Update of MMC studies for silicon-based sensors

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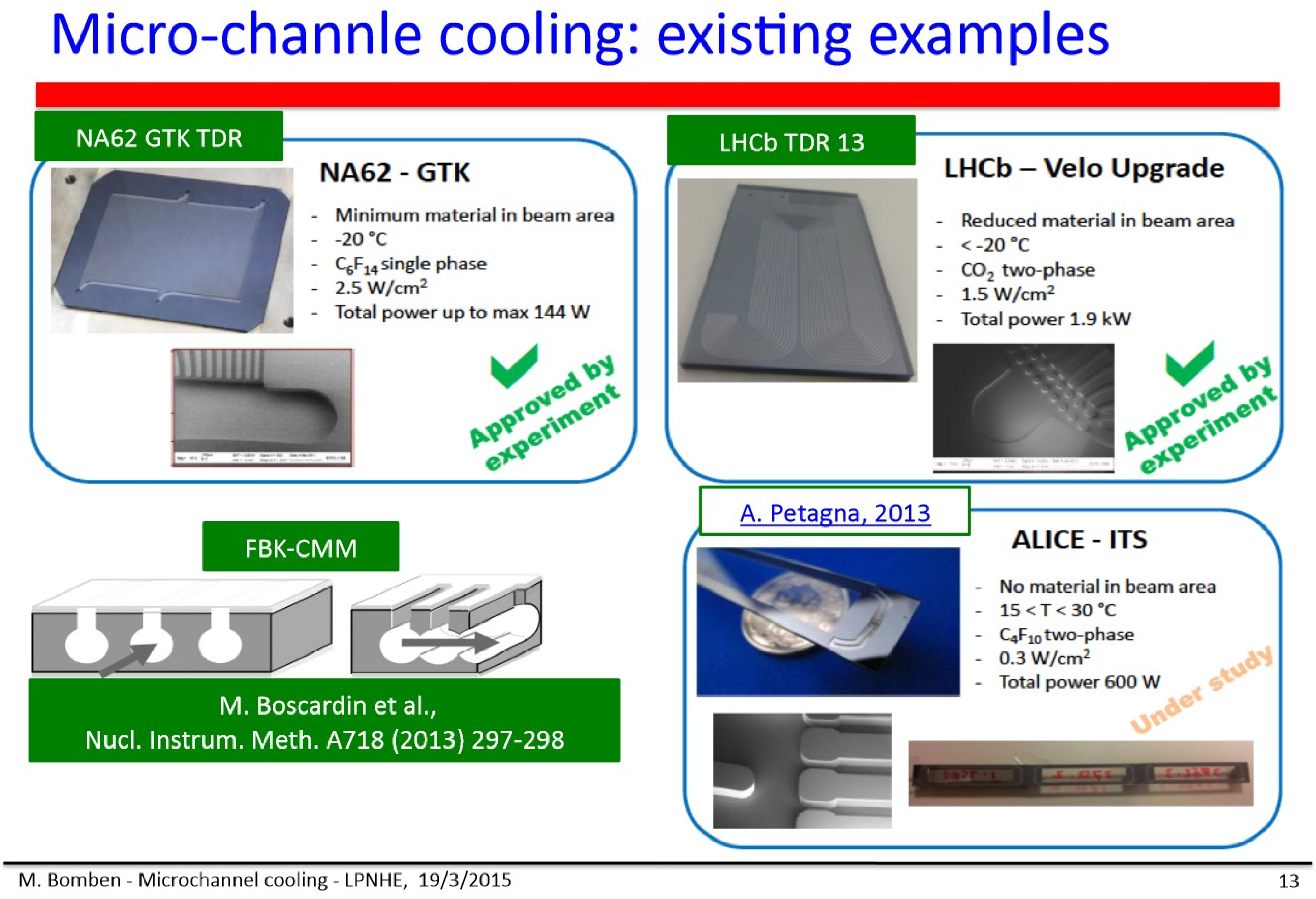
Outline

- Introduction of the setup
- Past results
- Present design and very next steps
- Future designs
- Conclusions

Introduction



Micro-channle cooling: existing examples

NA62 GTK TDR

NA62 - GTK

- Minimum material in beam area
- -20 °C
- C_6F_{14} single phase
- 2.5 W/cm^2
- Total power up to max 144 W

✓ Approved by experiment

LHCb TDR 13

LHCb – Velo Upgrade

- Reduced material in beam area
- < -20 °C
- CO_2 two-phase
- 1.5 W/cm^2
- Total power 1.9 kW

✓ Approved by experiment

FBK-CMM

M. Boscardin et al.,
Nucl. Instrum. Meth. A718 (2013) 297-298

A. Petagna, 2013

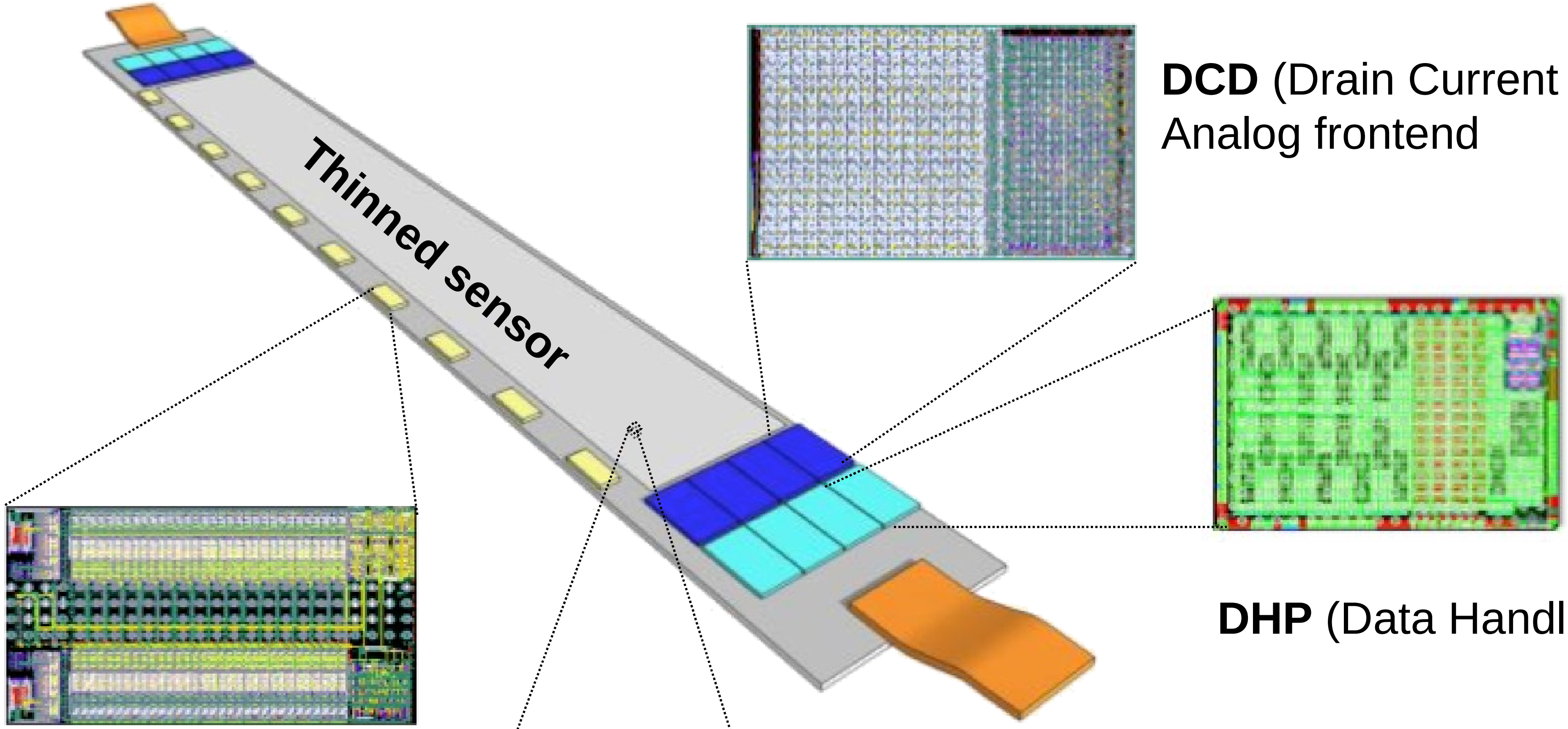
ALICE - ITS

- No material in beam area
- 15 < T < 30 °C
- C_4F_{10} two-phase
- 0.3 W/cm^2
- Total power 600 W

Under study

M. Bomben - Microchannel cooling - LPNHE, 19/3/2015 13

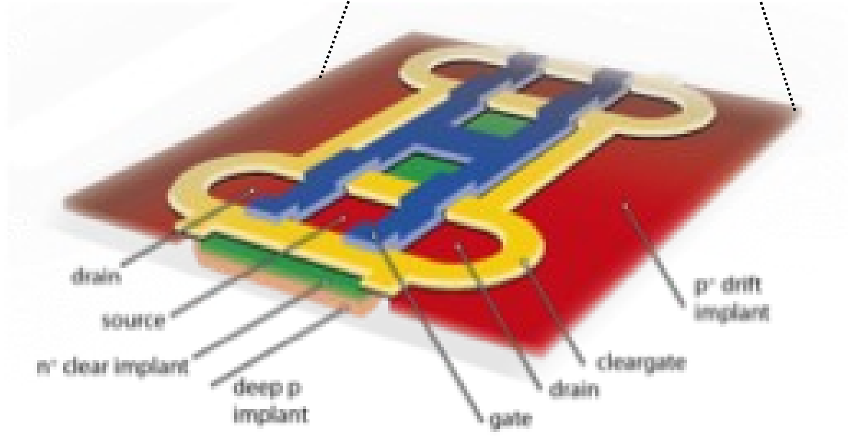
The DEPFET Ladder

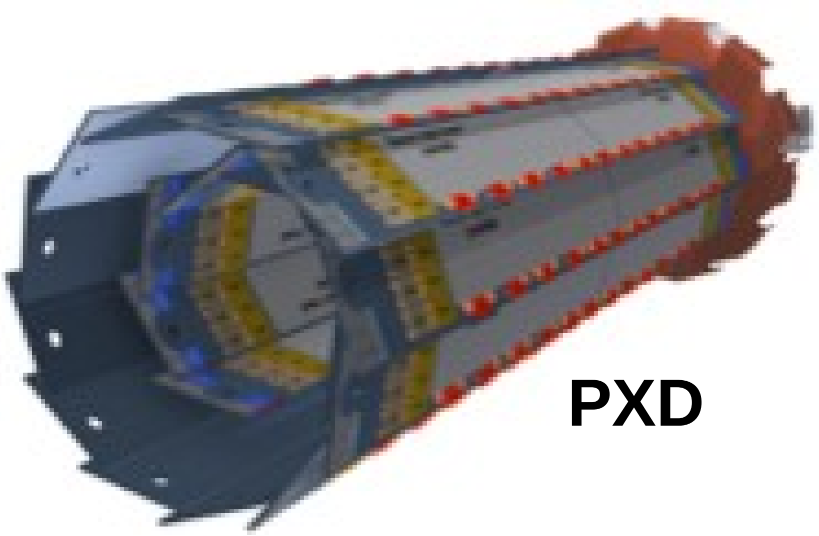


DCD (Drain Current Digitizer)
Analog frontend

DHP (Data Handling Processor)

