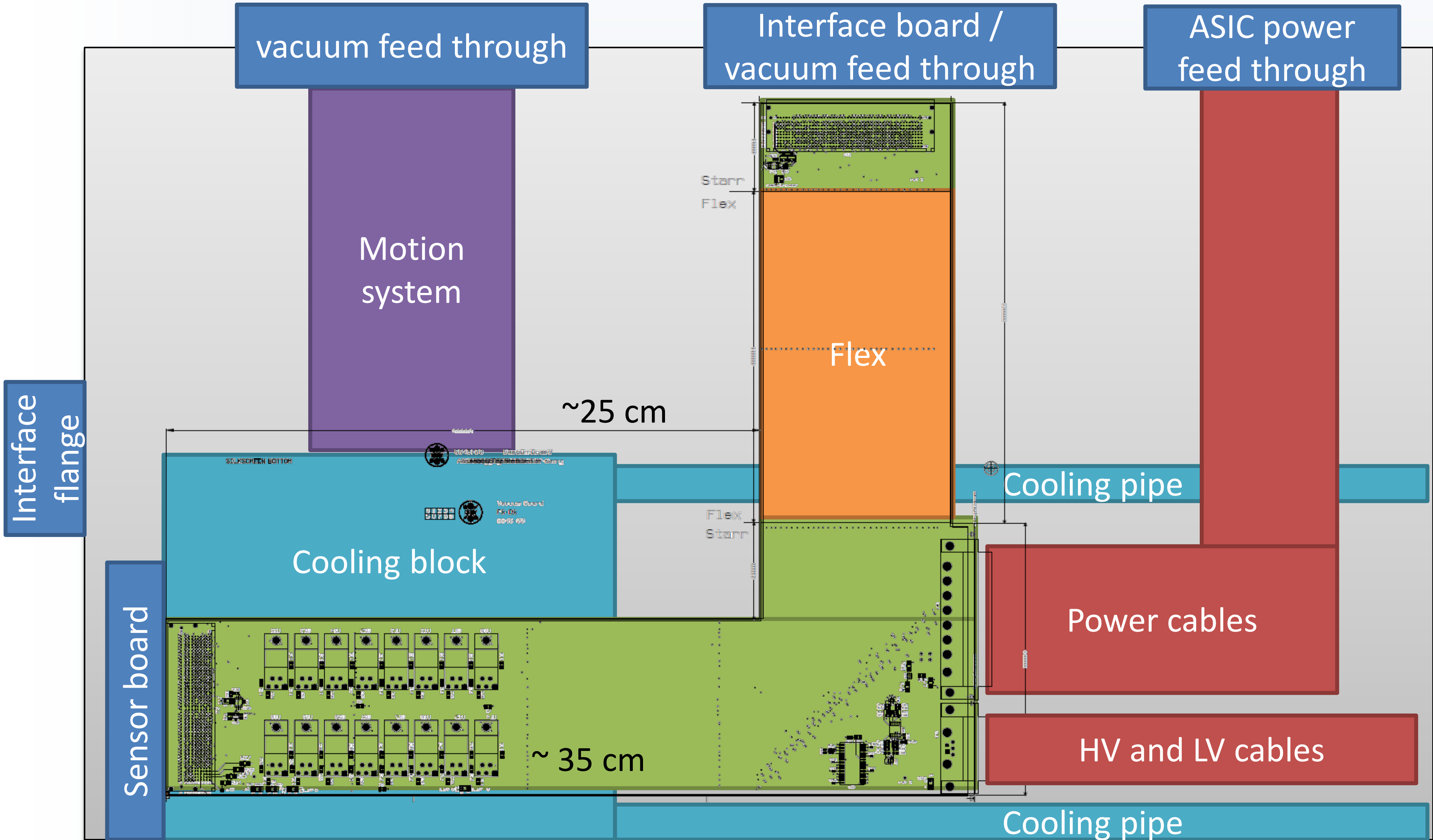
Flexible pipes



Pipes



Overview schematic



Notches for stability

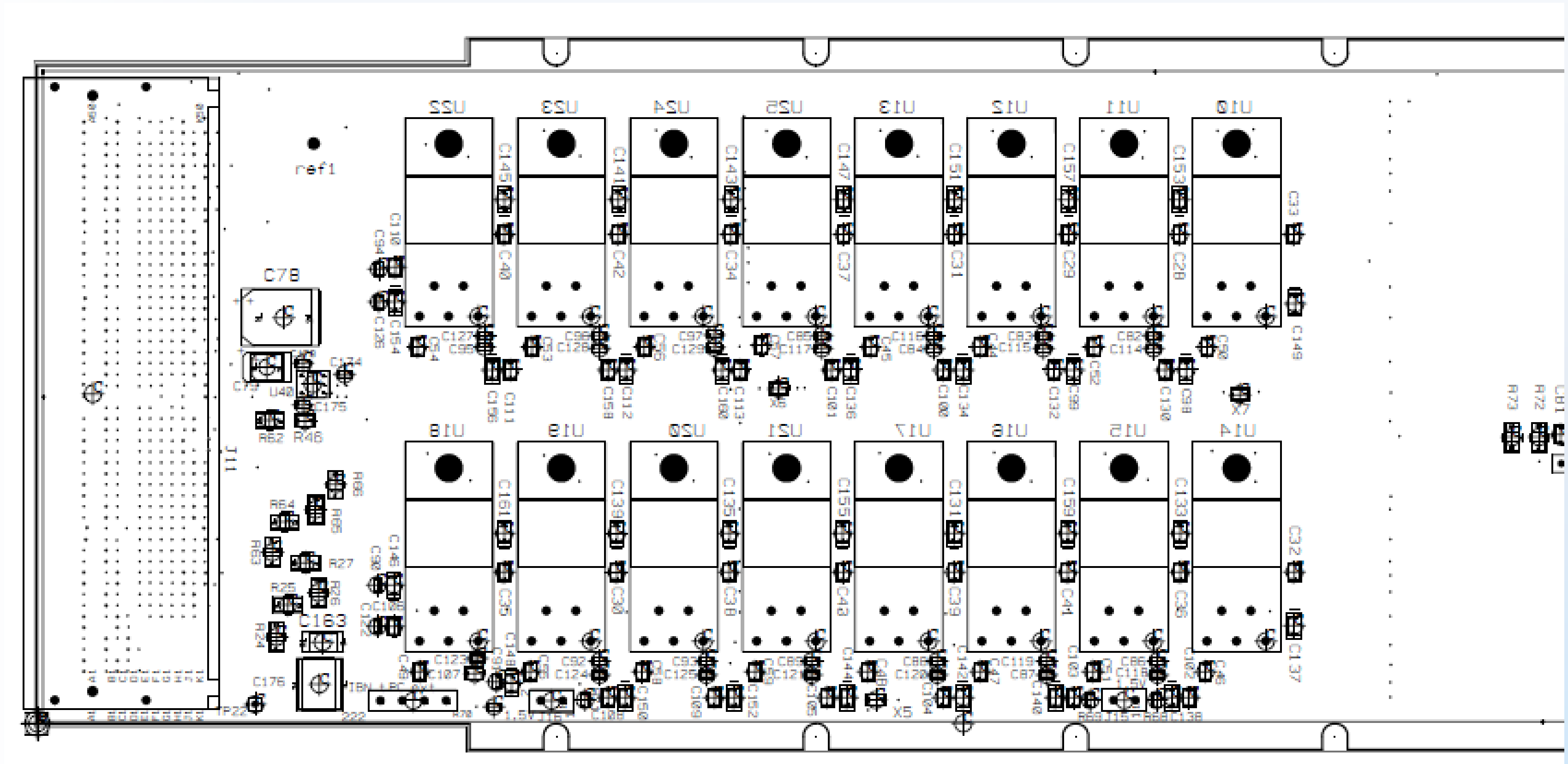
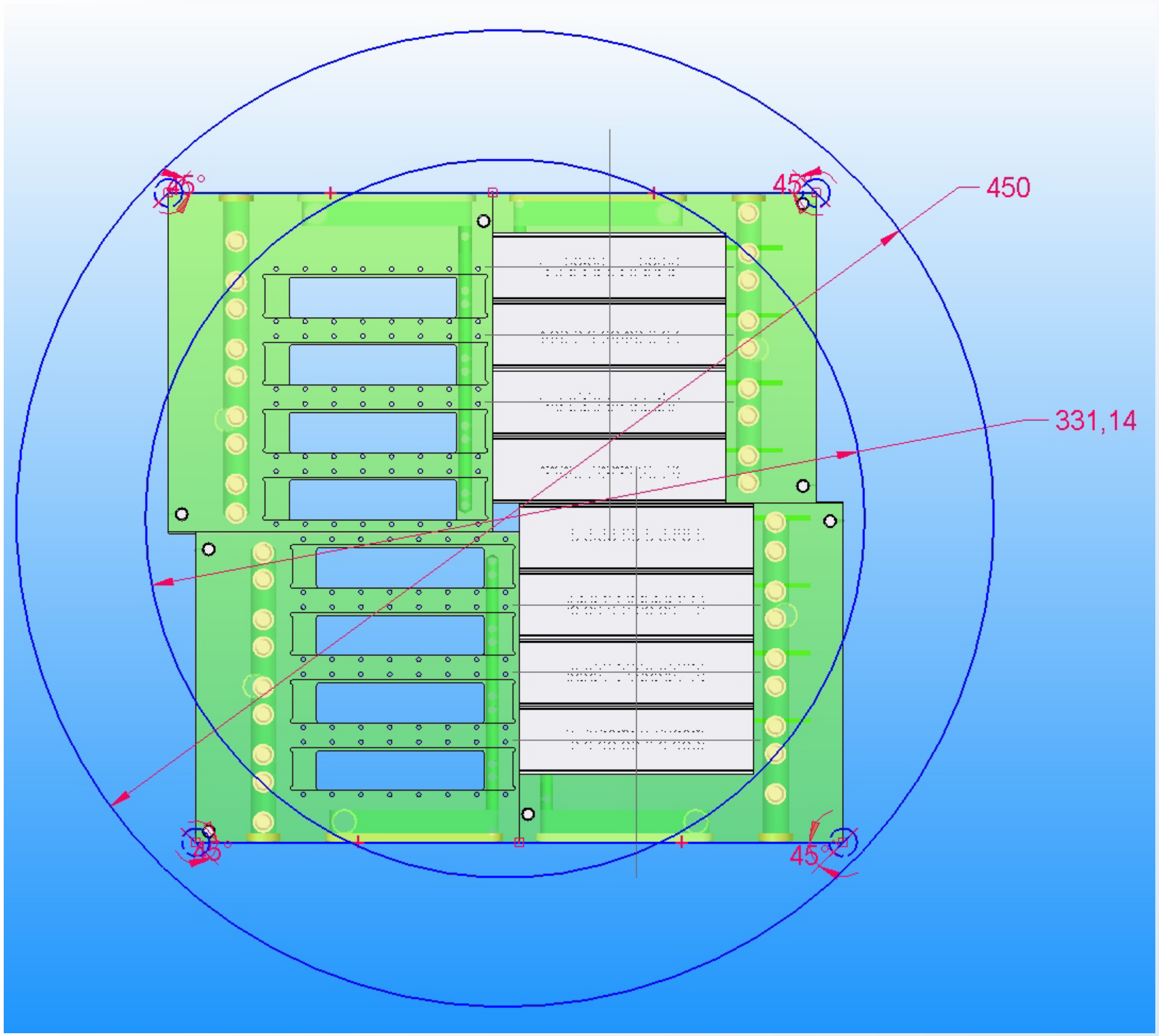