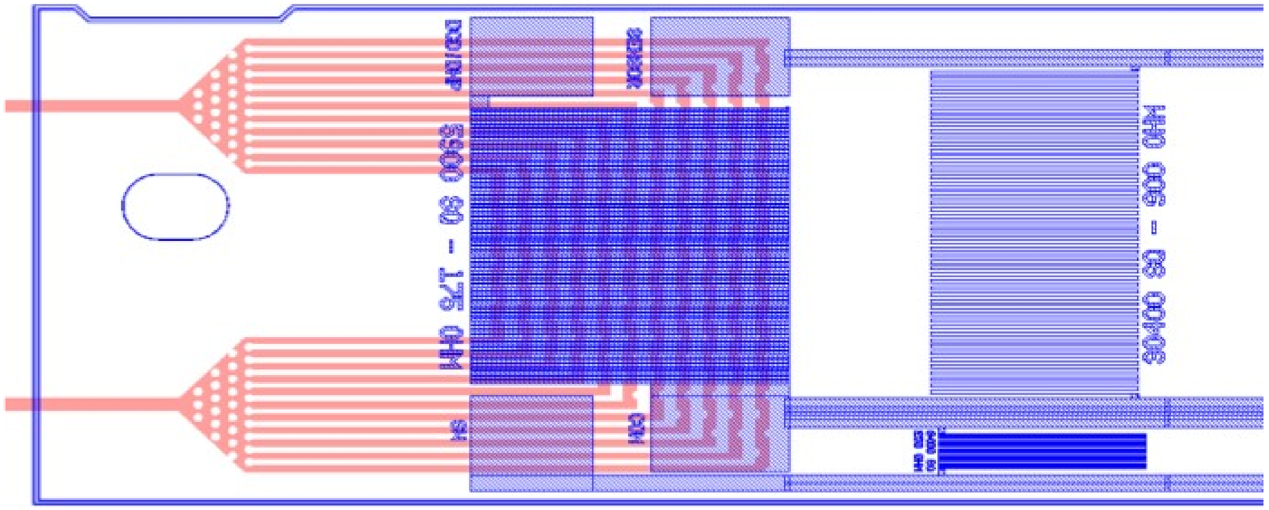
Switcher
Row control

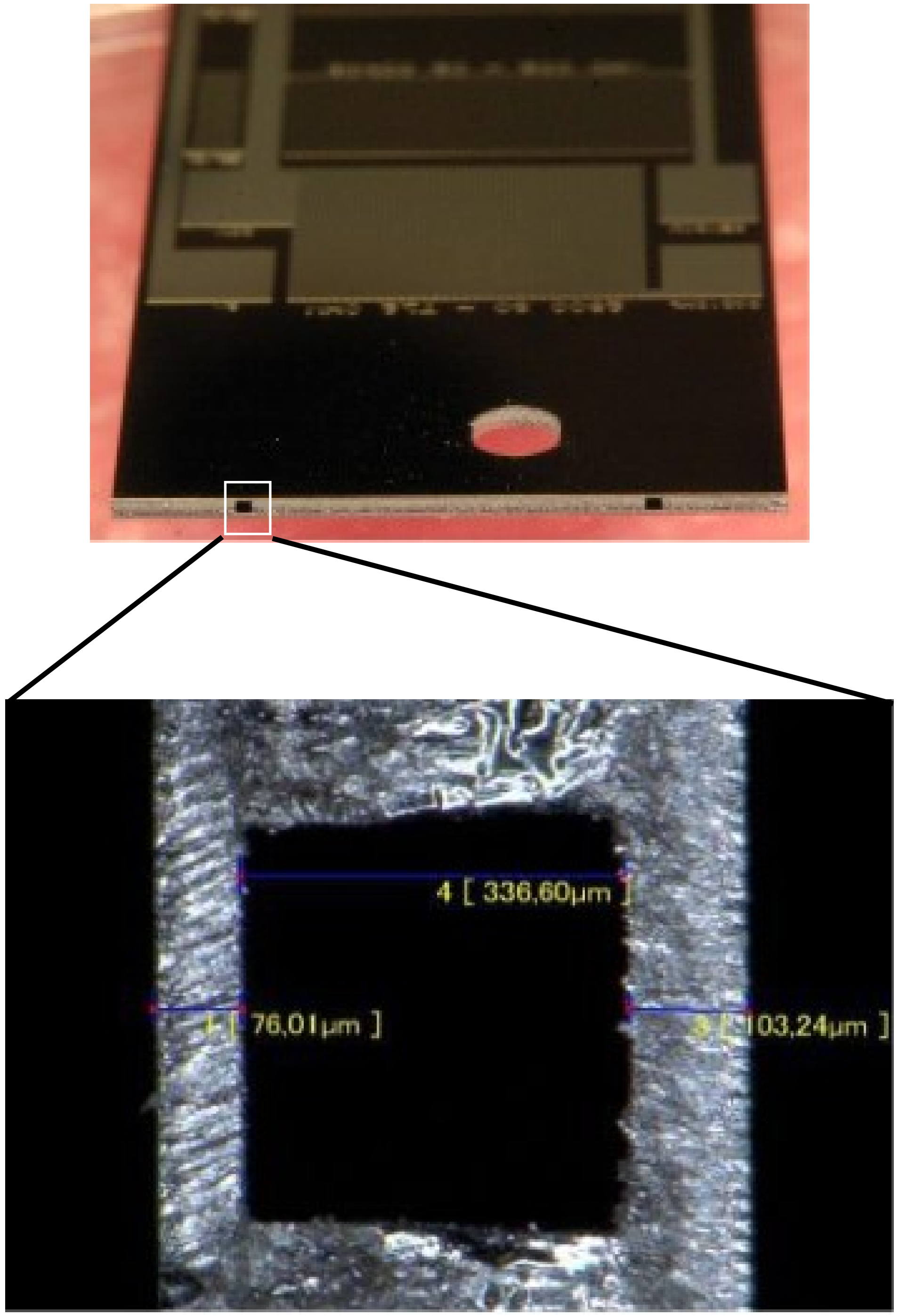


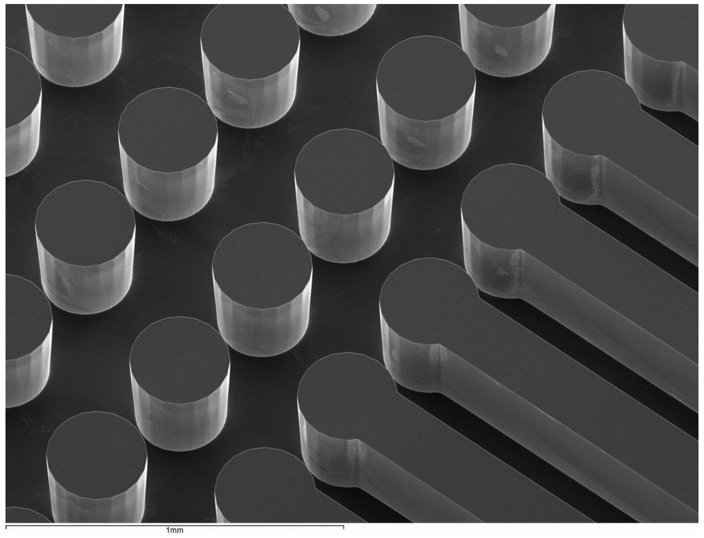


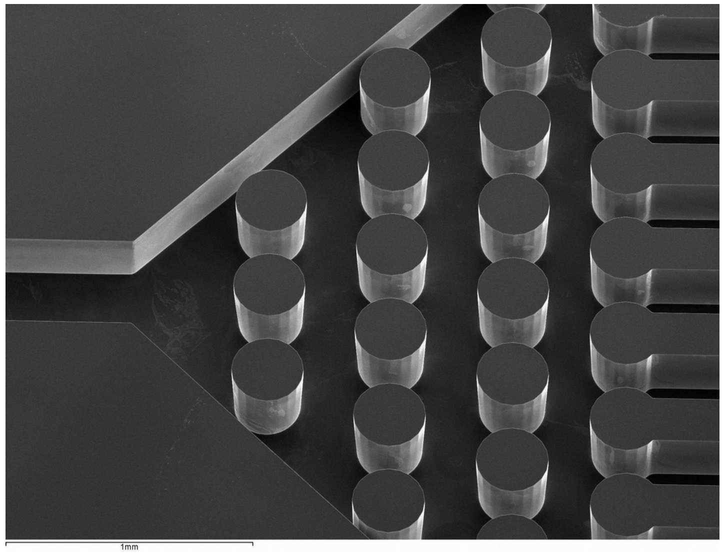
PXD

MCC prototype









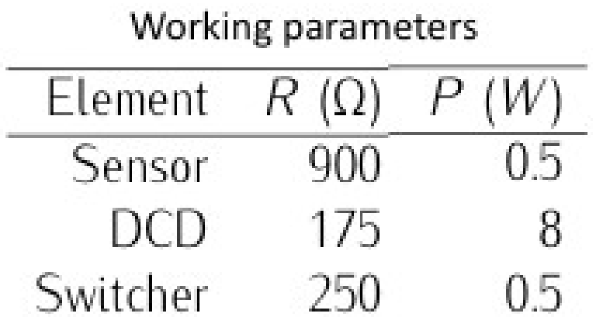
Micro-channel pattern in handle wafer

Inlet and outlet: ~350 x 350 µm

Silicon dummies concept

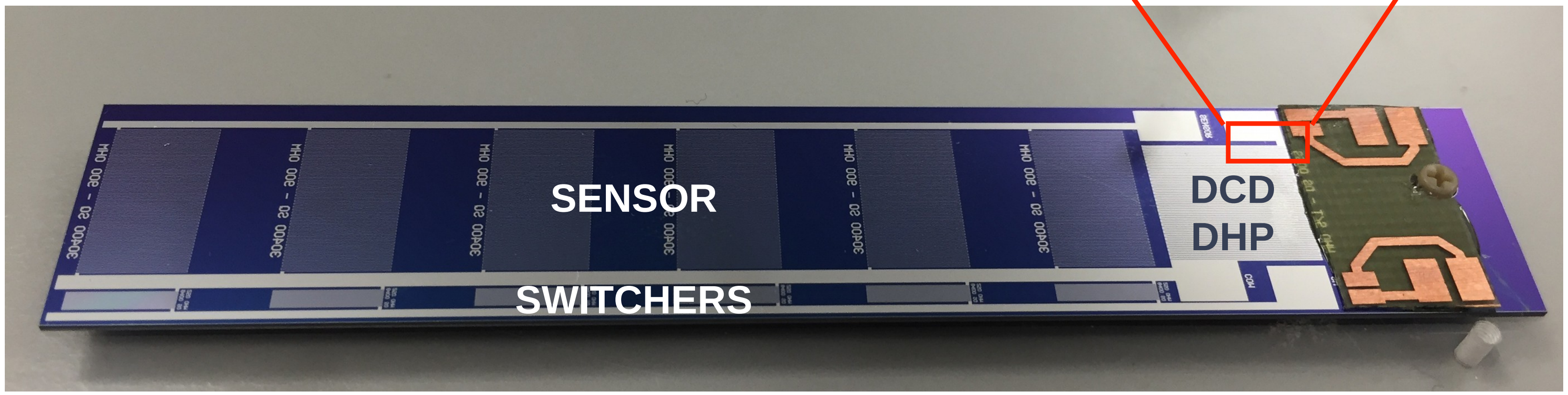
The resistive dummies with integrated micro-channels

- Si modules with the designed dimensions of the detectors
- Homogeneous thickness (thinned sensor area not needed)
- Modules do **not include** the **real electronics**
- Aluminum layer with resistor meanders on thin top wafer -> **simulate the power distribution**



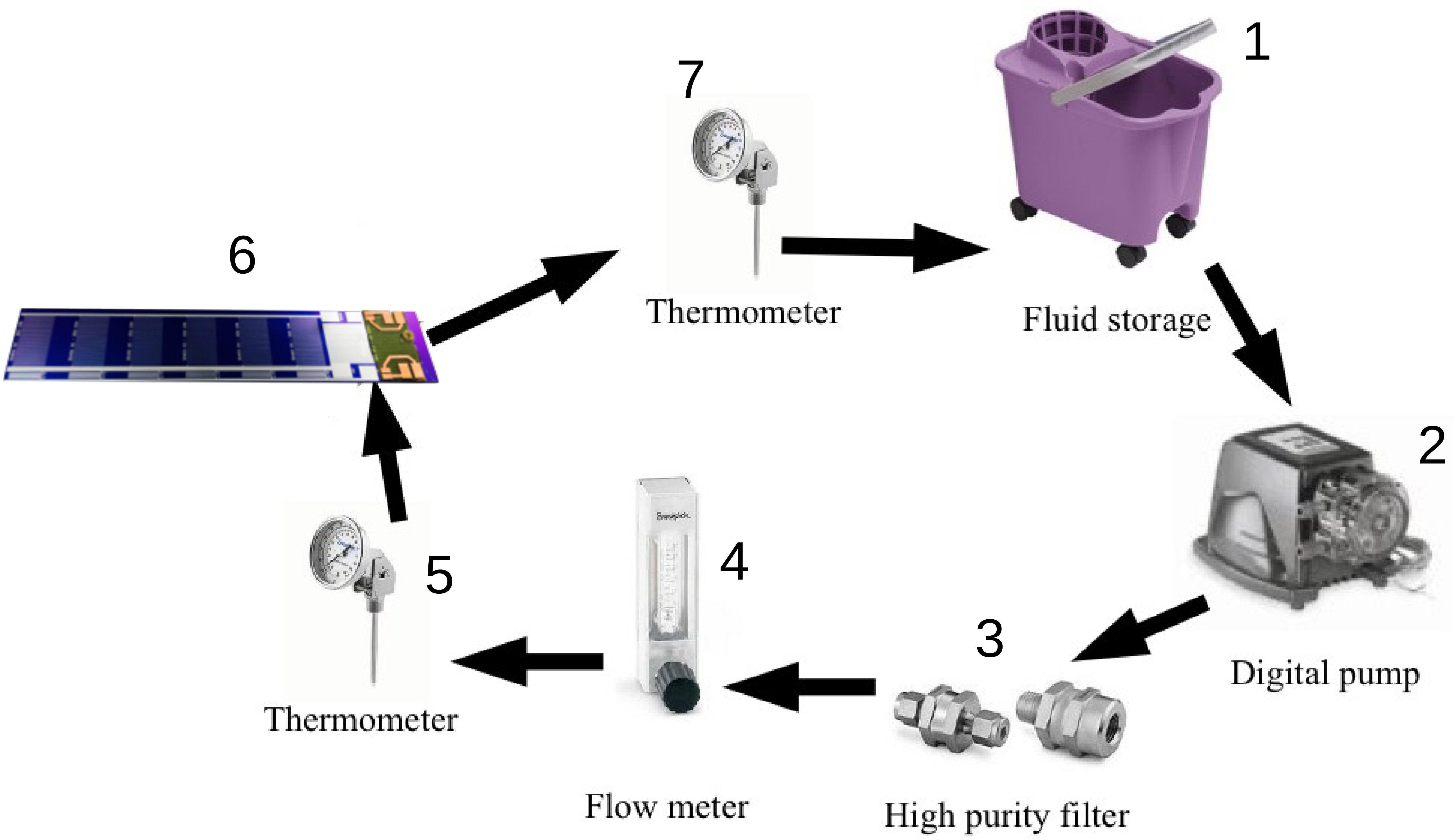
Working parameters

Element	R (Ω)	P (W)
Sensor	900	0.5
DCD	175	8
Switcher	250	0.5

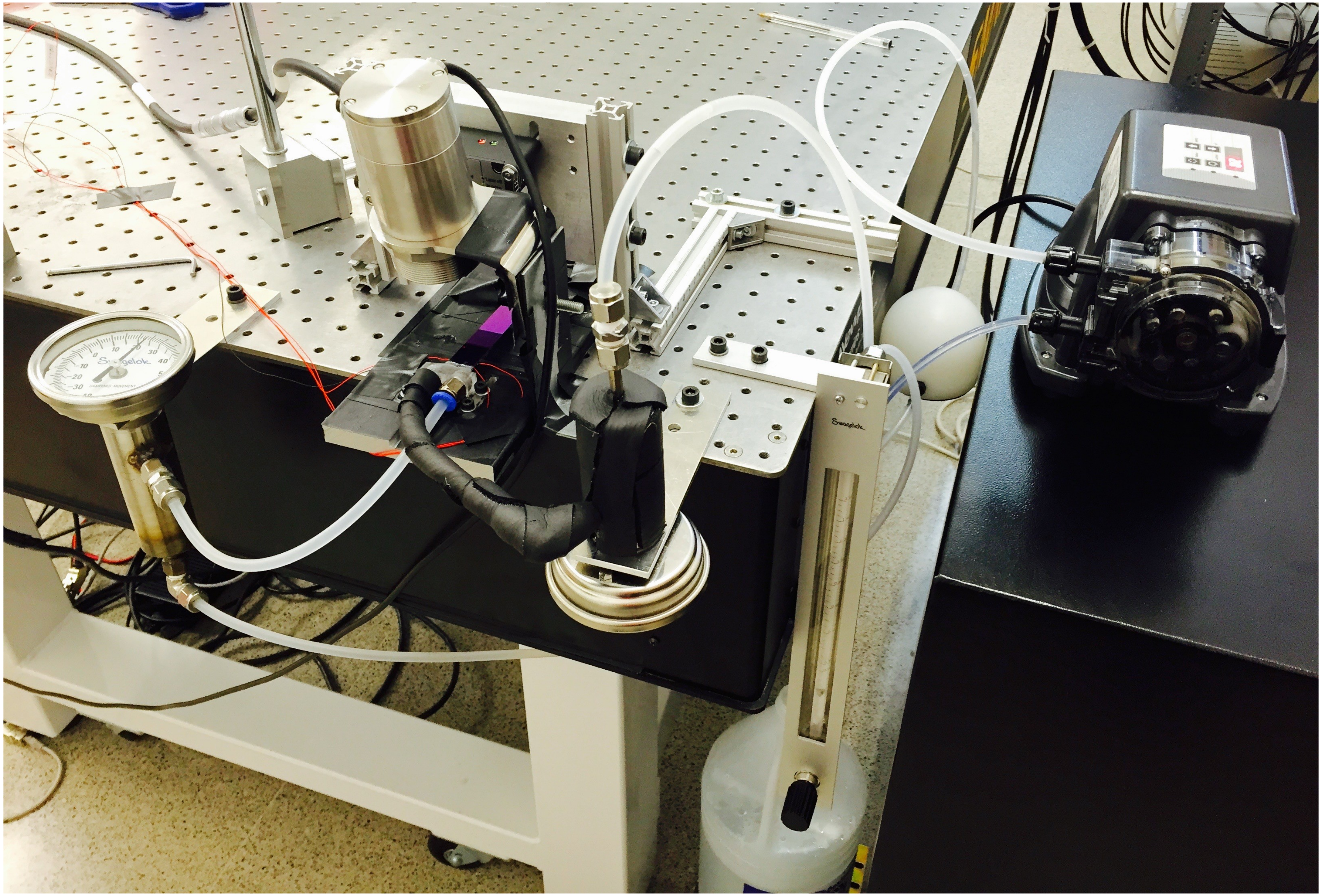


Half-Ladder for the inner vertex detector

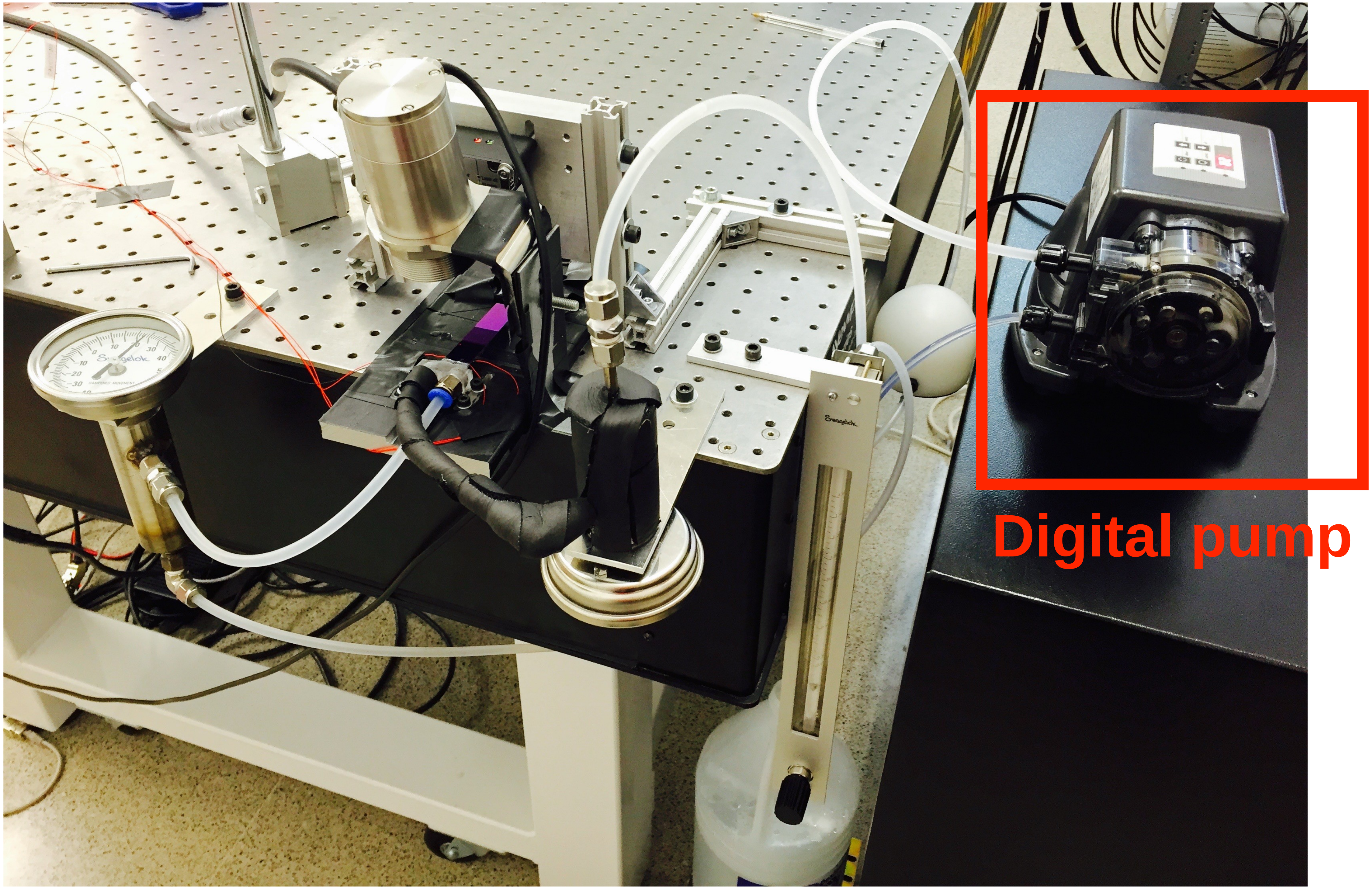
Experimental setup



Experimental setup

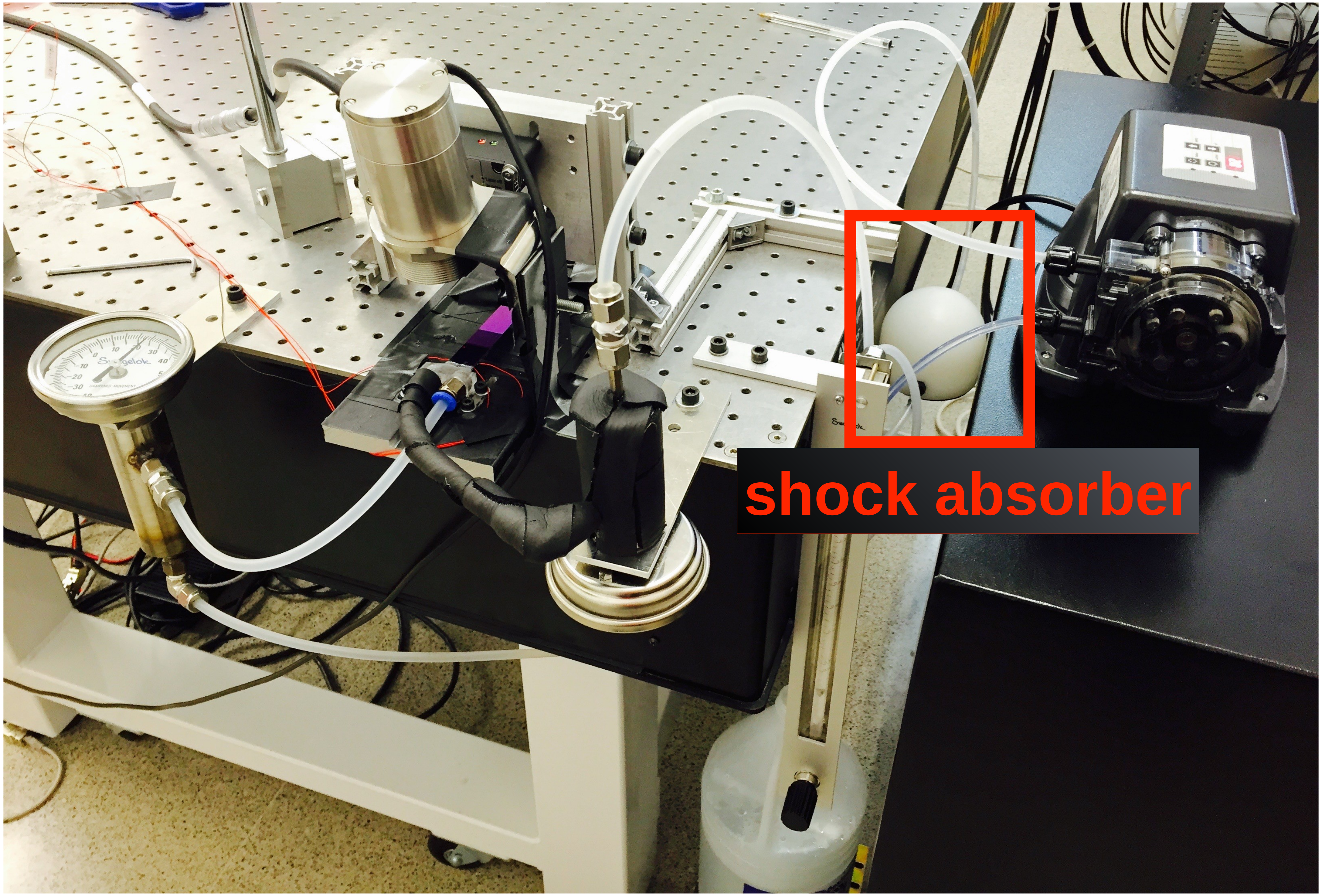


Experimental setup

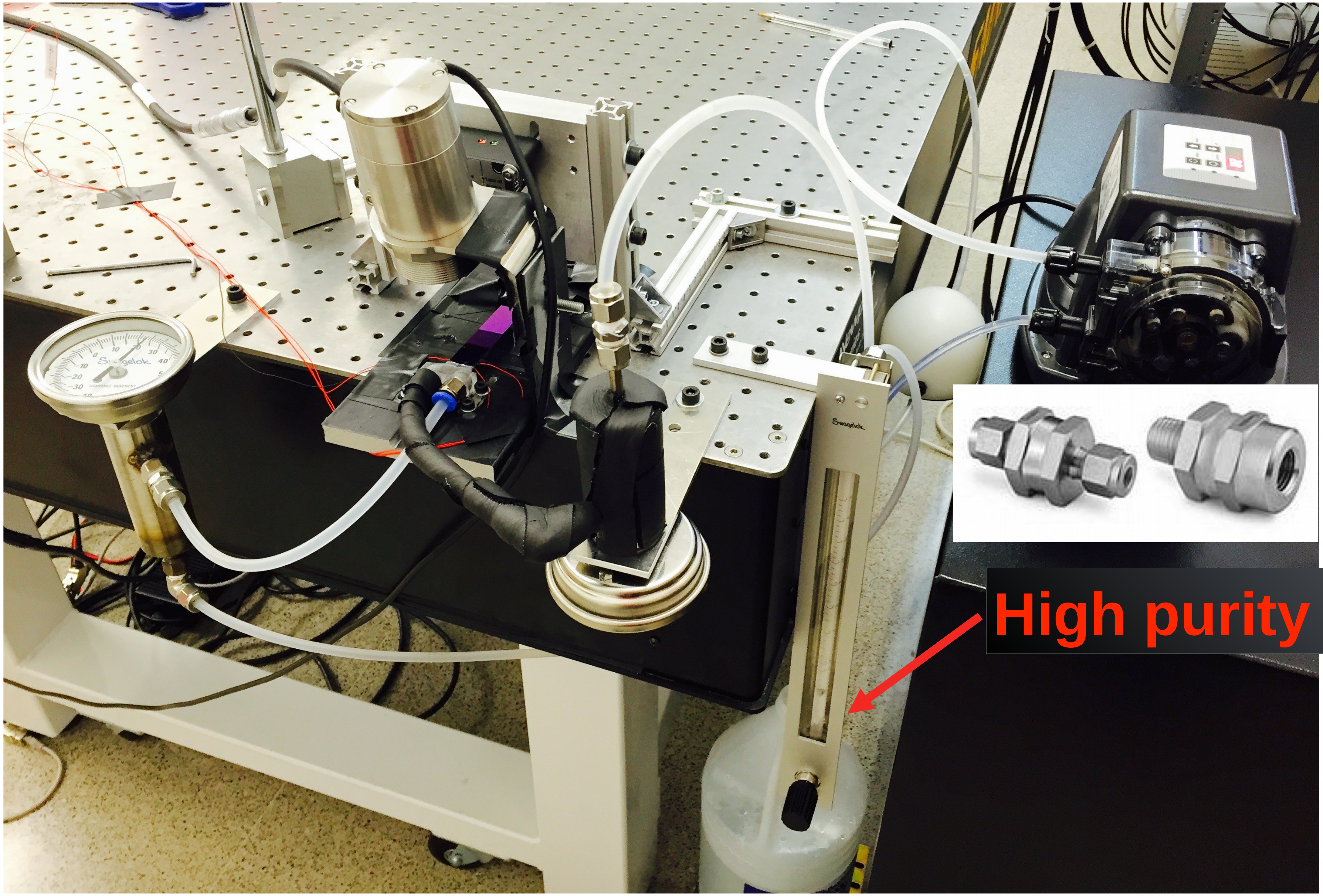


Digital pump

Experimental setup