Image plane



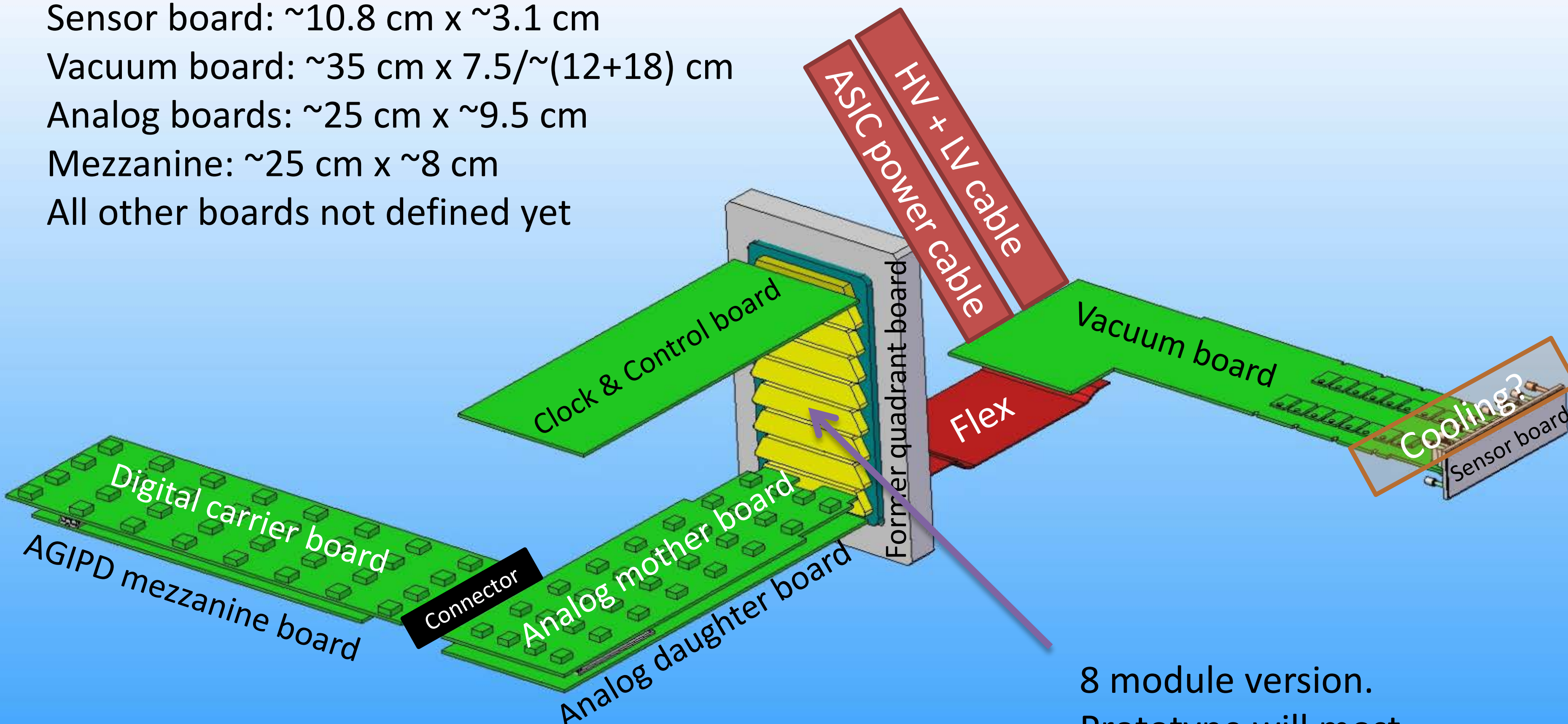
Holding harness for a potential stick-out arrangement not included in sketch!

Showing 15x15 mm^2 hole

350 mm flange seems sufficient if detector is not sticking out
Significantly bigger flange required otherwise

Module prototype

Sensor board: ~10.8 cm x ~3.1 cm
Vacuum board: ~35 cm x 7.5/~(12+18) cm
Analog boards: ~25 cm x ~9.5 cm
Mezzanine: ~25 cm x ~8 cm
All other boards not defined yet