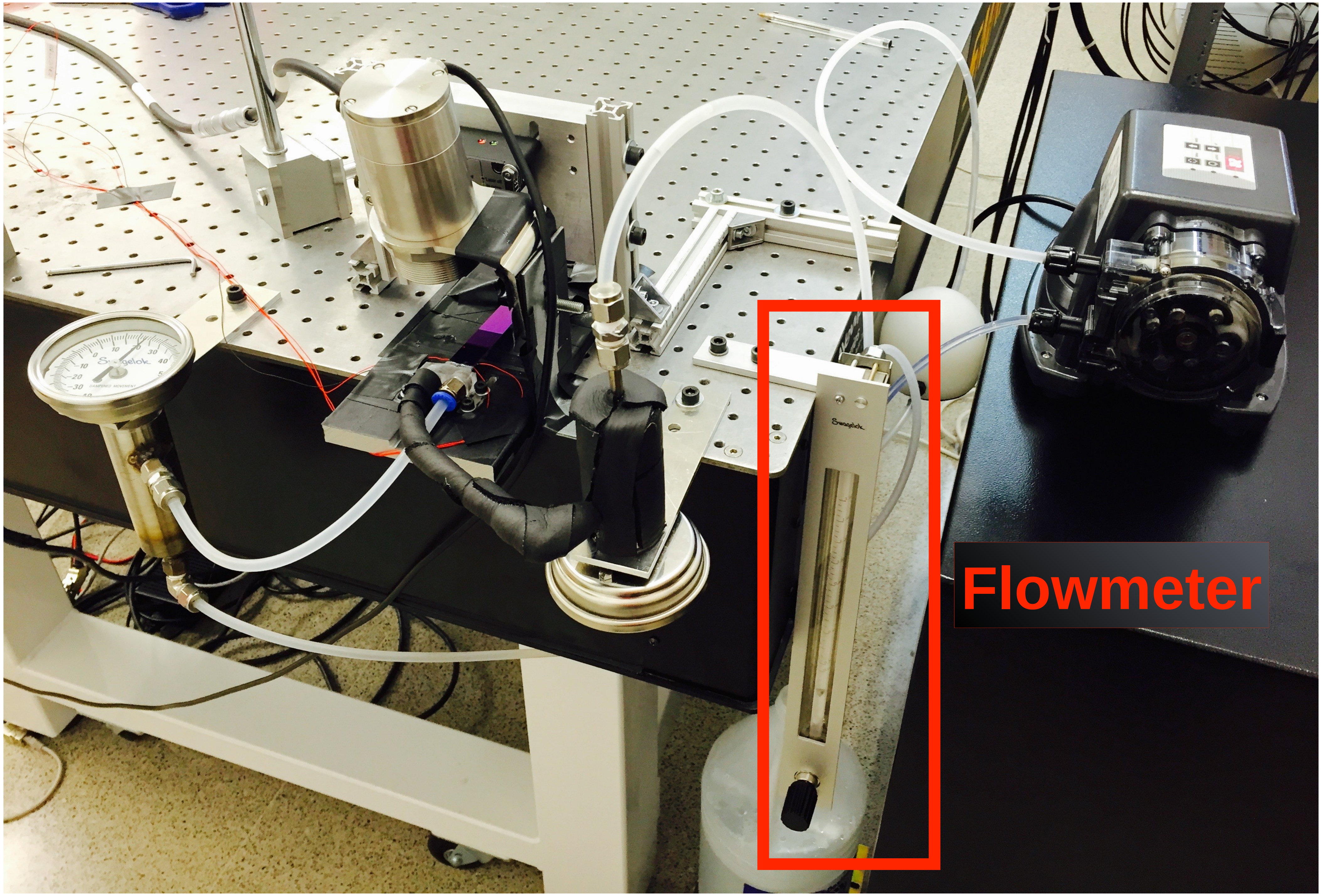


Experimental setup

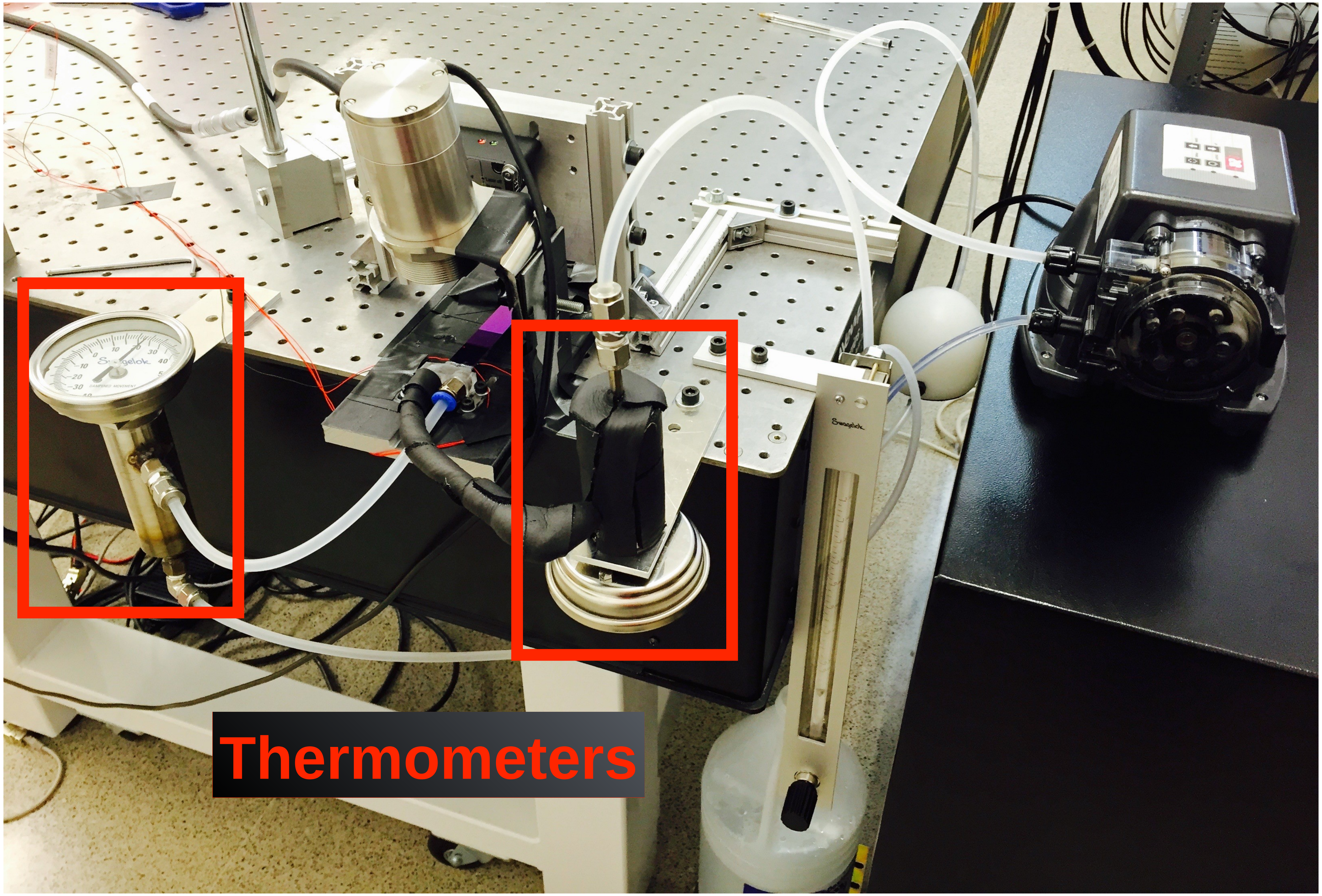


High purity filter

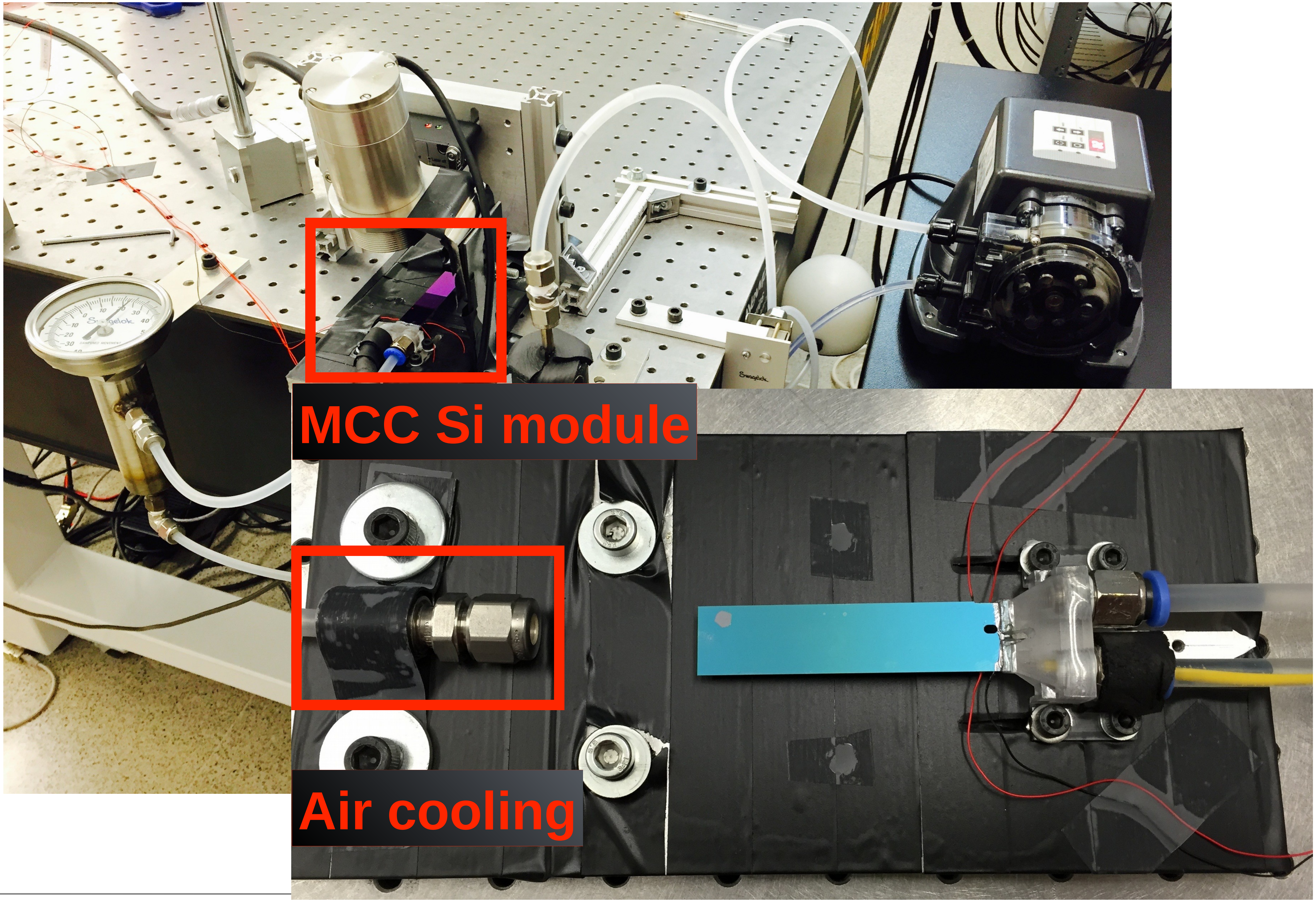
Experimental setup



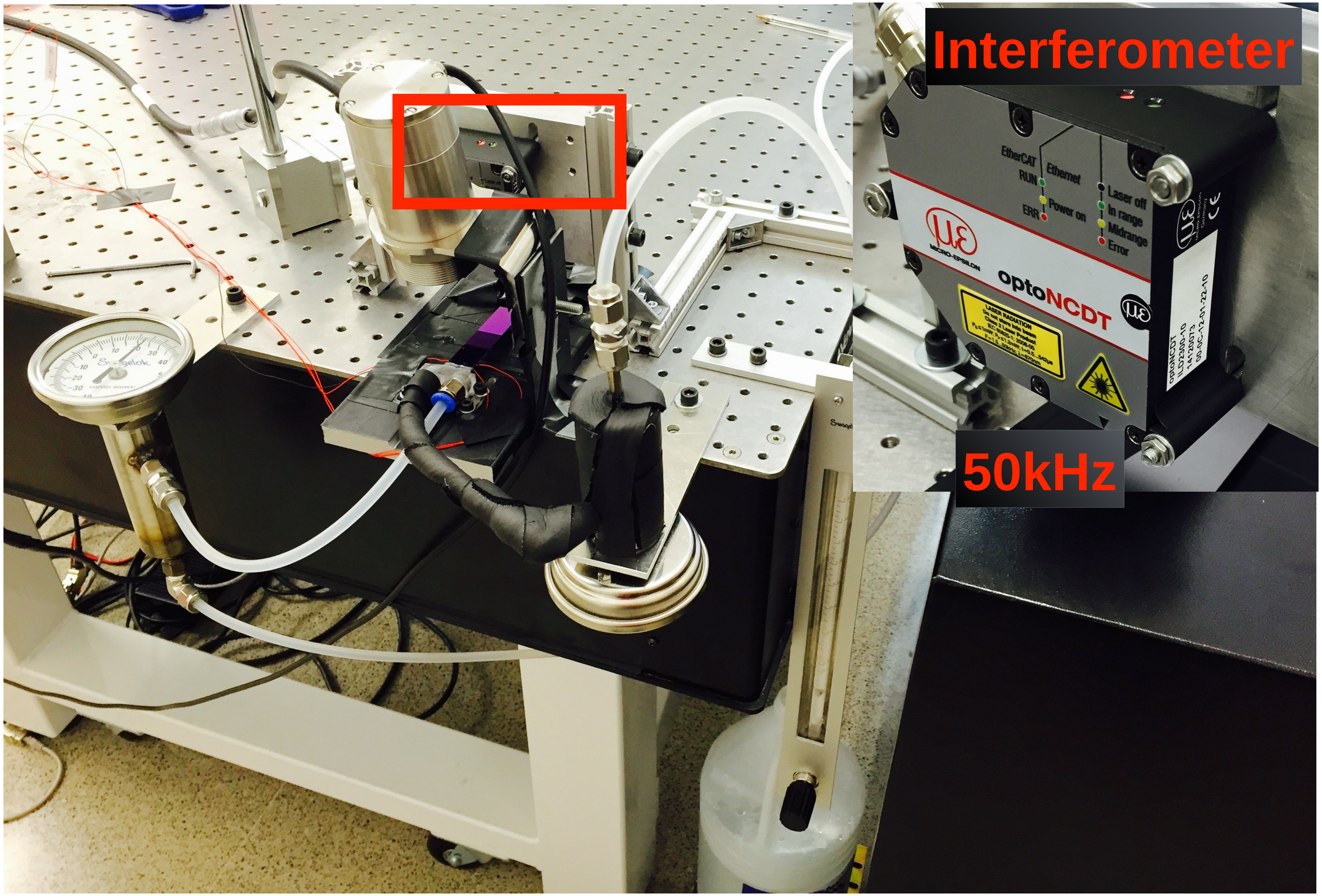
Experimental setup



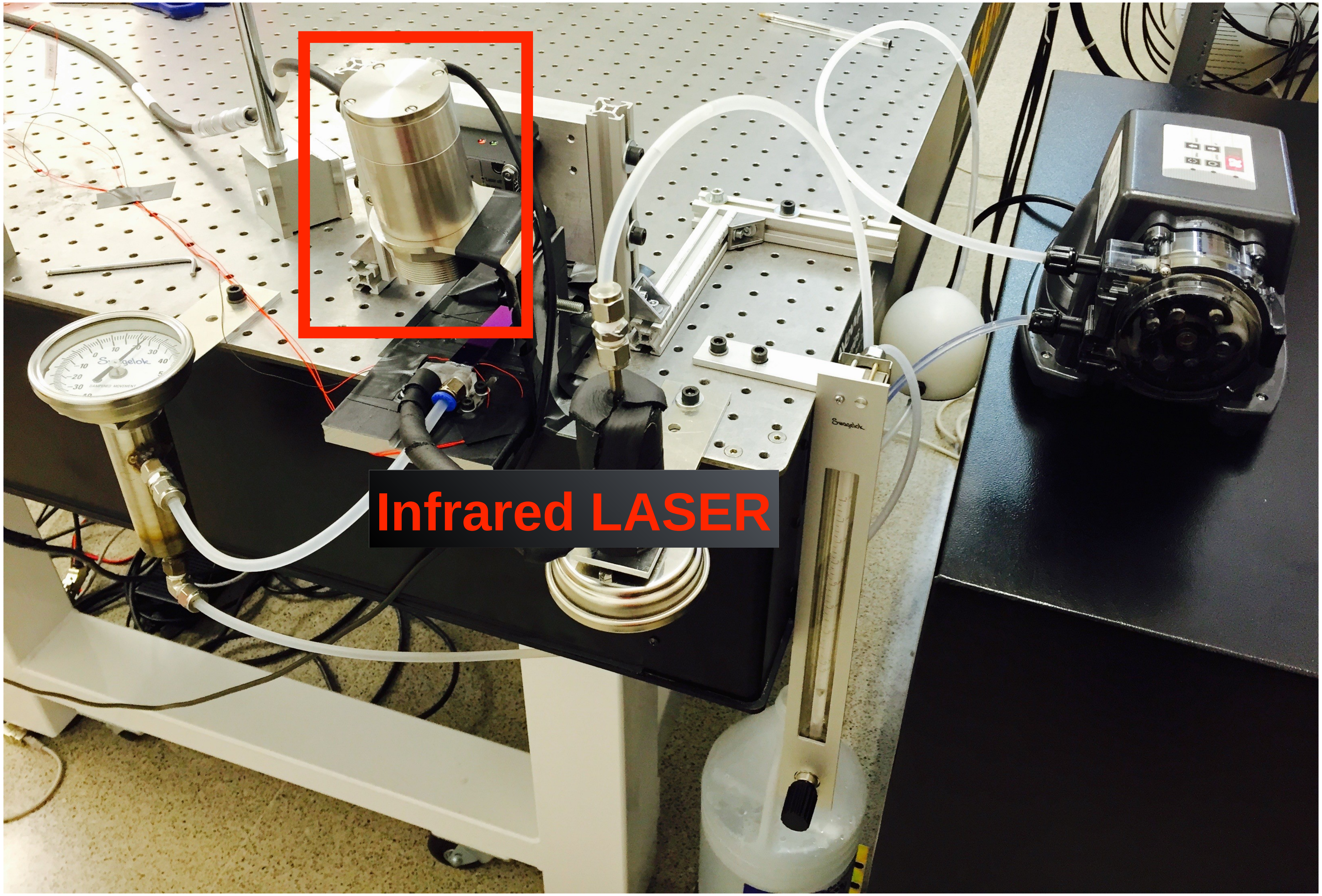
Experimental setup



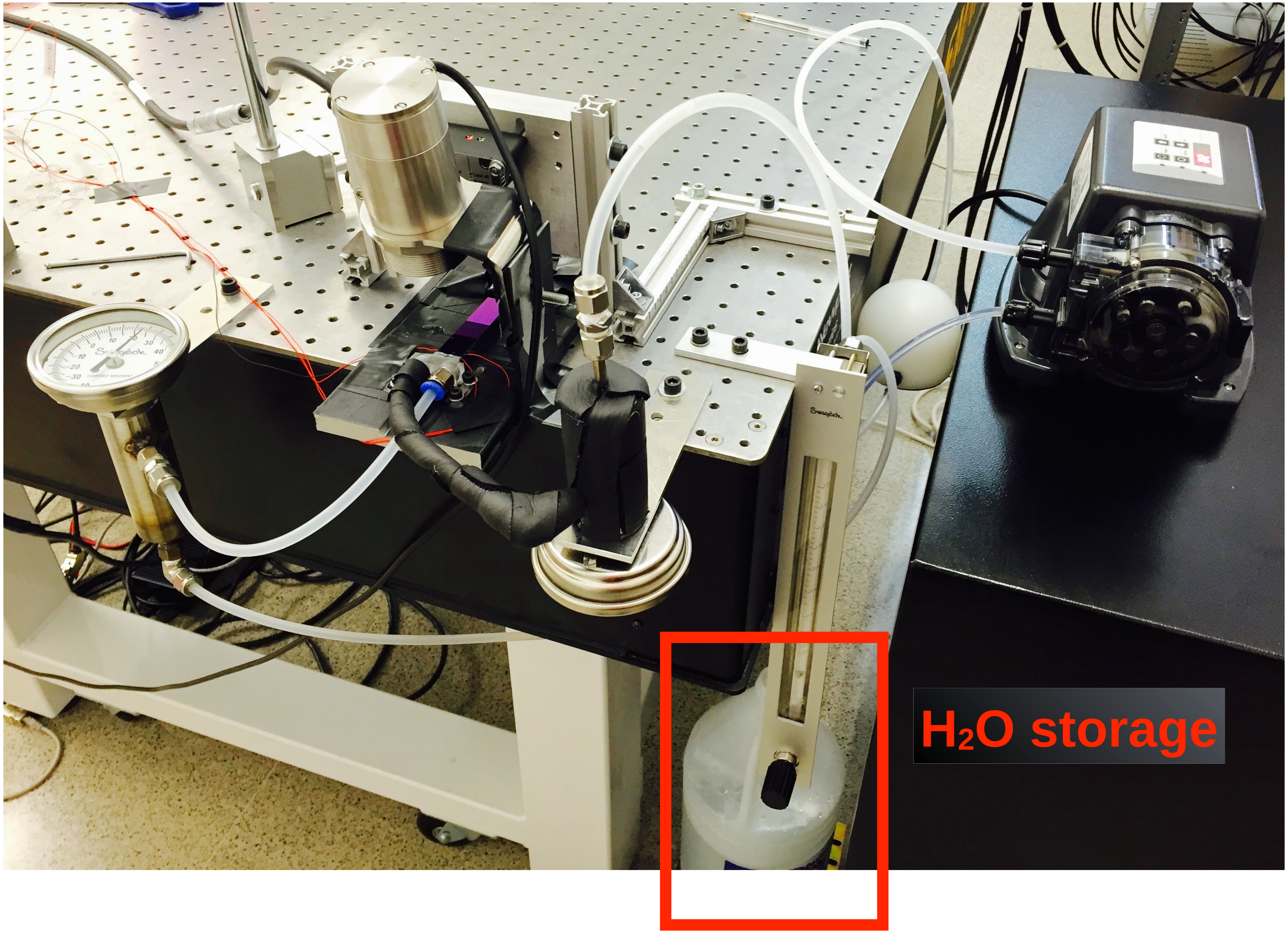
Experimental setup



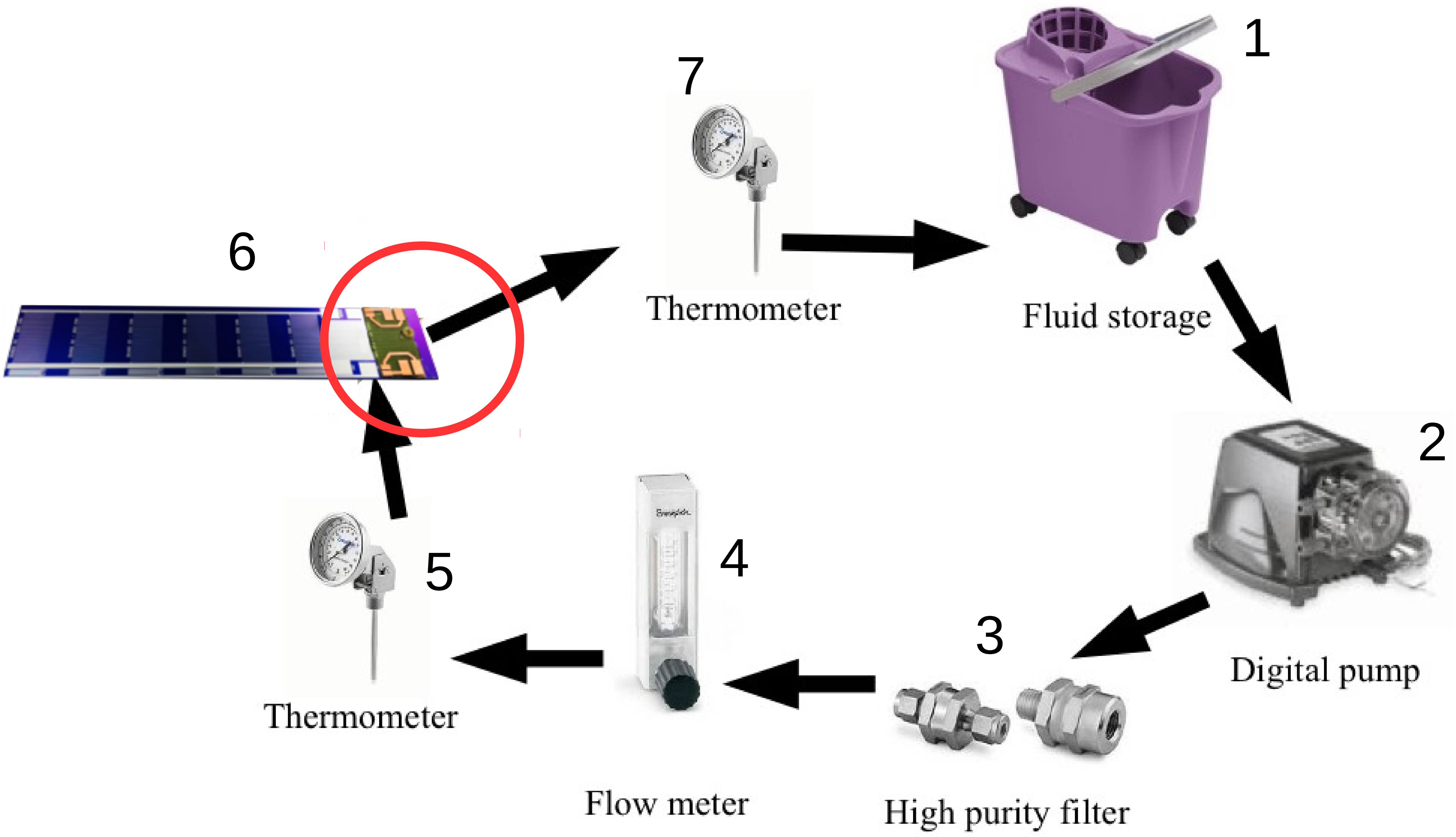
Experimental setup



Experimental setup



Experimental setup



Past results

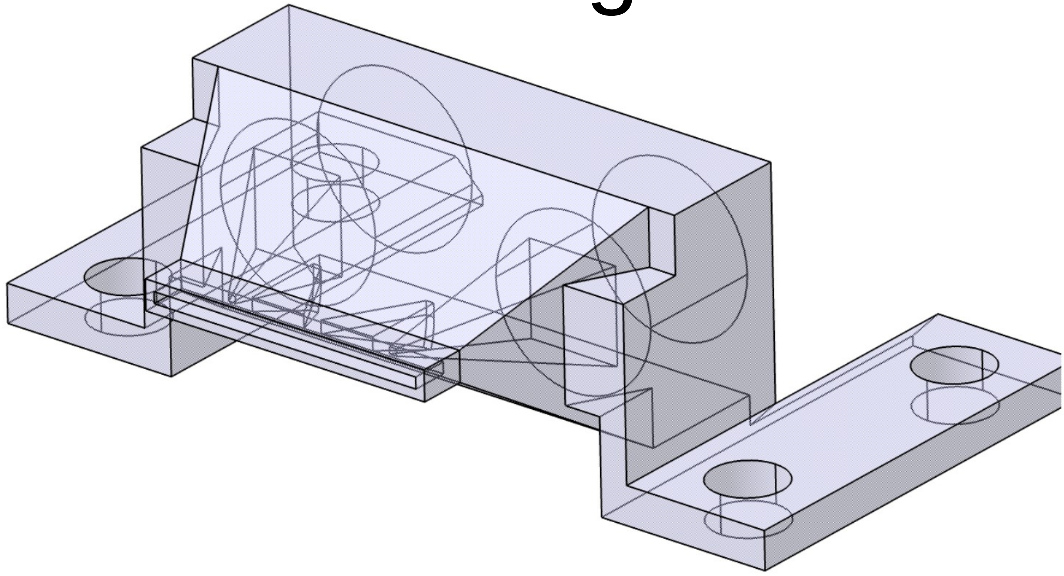
3D-printer technology

Built by 3D-printer (stereolithography technology):

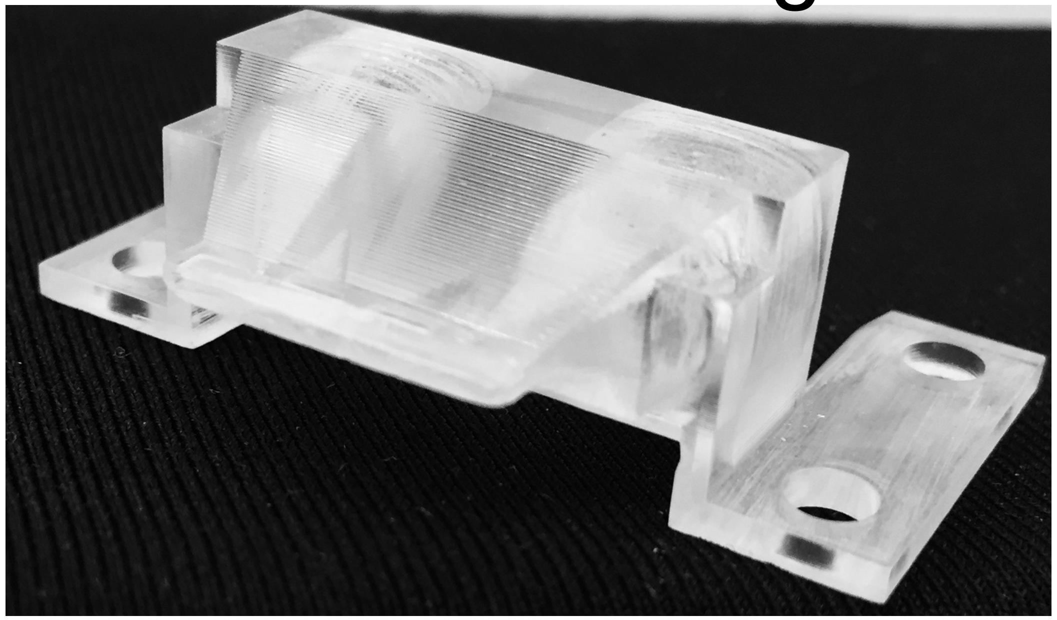
- 15 µm precision
- 300 µm per layer
- Very complex geometries
- Material: X0=350mm
- Joint: 3D Part glued to MC silicon module
- Cheap and fast manufacture (not the 3D printer)
- Good performance below 70ºC