8 module version.
Prototype will most prob. come with a 2 module version

Integration

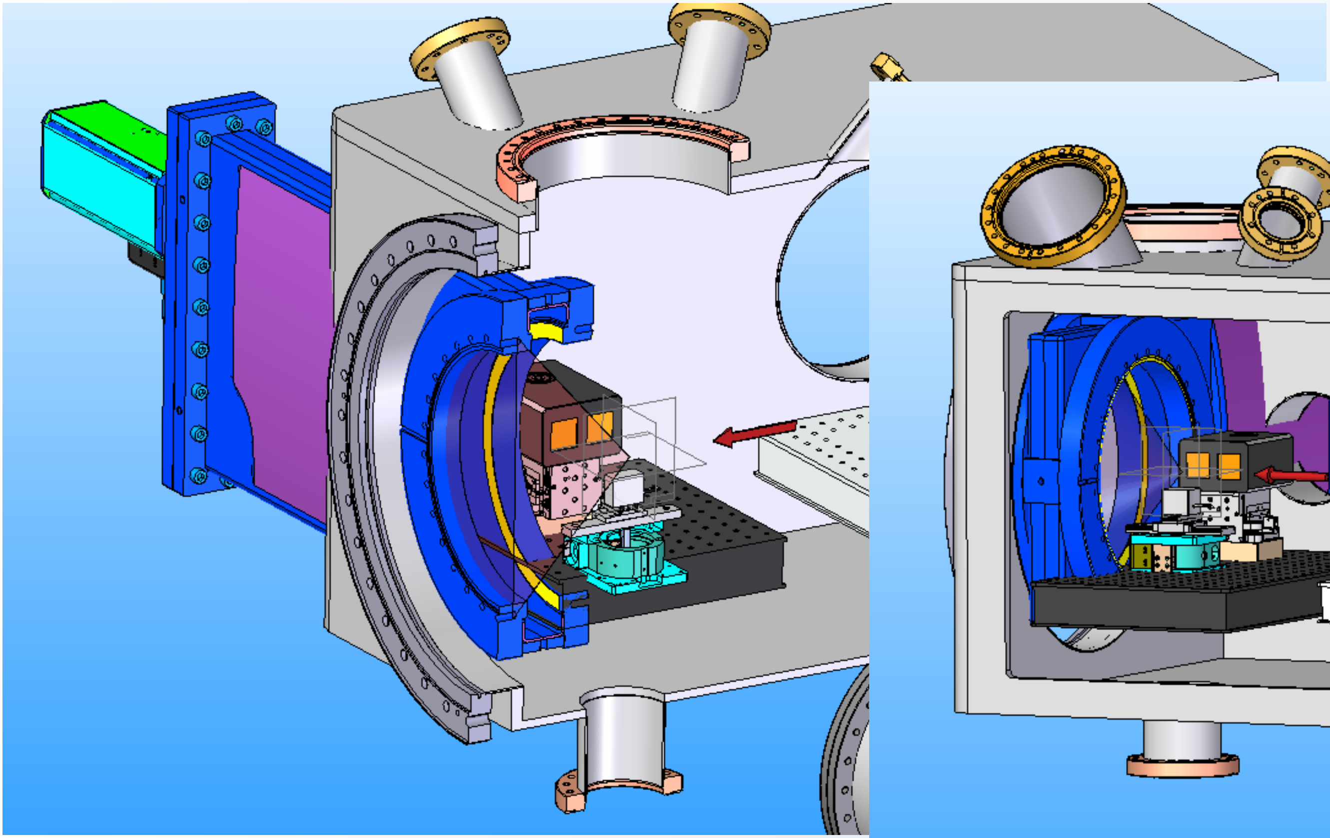
1^{st} 1M goes to SPB instrument

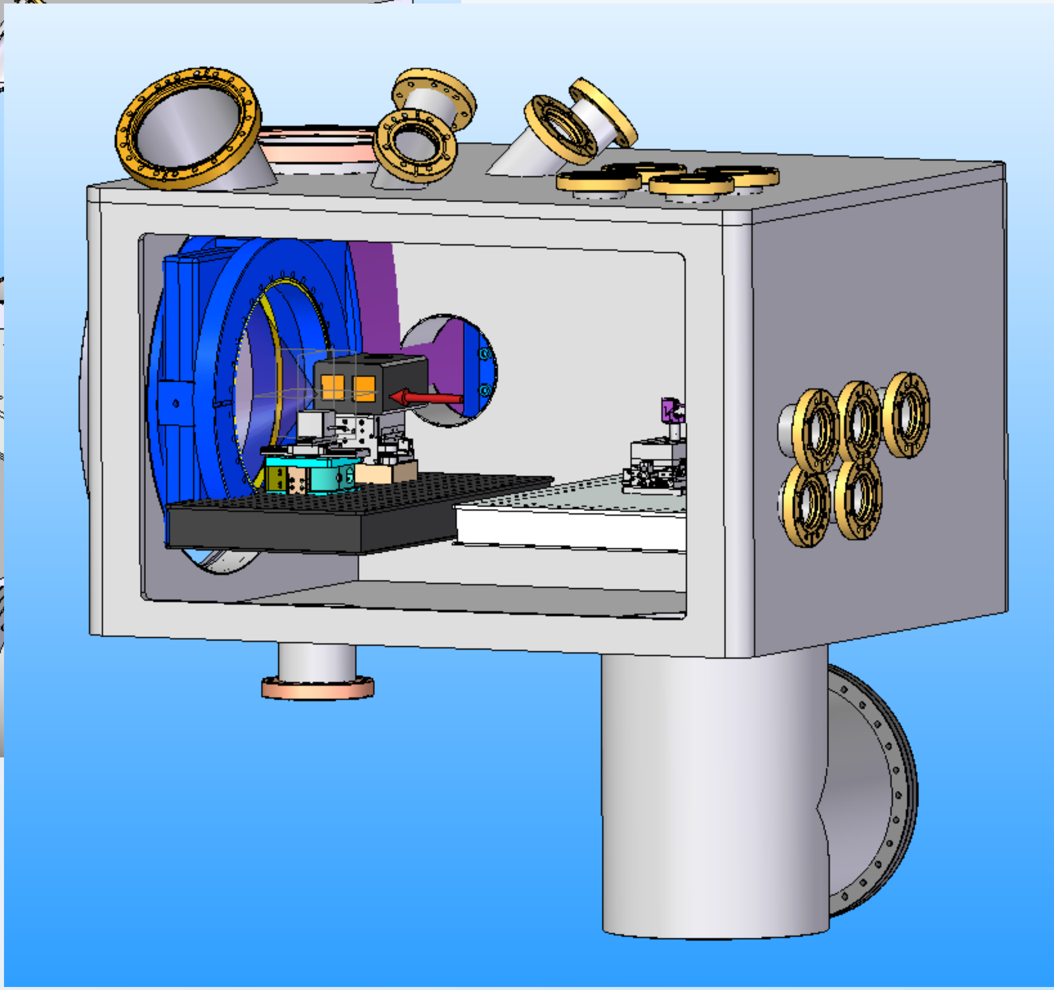
- Science requires high mobility along beam axis
- ≤ 100 mm sample to detector required for cutting edge crystallography
- Special design needed (500 mm flange?)
- Downstream 2-module detector requested

2^{nd} 1M goes to MID instrument

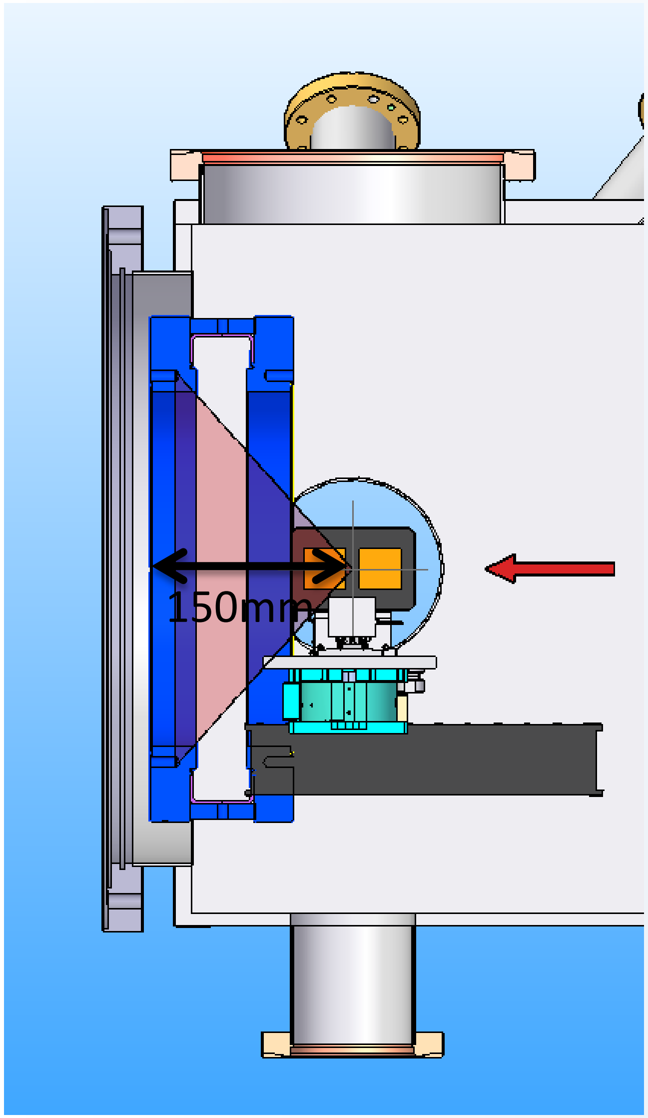
- Carbon copy of 1^{st} 1M
- 350 mm flange at sample chamber

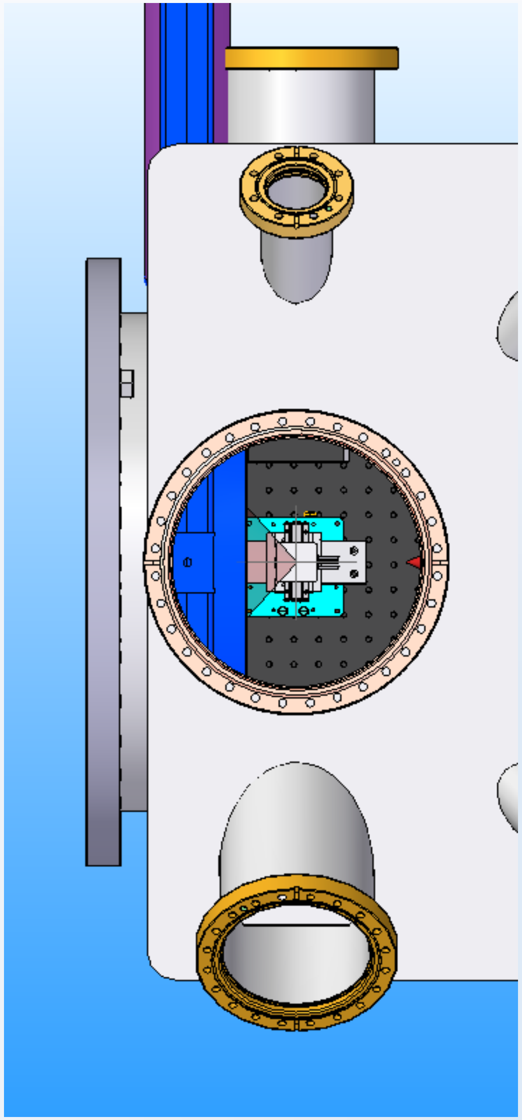
SPB sample chamber





Complicated integration





- SPB unable to make chamber any slimmer (220 mm to flange)
- Additional 50+ mm for bellows of movement system
- Gate valve mandatory
- Gate valve can possibly be integrated into the chamber wall
- Sticking out of image plane only possible solution found so far

Possible consequences of 'sticking out'

Part	change	consequence	probability	estimated impact
Cooling block	Off-axis movement	Loss of movement precision	certain	< 1/10 pixel accuracy probably no longer achievable
Cooling block	Off-axis support	Sagging	certain	Larger gap between quadrants
Cooling block	Off-axis support	Vibrations	unknown	Serious
Interface flange	Increased size	Different Interface	certain	XFEL to advise
Grapping harness & counterweight	Has to be there	Has to be designed and manufactured	certain	More time and material
All in vacuum parts	Position in narrow ring	Reduced serviceability	possible	Low-medium; service time increase

Preliminary estimate of possible consequences, the list is not exhaustive!