3D-printed adaptor

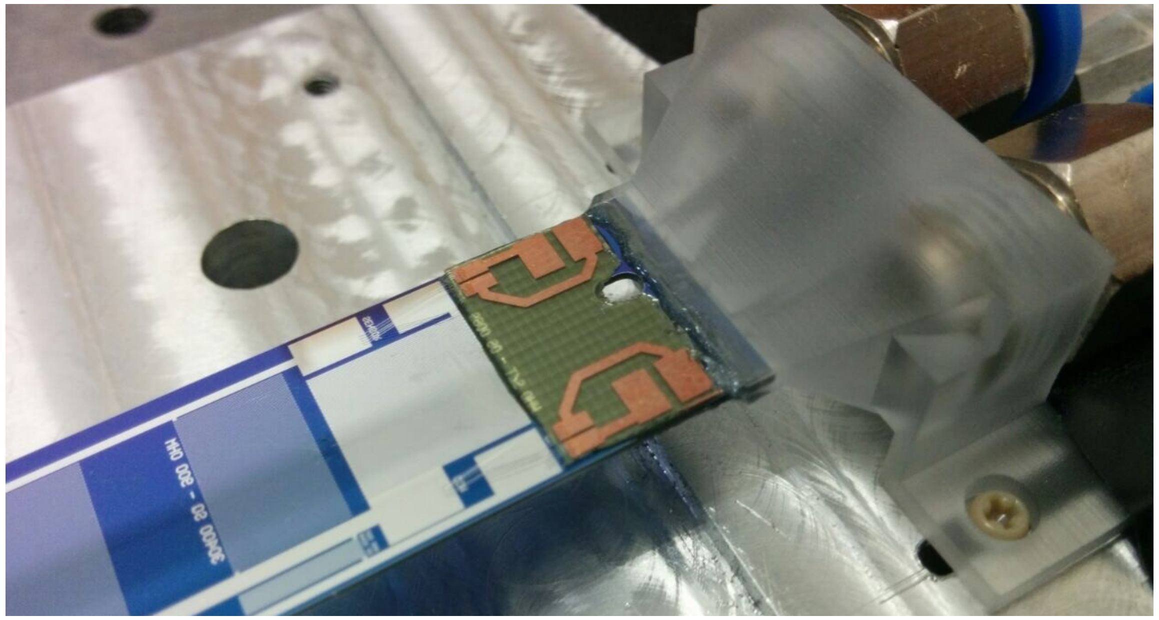
Design



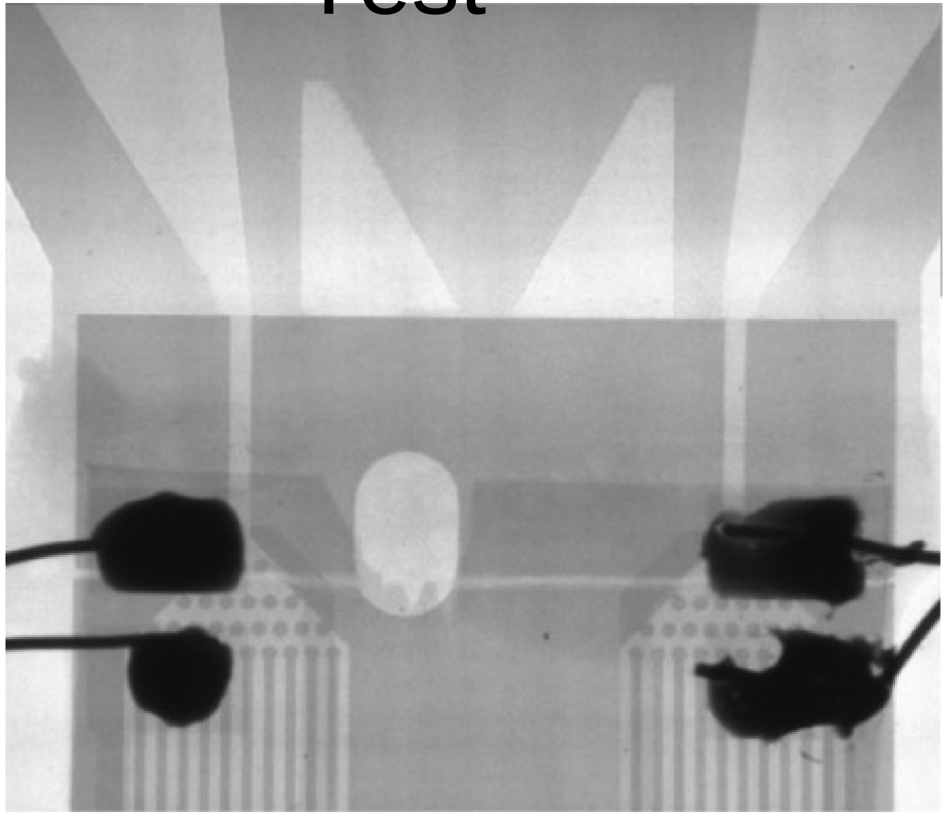
3D-Printing



Gluing



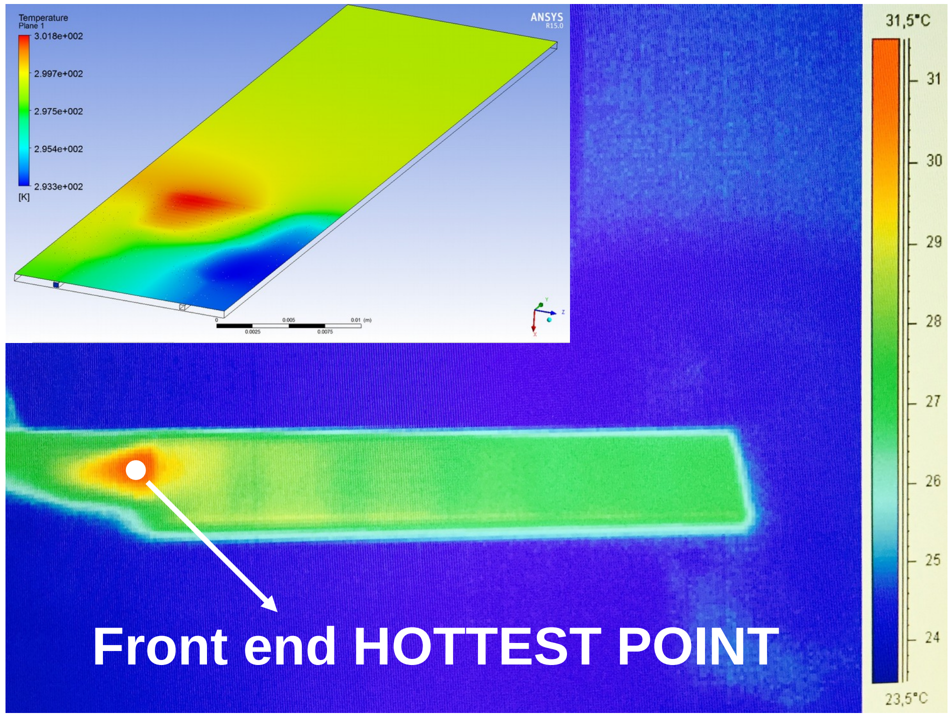
Test

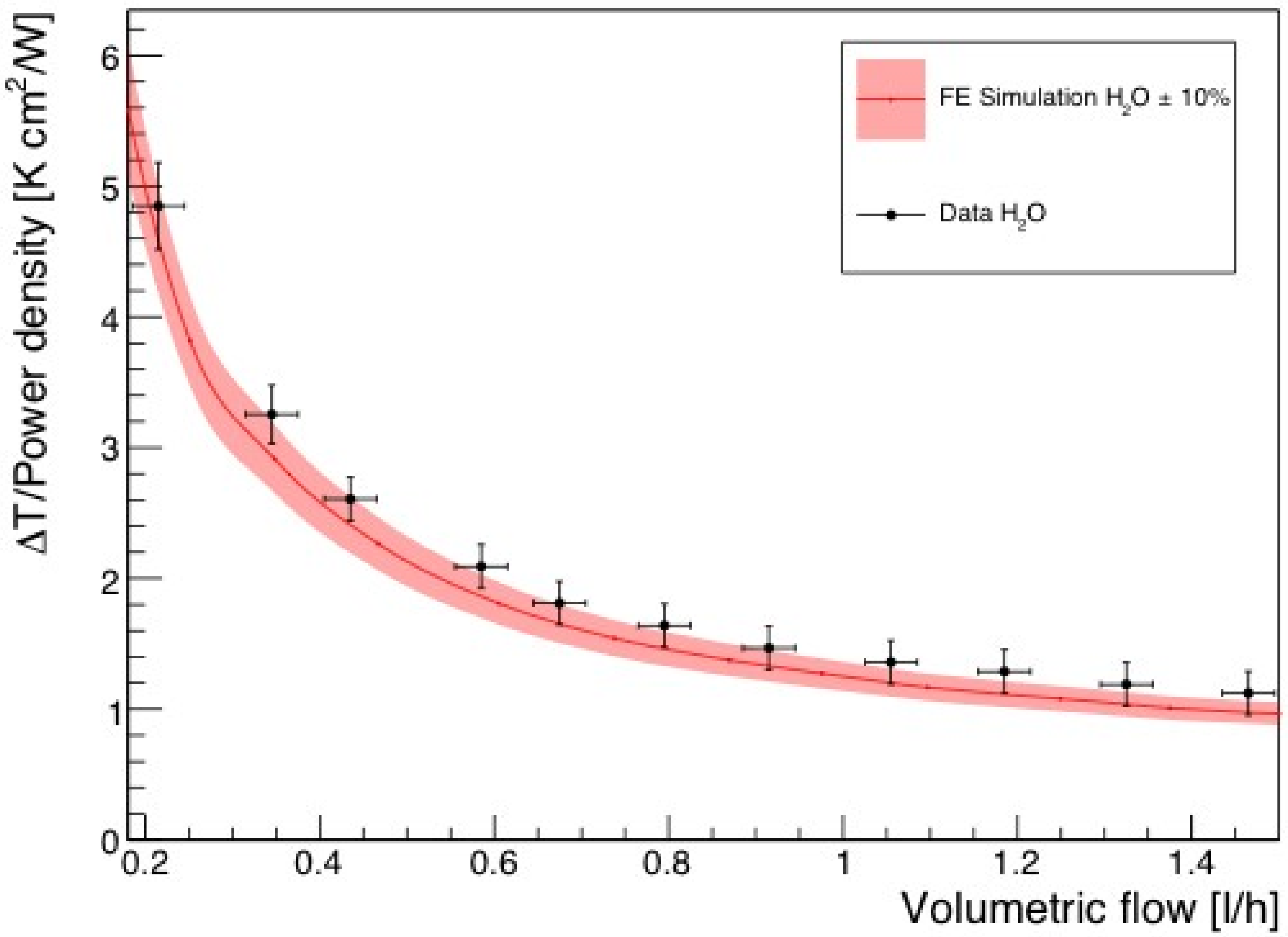


Experiment conditions

- For all-Silicon resistive dummies operating above 0°C **mono-phase fluid** is chosen (**H_2O**)
- **Possibility of use CO_2 at high pressure but not necessary at the power densities we have to manage**
- Controlled environment to quantify cooling performance. **Room temperature stable at 25°C**
- Operated non-stop for a week with **no leaks, no clogging**

Thermal measurements: MCC



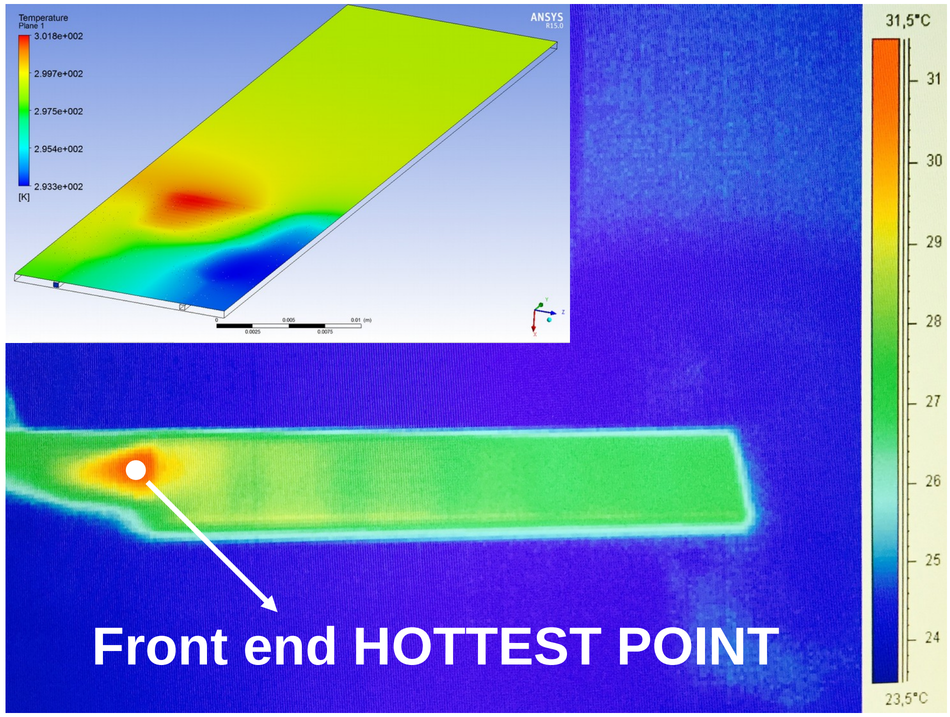


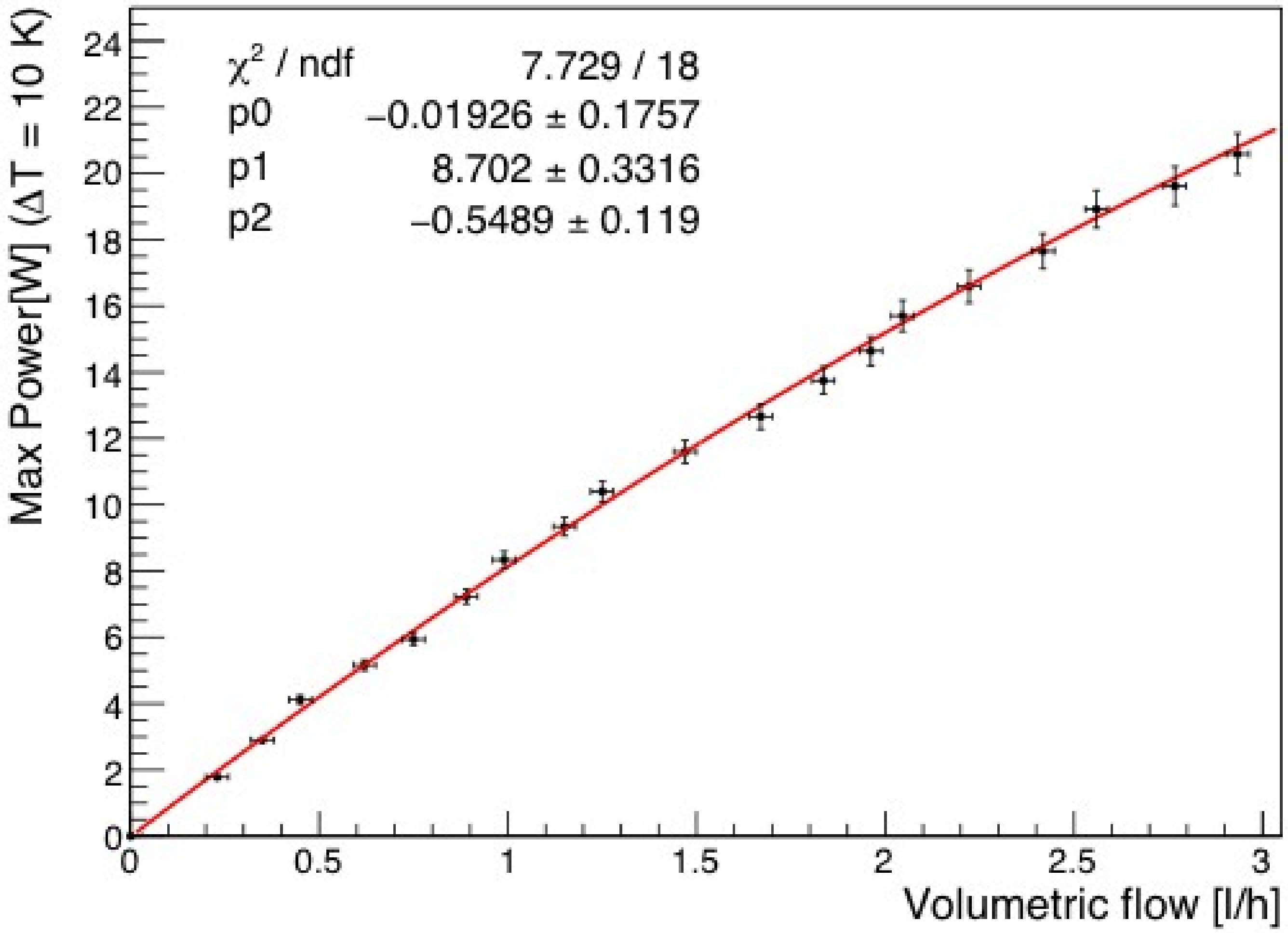
- Low cost mono-phase fluid: H_2O
- **Low volumetric flows (~1l/h) and low pressure (<1bar) are enough to dissipate the heat in the front end**
- **Good agreement** with the **FE simulation** inside an error area of **10%**