Cooling

- PDMS (silicone oil) based liquid system
  - Chemically inert -> no corrosion of metal parts, non-flammable, no special handling
  - Physiologically inert -> edible but not nutritious, no protection gear necessary
  - Low vapor pressure -> allows (poor) vacuum even if residue is in the chamber
- 30+ m of distance between cooling plant and detector

Cooling plant for AGIPD 1M

JULABO FPW91-SL + Pump upgrade

- Cooling bath design (slow but stable)
- 2.7 kW cooling power at -40° C
- 1.5 kW cooling power at -60° C
- Up to 3 bar pressure / 30 l/min (upgraded)
- Compact design (85x76x116 cm)
- 320 kg (empty, 22l coolant volume)
- PDMS (silicone oil) coolant
- Power consumption ~13 kW plant, ~1 kW pump -> about 1.1 kW dissipated to air, rest to cooling water

This cooling plant is probably overspec'd. However we don't know better before the system is further advanced.

Cooling plant in action

Thermal simulations

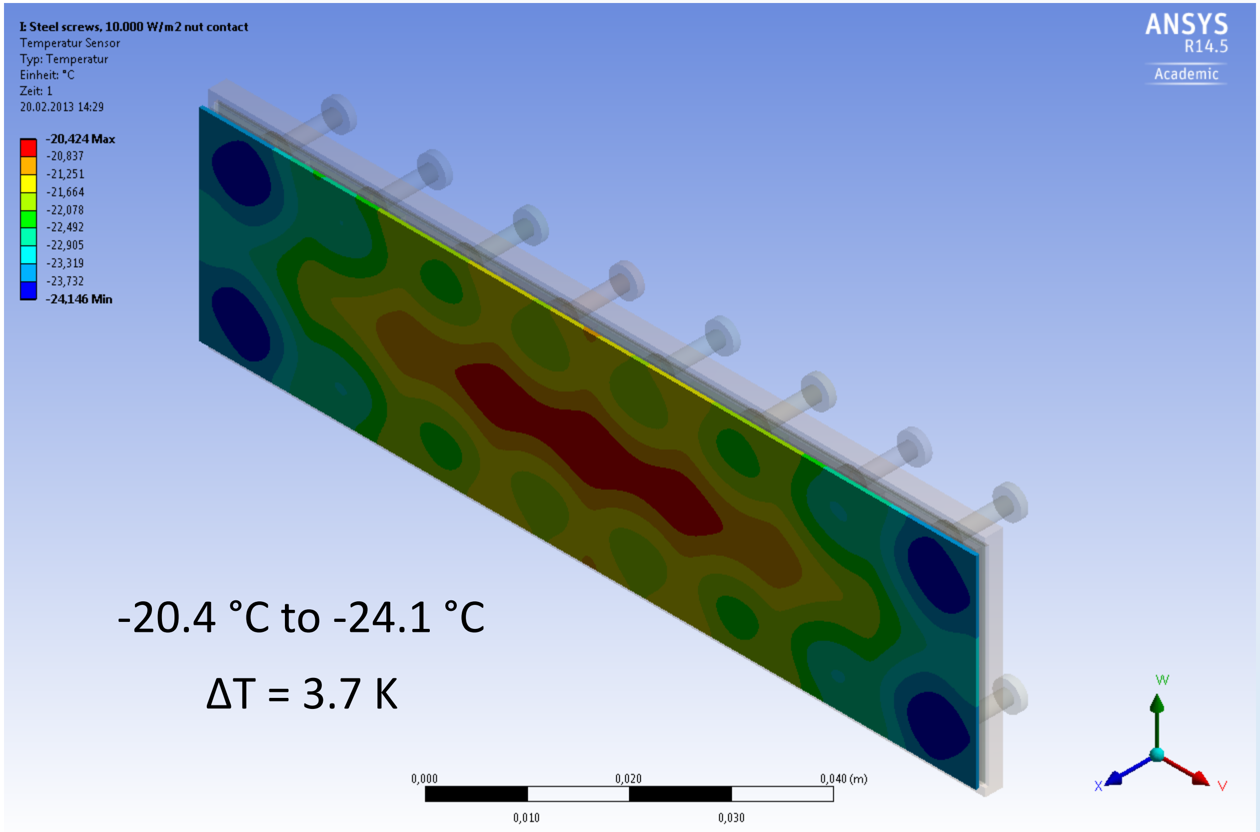
Thermal requirements:

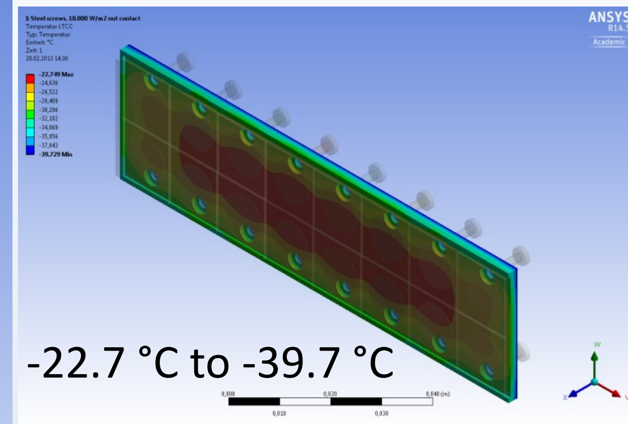
- ASIC temperature ≤ -20°C
  - reduces droop after irradiation
- ≤ 5 K temperature spread
  - Reduces spread of ASIC parameters due to temperature

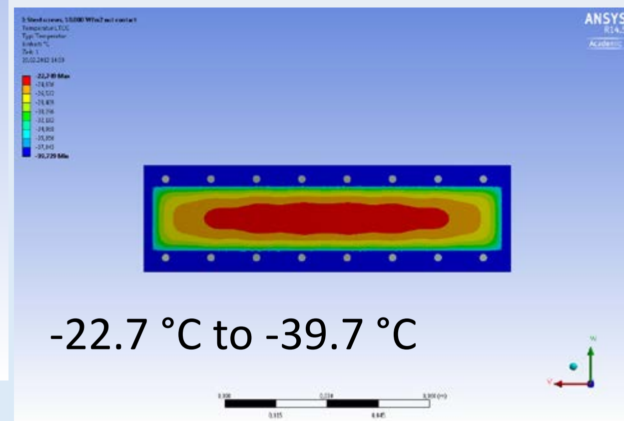
All simulations with ANSYS; fluid simulations using the CFX solver included in ANSYS V14.5

Thermal simulations sensor stack

AGIPD







- Simulation conditions somewhat pessimistic
- Allow for additional spread in temperature when looking at the quadrant level

Cooling with a non compressible coolant

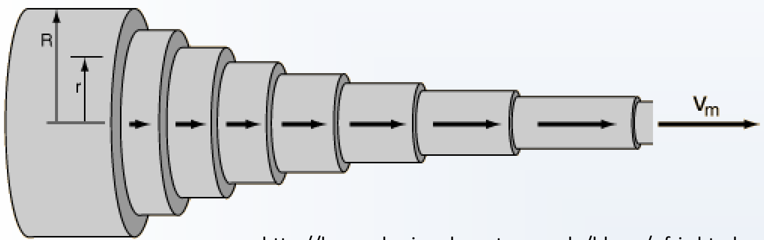
$$P = c\,\rho\,A\,v\,(T_{out} - T_{in})$$

- Total heat load P: ~ 300W/Quad
- Cross section A (10 mm tube): ~ 80mm^2
- $c = 1.5\,J/g \cdot K$
- $\rho = 0.98\,g/cm^3$
- $v = 3.1\,m/s$ (15 l/min)

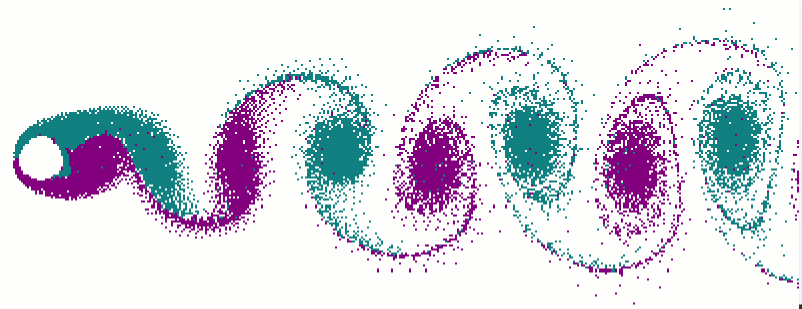
$$\Rightarrow (T_{out} - T_{in}) = 0.8\,K$$

Only valid for average value, resp. perfect mixing!

Laminar flow, Reynolds number & vortex streets



http://hyperphysics.phy-astr.gsu.edu/hbase/pfric.html


http://en.wikipedia.org/wiki/File:Vortex-street-animation.gif

From Wikipedia:
Laminar flow occurs when a fluid flows in parallel layers, with *no disruption between the layers*. At low velocities the fluid tends to flow **without lateral mixing**, and adjacent layers slide past one another like playing cards. *There are no cross currents perpendicular to the direction of flow, nor eddies or swirls of fluids*.

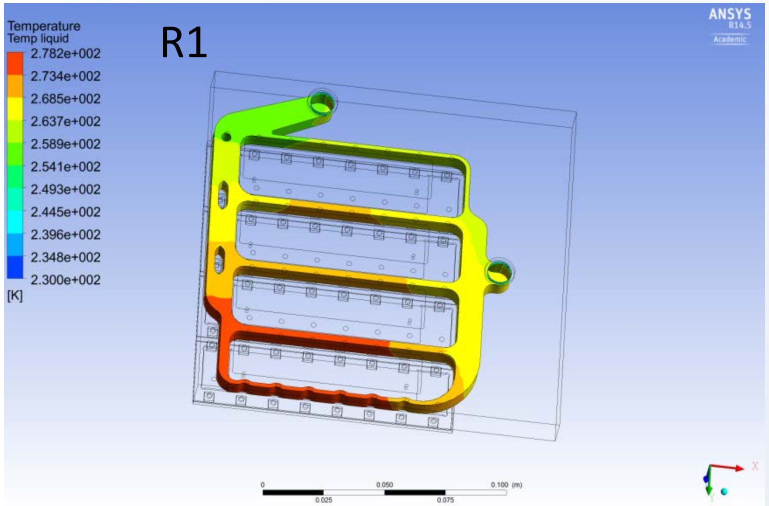
$$Re = \frac{\rho v}{\mu} L$$

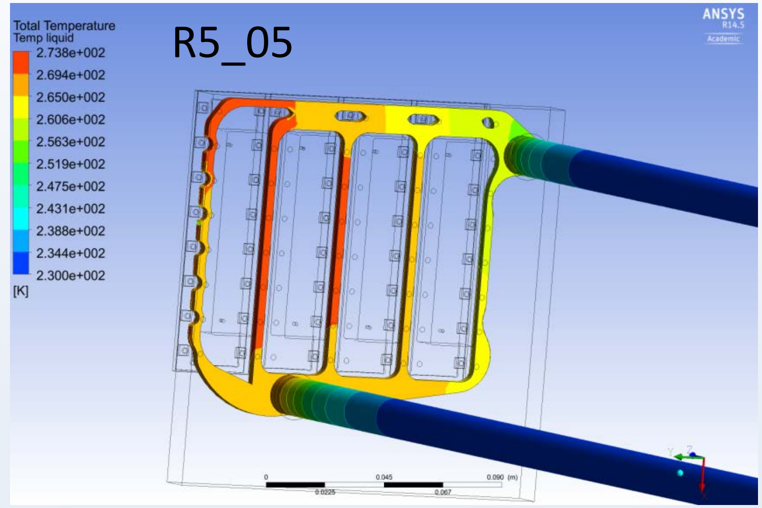
$$\frac{\mu}{\rho} \approx 10 - 20\, mm^2/s$$

Re ≤ 2000
→ Laminar flow
Re ≥ 4000
→ Turbulent flow


A Kármán vortex street off Jeju Do (left), caused by the downward windflow of Typhoon Prapiroon (8.-19. Oct 2012).
http://en.wikipedia.org/wiki/Vortex_street

Cooling block design V1

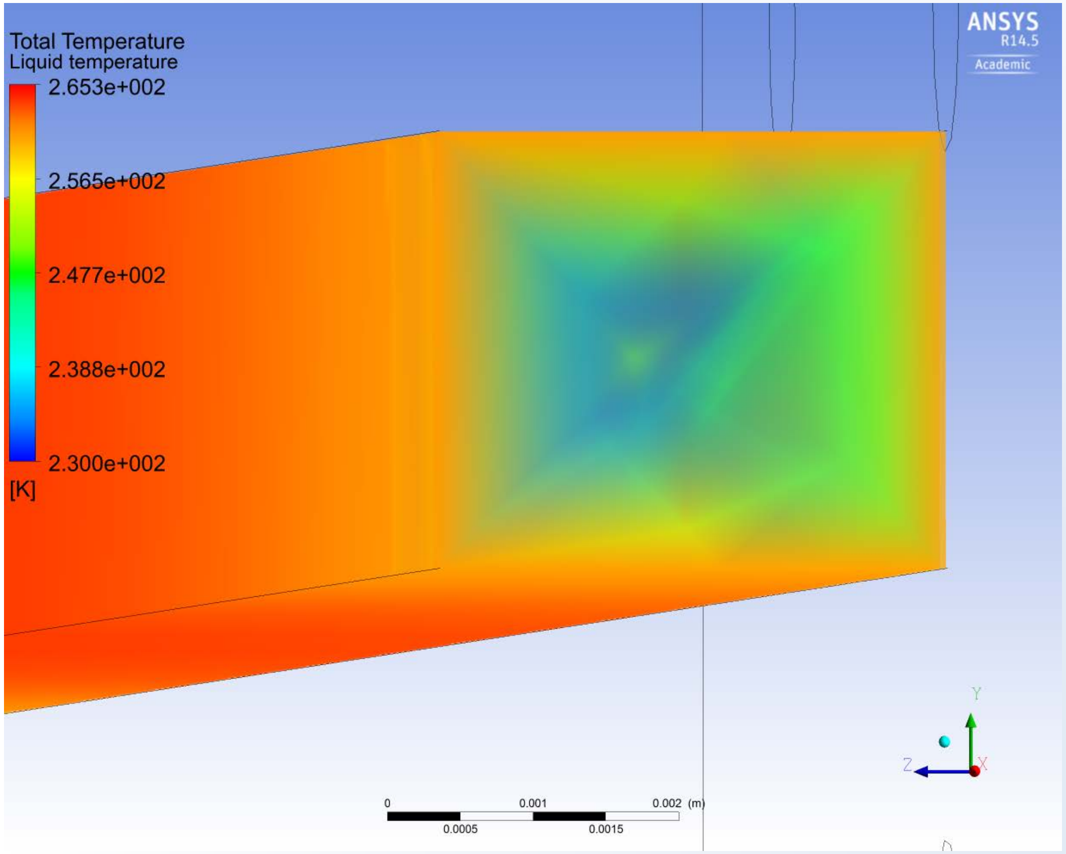




Layout name	*changed feature*	*dP [bar]*	*max v [m/s]*	*Location*	*Eddy dissipation E/m/t*	*Kinetic energy*	*Location*	*dT (T_{max}-T_{inlet})[K]*
R1	60 g/s mass flow	0,03	1,67	Outlet	8,93E+00	1,13E-01	Outlet	**48,20**
R2	smooth inlet	0,02	1,63	Outlet	7,62E+00	1,03E-01	Outlet	**47,50**
R3	inlet, flow joint, pipes	0,04	1,30	Outlet	8,41E+00	1,02E-01	Outlet/last screw hole	**42,70**
R4	Flow joint, far channel	0,04	1,20	far channel	3,89E+00	6,43E-02	Outlet	**43,30**
R5_01	id to R4?	0,04	1,20	far channel	4,13E+00	6,74E-02	Outlet	**44,50**
R5_02	bigger pipes	0,01	1,21	far channel	3,61E+00	5,63E-02	last screw hole	**46,70**
R5_04	changed return on near channel, indentations on far channel	0,01	1,16	far channel	2,87E+00	5,13E-02	last screw hole	**49,10**
R5_05	reduced channel height	0,04	2,37	far channel	1,88E+01	1,32E-01	Outlet	**43,80**