Measurement data errors

- P ±1% W
- T ± 1 ºC
- ΔT/Power density ± 0,14 ºC/W
- flow ± 0,03 l/h

Thermal measurements: Maximum Power vs Volumetric flow

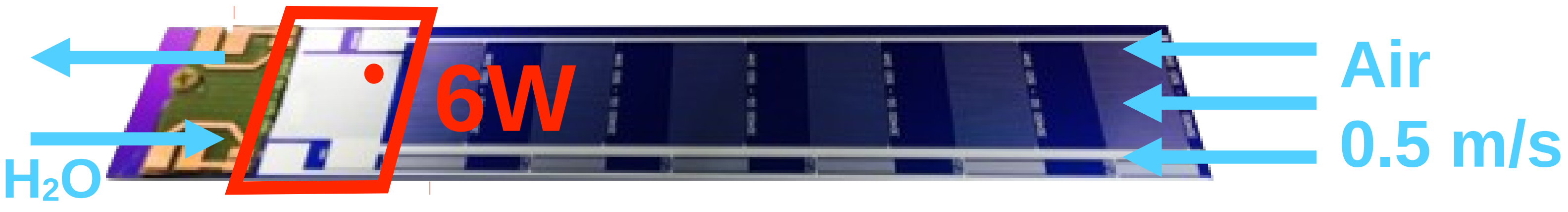


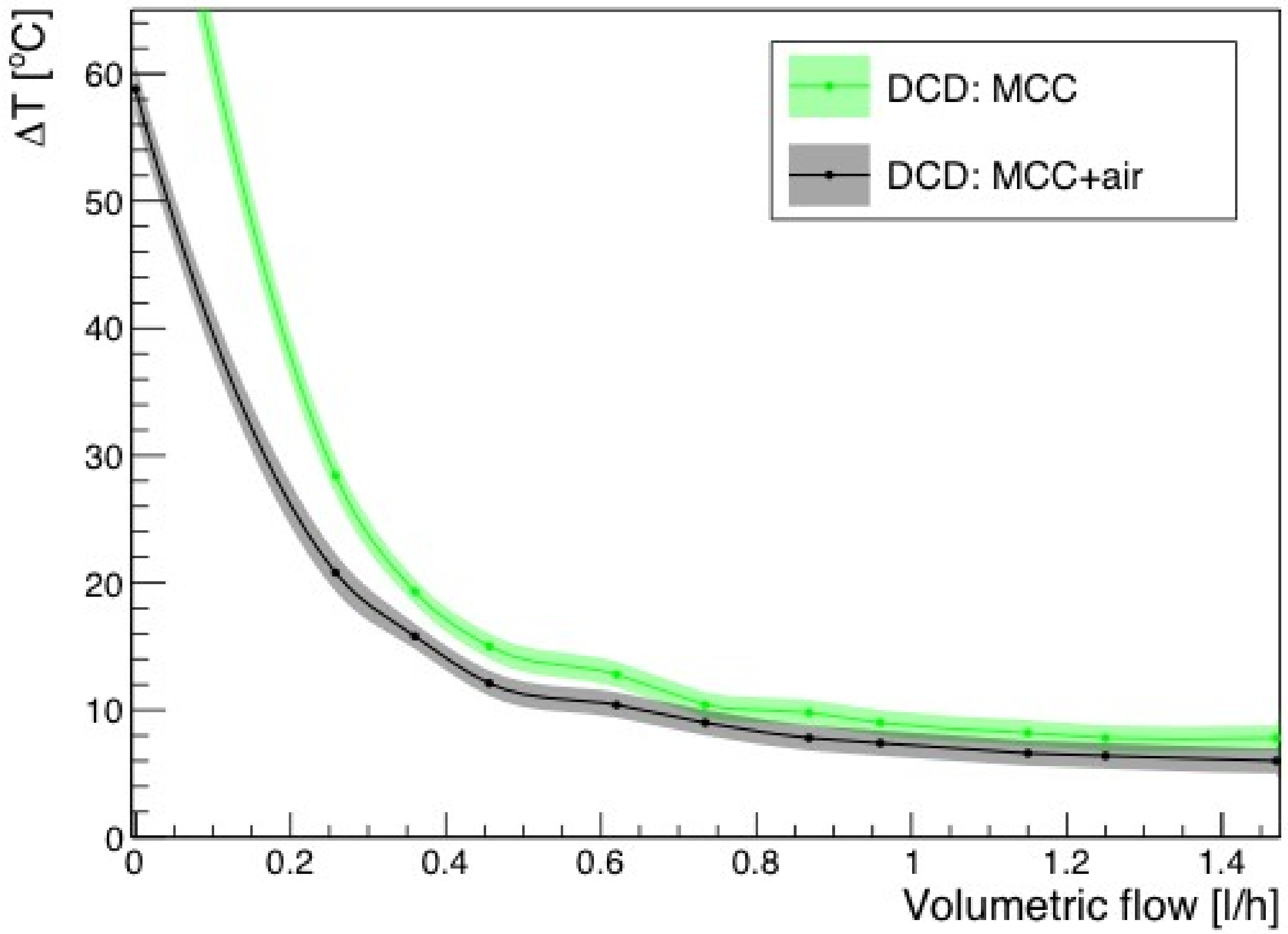


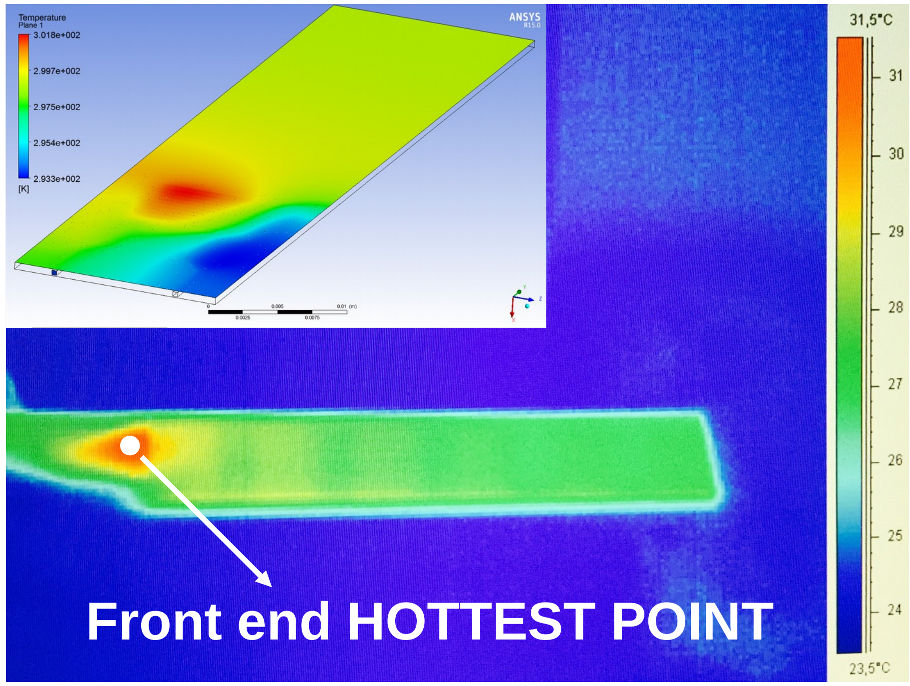
Maximum power supported for a ΔT of 10 ºC as a function of the volumetric flow

- **Temperature stable** even with power density of **25 W/cm²**
- **Power vs vol. flow** at max. pump power (~ 3 l/h)
- **Low pressure** needed: 0.2 - 1.5 bar

Thermal measurements: MCC+air



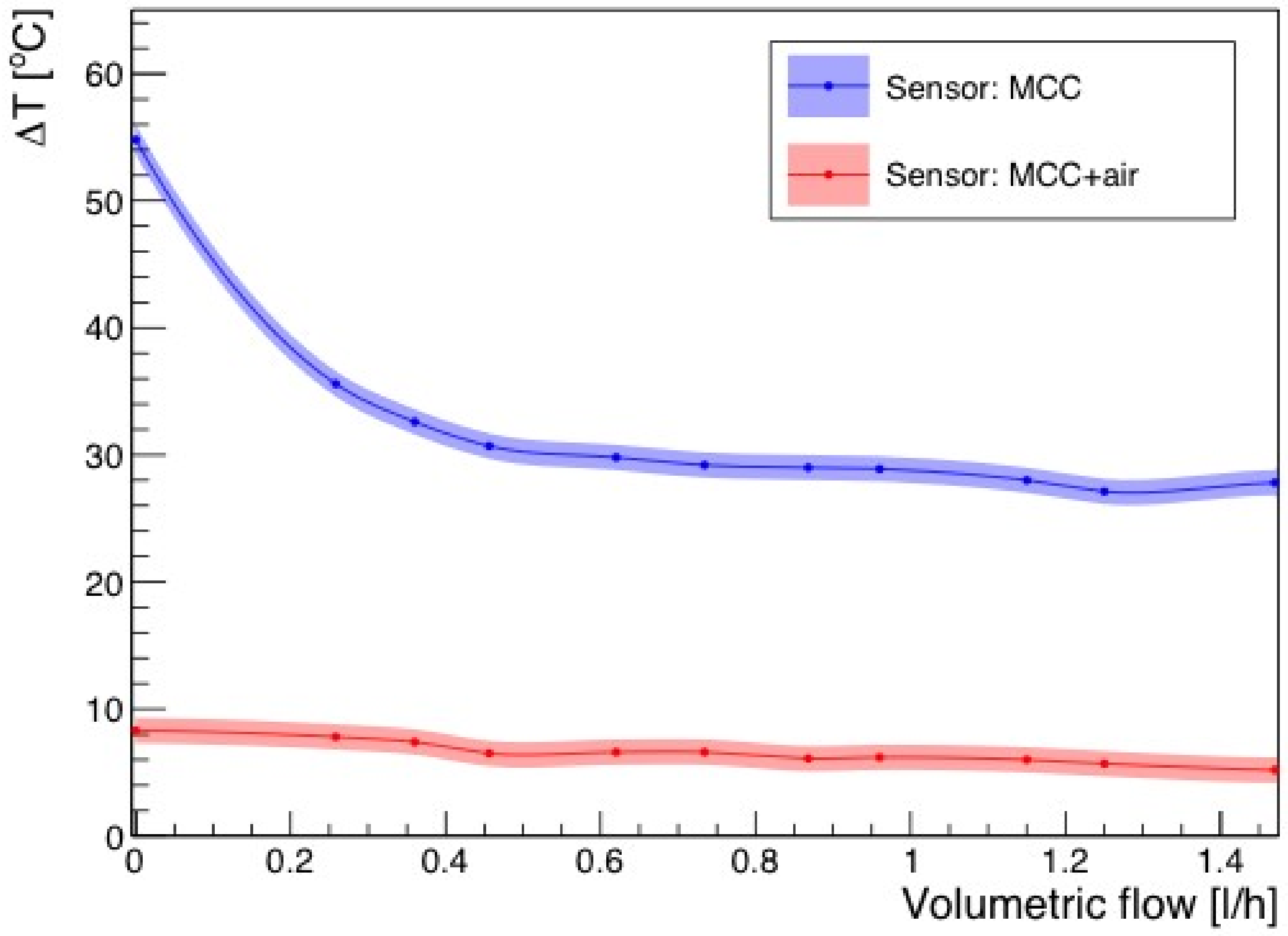


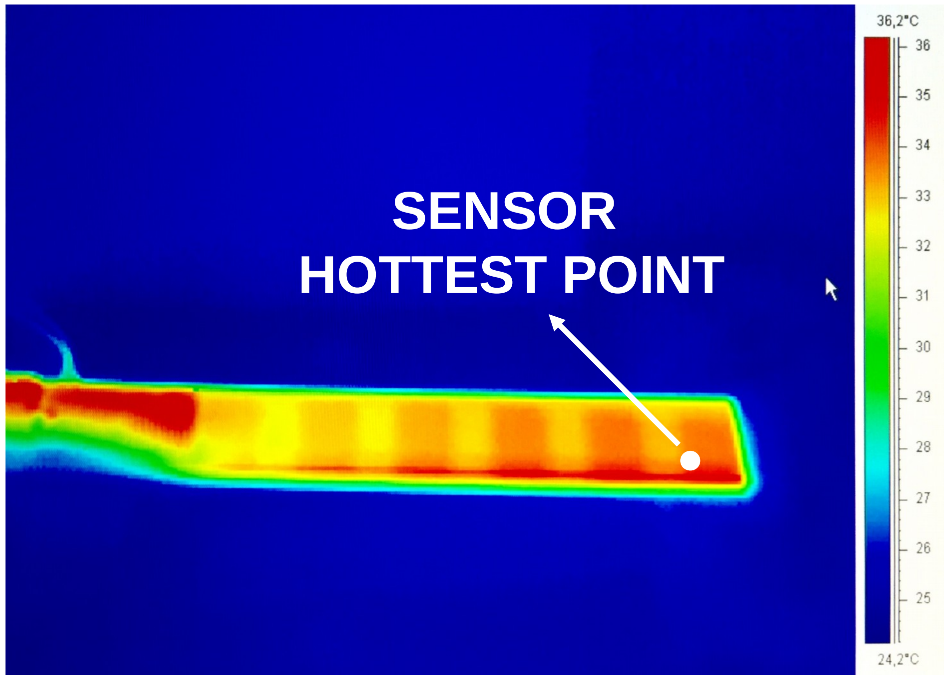


- **There is not big difference between MCC and MCC+air at the DCD hottest point**
- **Farthest regions to the air inlet are less affected**
- **Even with low volumetric water flow, high cooling**
- **93% of total heat removed by MCC**

Cooling strategy: micro-channels running under the front end and gentle air flow on the sensor part