Temperature of liquid does not transfer to the cooling block **-> laminar flow**

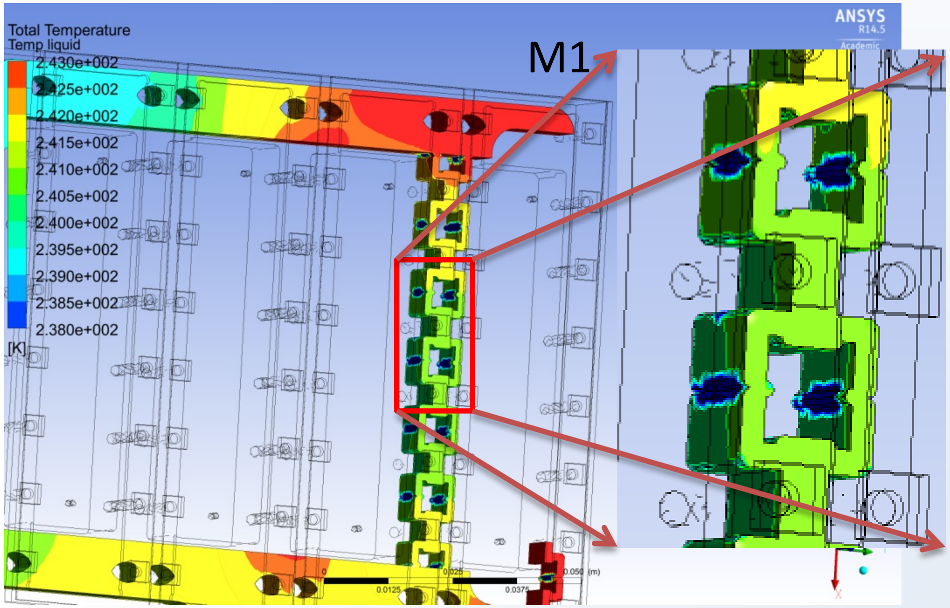
Drawback of laminar flow

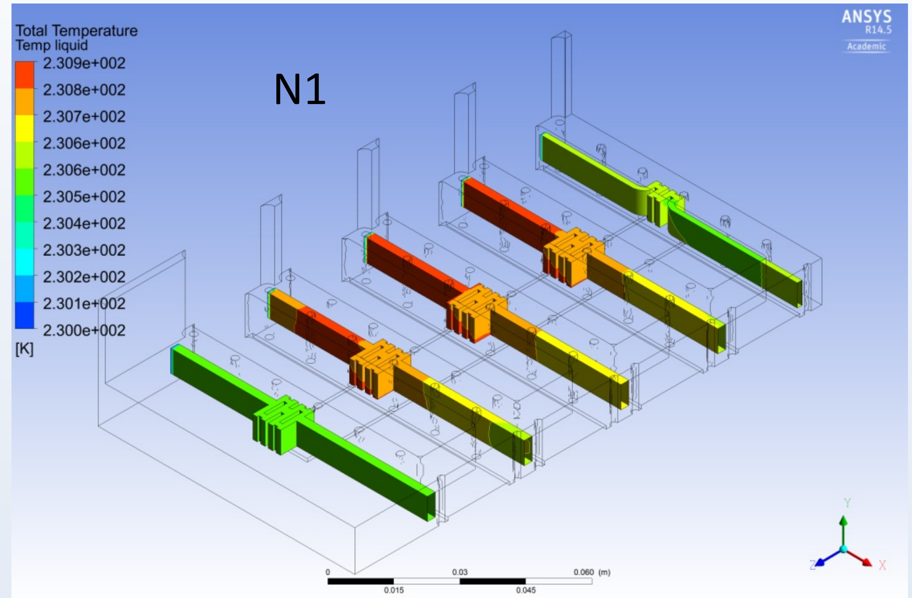


- Average temperature increase of fluid 1.3 K
- Surface temperature increase 40-50 K
- Thermal conductivity of fluid 0.1 J/W/m (1/5 of water, x2 of Styrofoam)
- Viscosity of 12.6 mPas (~ ethylene glycol, x10 of water, 1/5 of motor oil)

=> More channel surface needed, design under revision

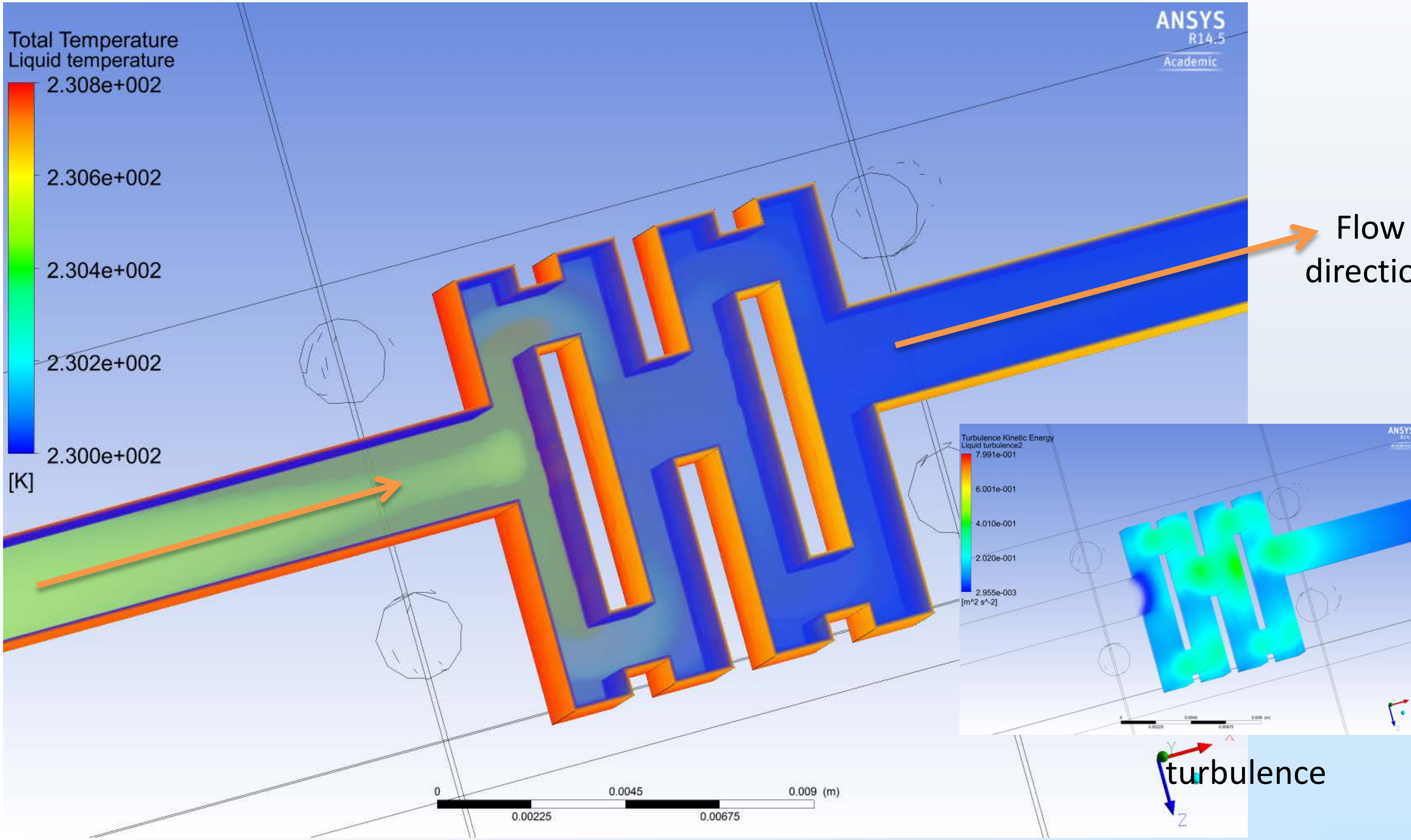
Utilizing turbulence





Layout name	*changed feature*	*dP [bar]*	*max v [m/s]*	*Location*	*Eddy dissipation E/m/t*	*Kin. Energy*	*Location*	*dT (T_{max}-T_{inlet})[K]*	*comment*
M1	Pointy mixers	0,13	1,18	mixer	6,40E+01	3,04E-01	mixer	11,50	1 link only, 1/4 mass flow, 2/8 heat flow
N1 - coolant only	**dense mixing chain**	**0,26**	**1,05**	**Outlet/mixer**	**8,11E+01**	**2,87E-01**	**mixer**	**6,40**	**temp estimated from single element simulation**
N1 mutilated	one chain element only	0,08	1,94	near mixer	1,93E+02	4,81E-01	mixer	0,60	
	representative element	0,04	1,00	middle mixers	9,66E+01	2,42E-01	mixer	0,80	values are consistent with results from coolant only simulation

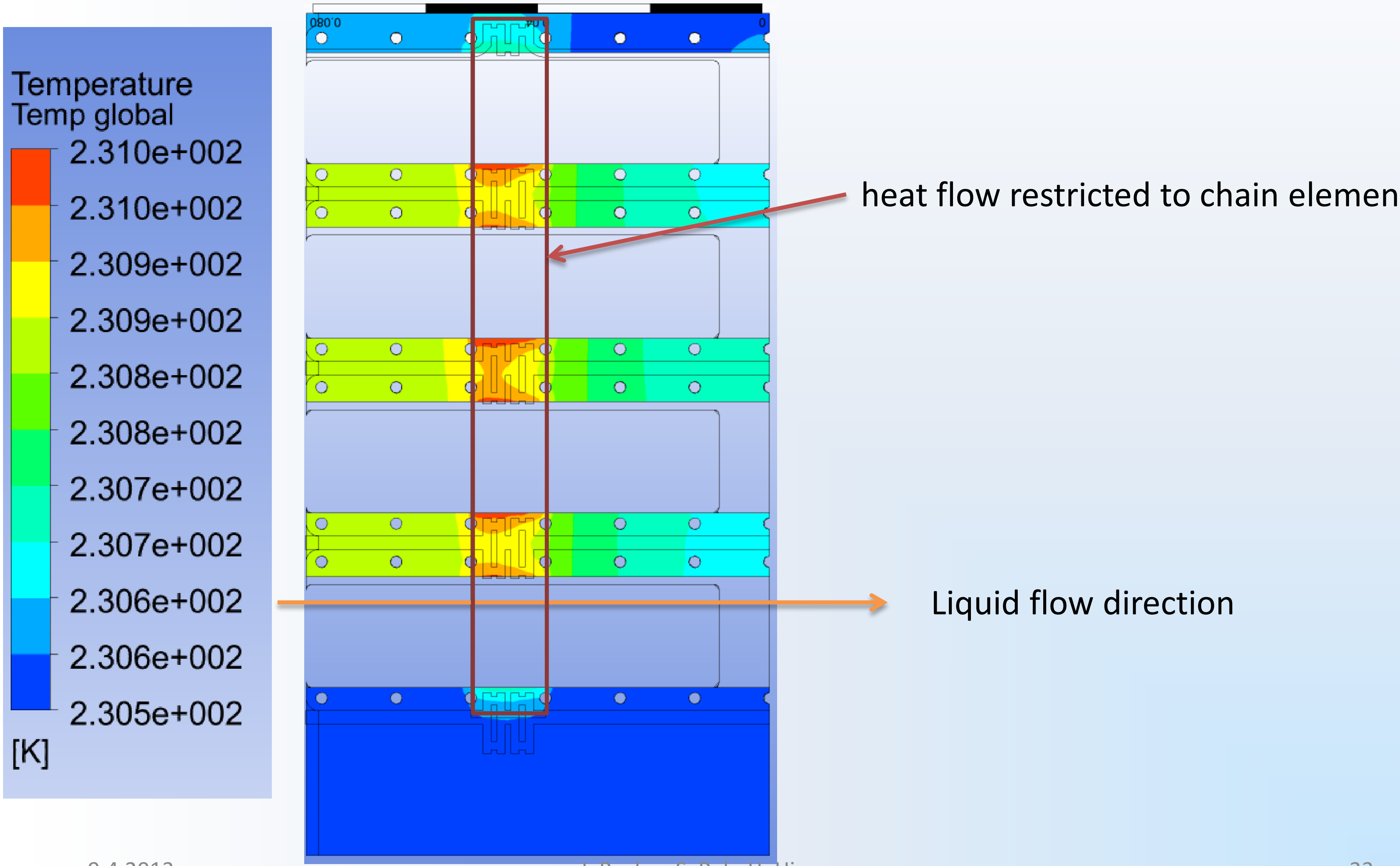
Still laminar flow



Flow direction

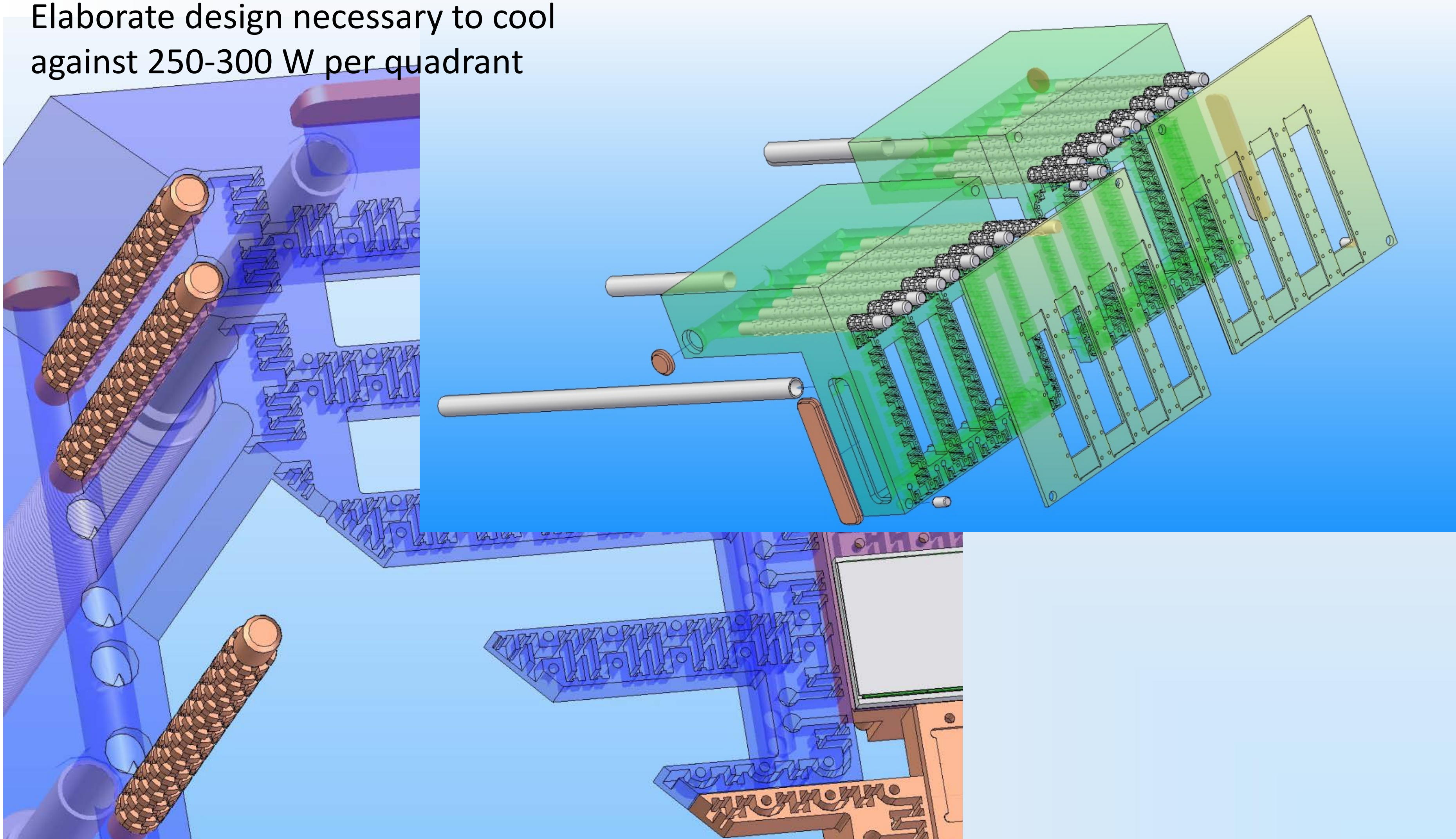
turbulence

CuBe plane


Temperature
Temp global
2.310e+002
2.310e+002
2.309e+002
2.309e+002
2.308e+002
2.308e+002
2.307e+002
2.307e+002
2.306e+002
2.306e+002
2.305e+002
[K]
heat flow restricted to chain element
Liquid flow direction

Cooling block

Elaborate design necessary to cool against 250-300 W per quadrant



Results from thermal simulations

Sensor stack

Steady state simulations

- ΔT, across stack ~ 20-25 K
  -> design is sufficient
- Inhomogeneity in sensor ~ 3.5 K
  -> within tolerance

Cooling block

Flow simulations

- Δ T, liquid to sensor stack ~ 5-10 K
- Δ P < 0.5 bar at 15 l/min
  -> cooling plant is sufficient
- Silicone oil at -45 to -55 °C
  -> cooling plant is sufficient

Summary

- LTCC boards ordered, arriving at DESY 3rd of May
- Mechanics design with movable quadrants available
- Integration at SPB beamline poses challenges
- Cooling plant arrived and working
- Extensive thermal simulations
- Cooling block layout close to final

BACKUP

Cooling concept & requirements

Conventional liquid cooling as baseline solution

Cooling plant requirements:

- ≥ 2 kW cooling power at -40°C
- ≥ 2.5 bar pump pressure
- Heat dissipated to cooling water

Heat load in vacuum:

P_v = 0.8 kW ASIC + 0.3 kW board + motors + heat load of 30m pipes + safety ≤ 2 kW

Coolant temperature:

T_c = -20 °C operating temperature (worst case)
– 10-15 K ΔT through LTCC – 5 K inhomogenity*
– 0-5 K T_c increase along 30m pipe ≤ -40 °C

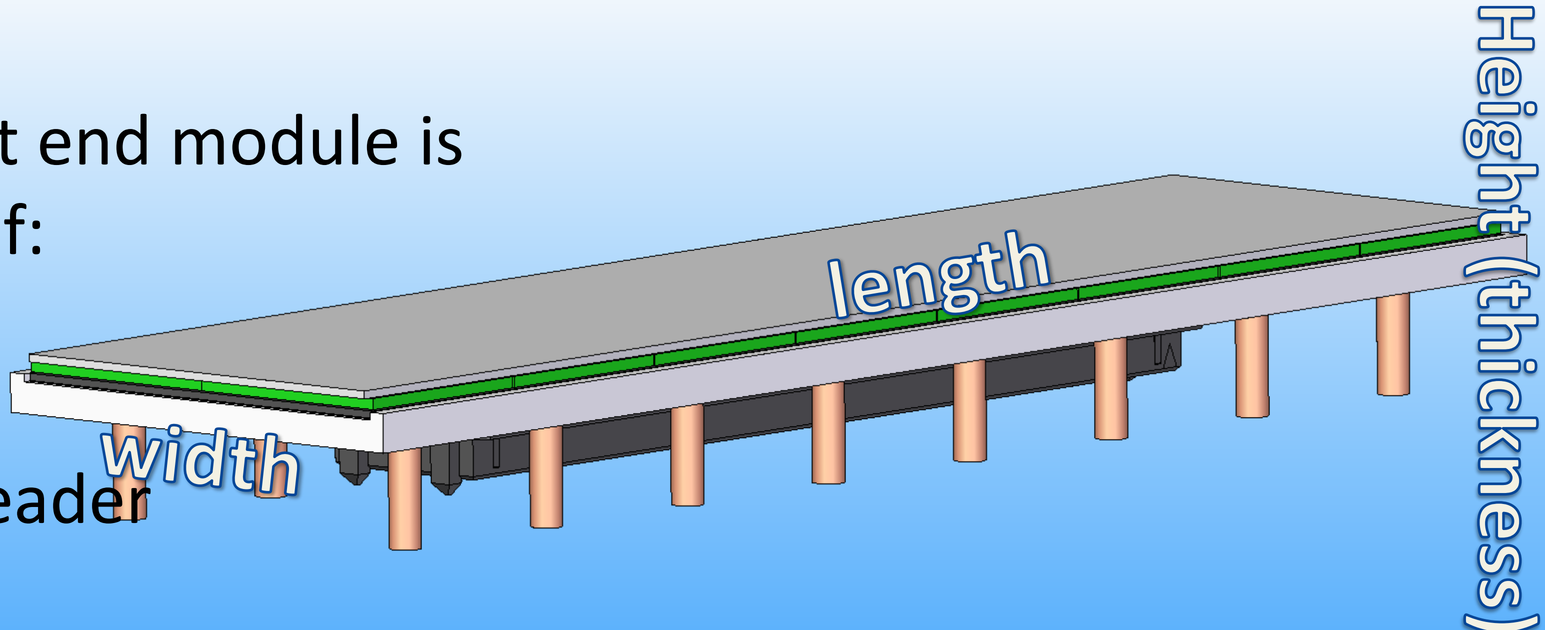
Pump pressure:

P_p= 2 bar pressure drop in typical capillary heat exchanger + 0.5 bar pressure drop along 2x30m pipe with 2 cm inner diameter

* This implies a coolant volume flow of 17.5 l/min

Module layout

The front end module is a stack of:
Sensor
ASIC
Heatspreader
LTCC
Screws
Connector

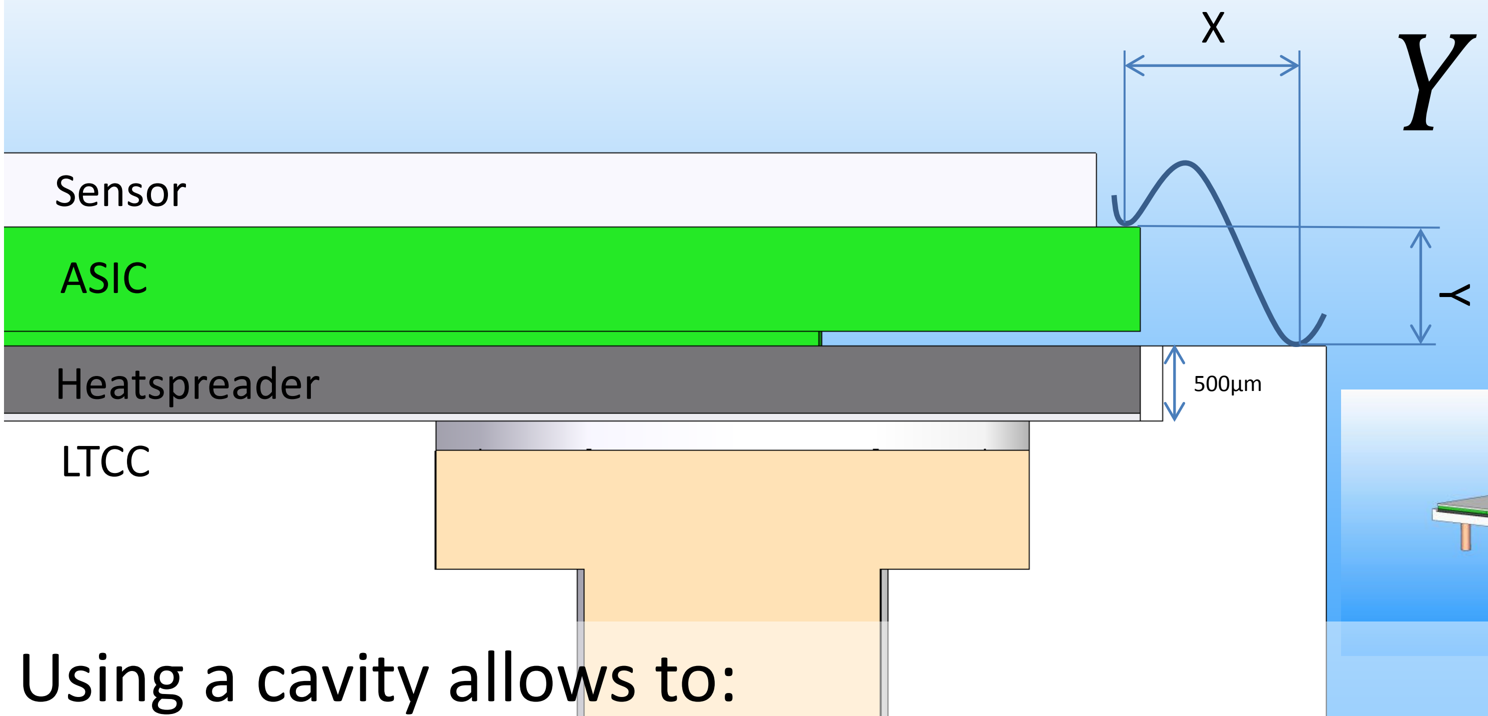


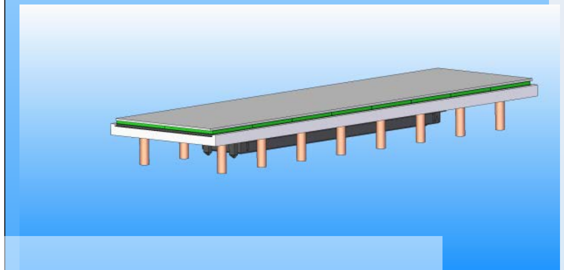
AGIPD Sensorstack

Bonding step and cavity

For stable wirebonding:

$$Y \leq X$$



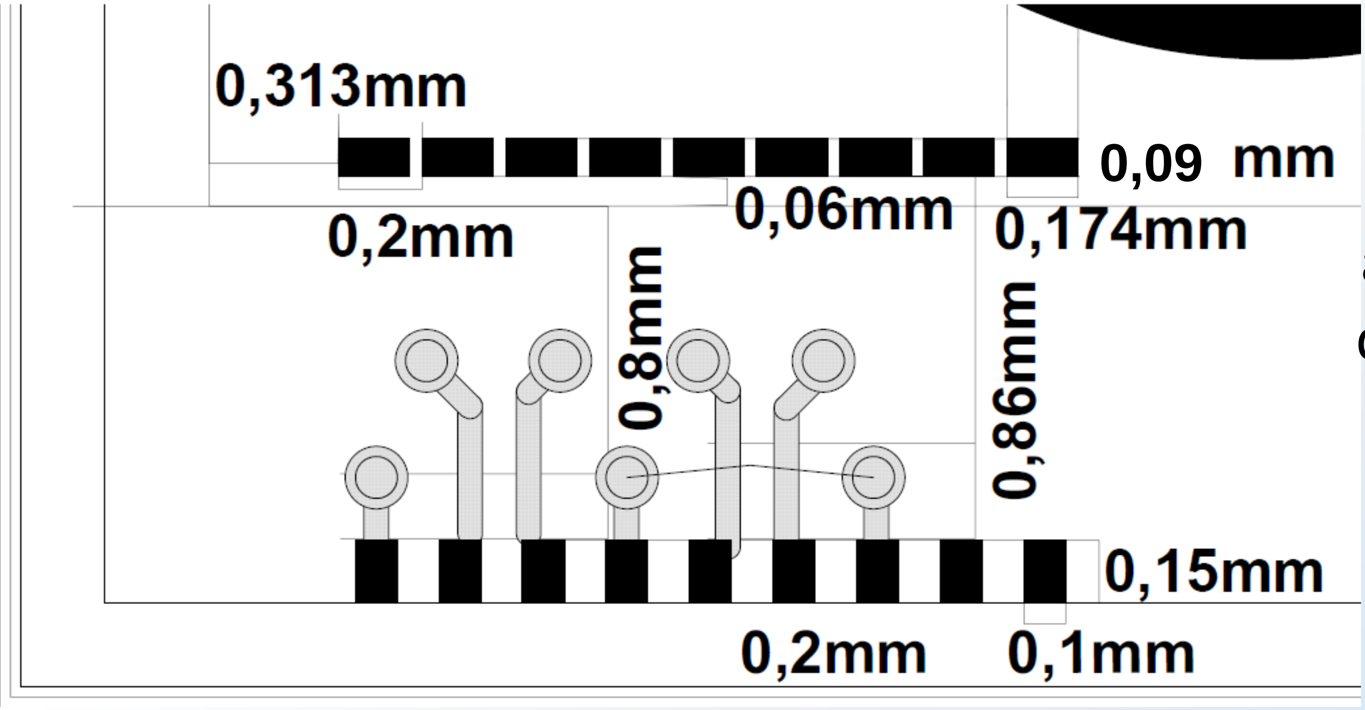


Using a cavity allows to:

- Reduce the effective step height
- Minimize dead area between sensors
- Reduce the thermal resistance of the LTCC board

Wirebond pad pitch

AGIPD layout: 200 µm pad pitch



Moving vias under the bond loop allows to minimize dead space toward the edge
-> up to 3 pixels less dead space compared to LAMBDA design (150 µm pitch)!

ASIC design rules allow for pads that are wider than long
-> Sufficient space to try bonding 3 times next to each other!
-> minimum length for bonding reduces dead space!