Thermal measurements: MCC + air

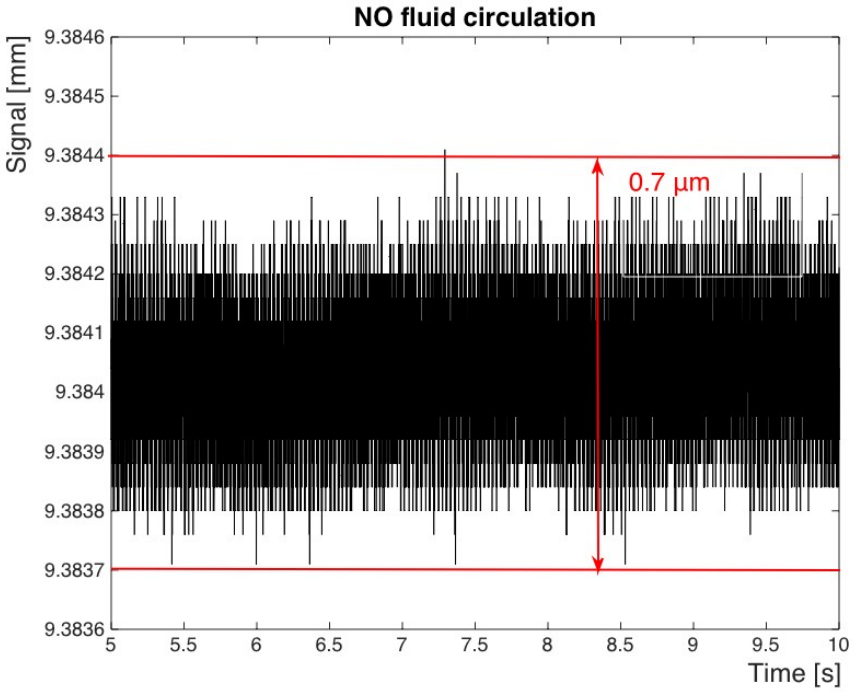


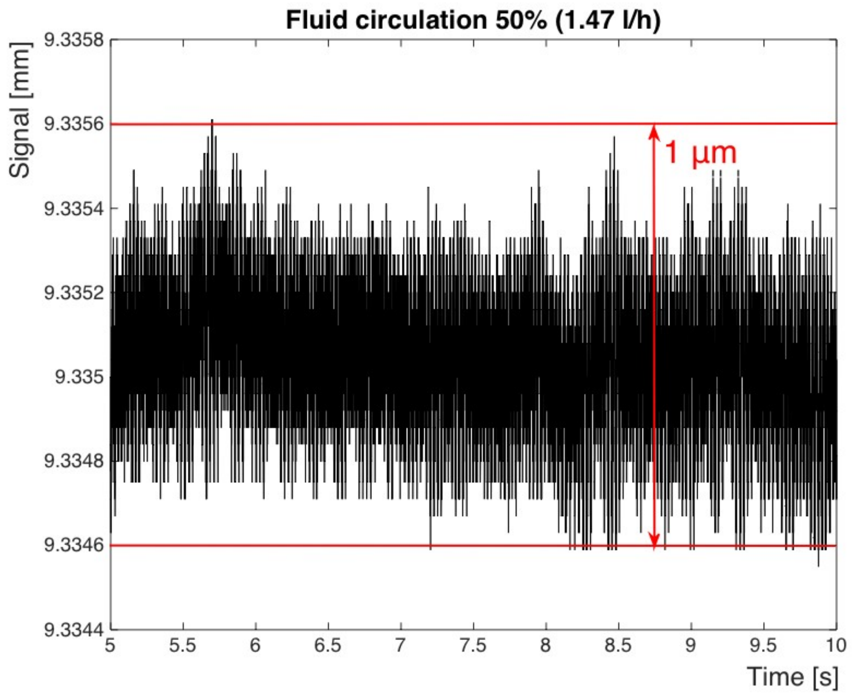


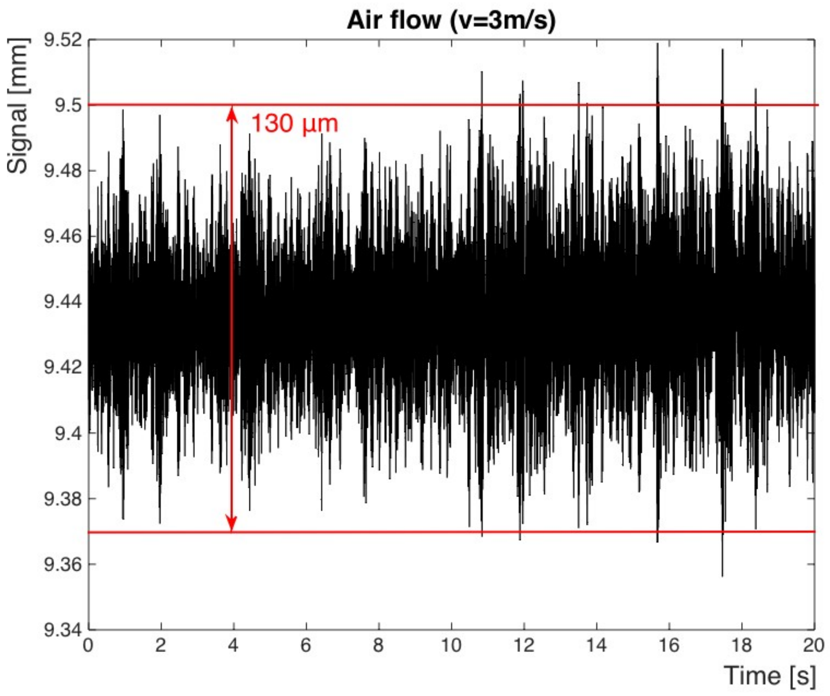
Cooling strategy: micro-channels running under the front end and gentle air flow on the sensor part

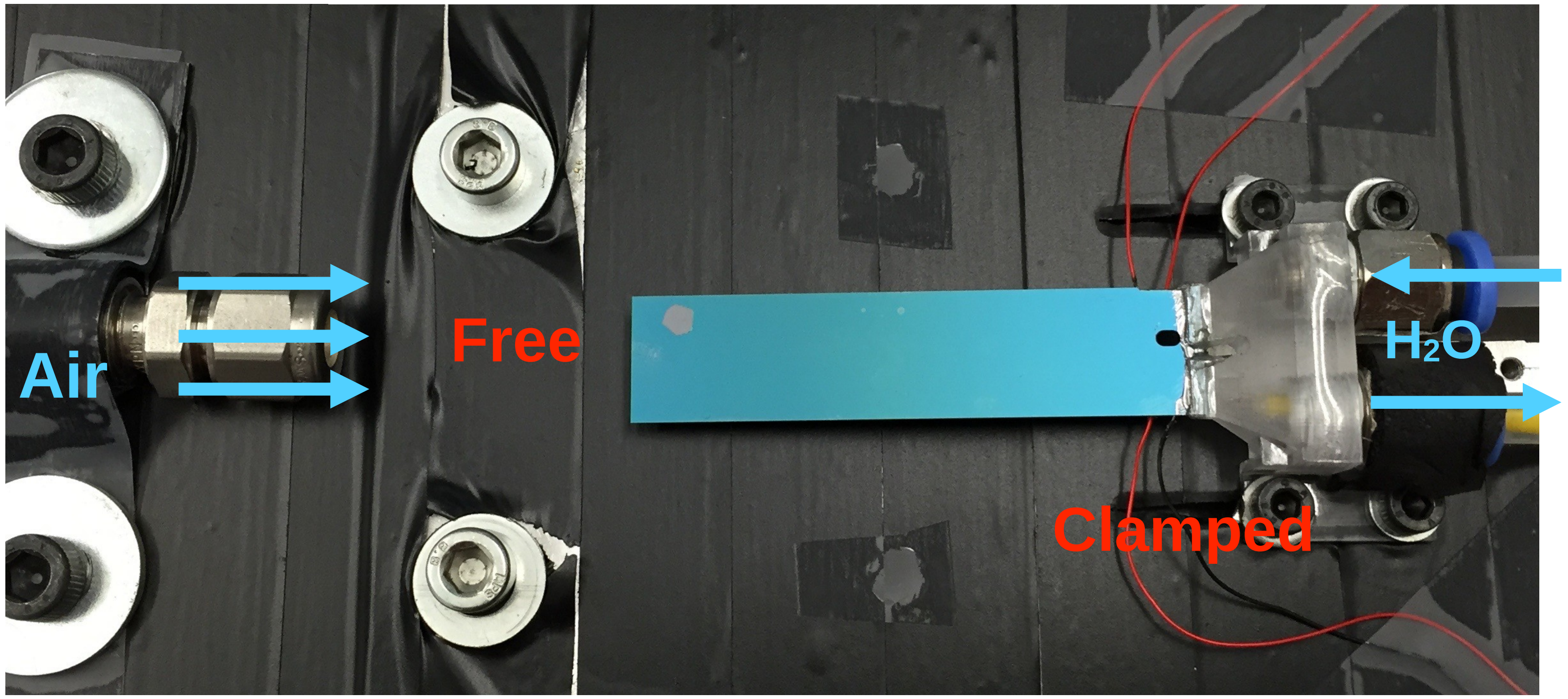
- **Big difference between MCC and MCC+air at the sensor area hottest point**
- **Nearest regions to air input are efficiently cooled even with low air flow**
- **MCC has less impact in away points as expected and great cooling locally**

Vibrations and deformations


NO fluid circulation

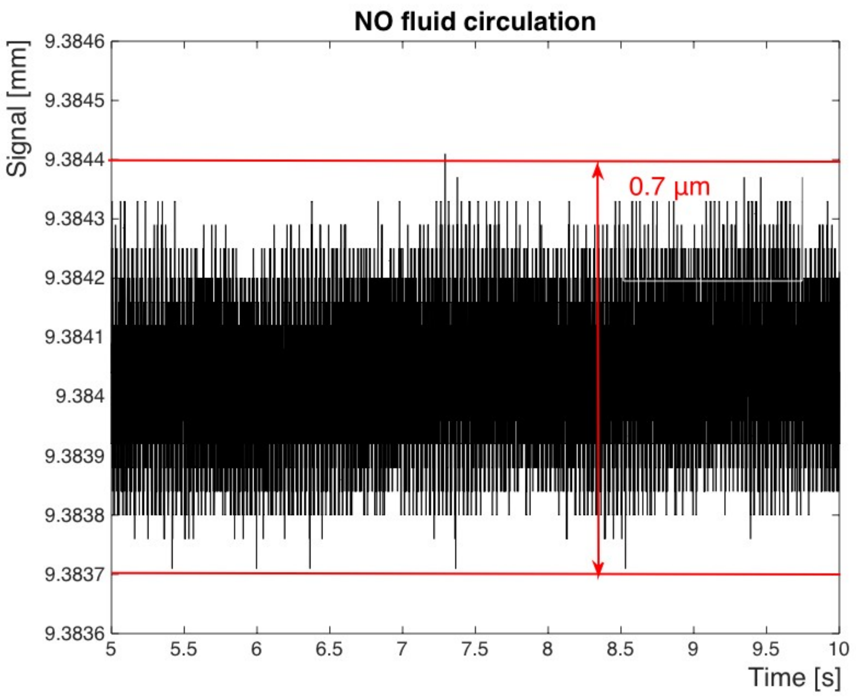

Fluid circulation 50% (1.47 l/h)

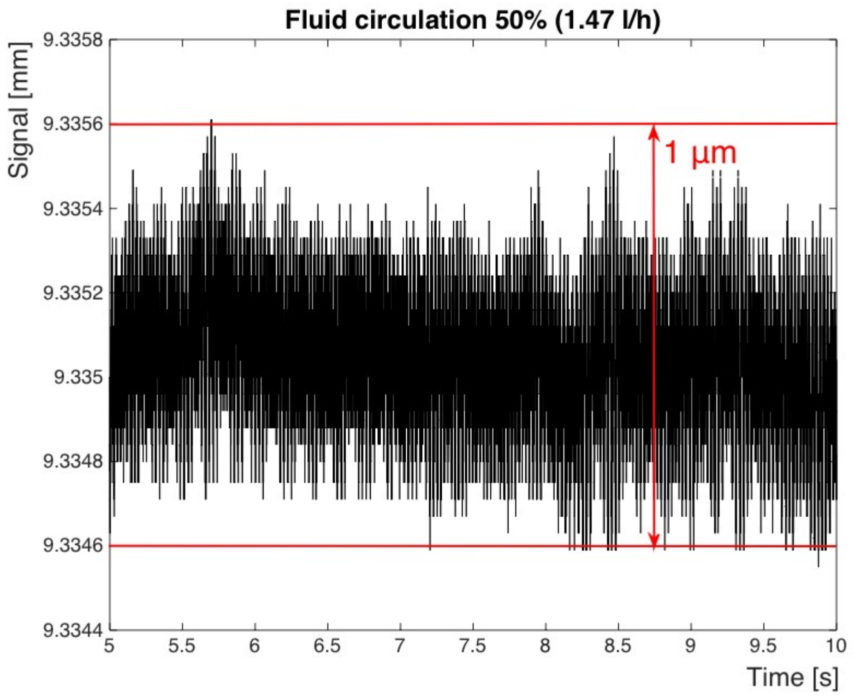

Air flow (v=3m/s)

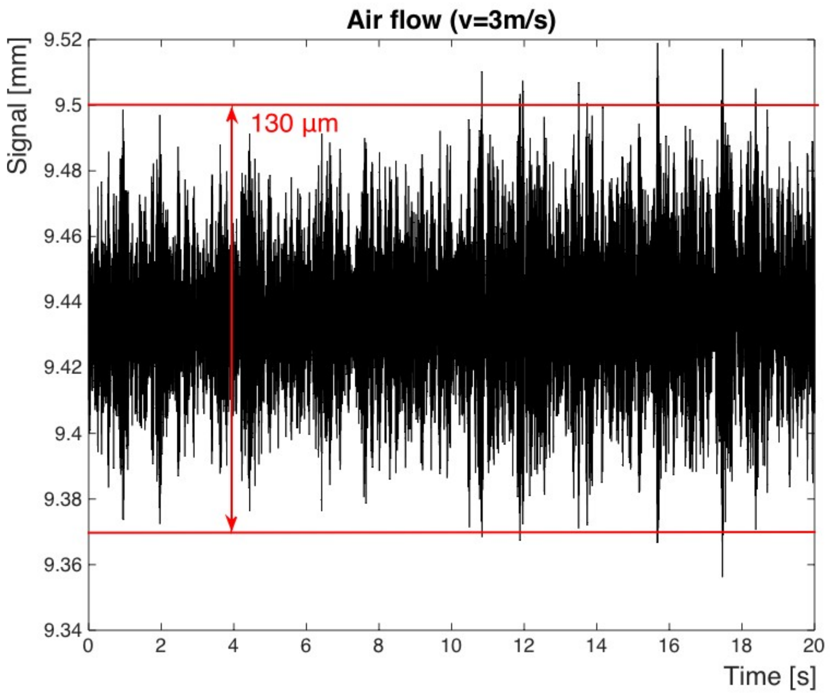


Clamped-free (CF) configuration: One extreme of the dummy is clamped to the 3D adaptor while the other is free of movement

Vibrations and deformations



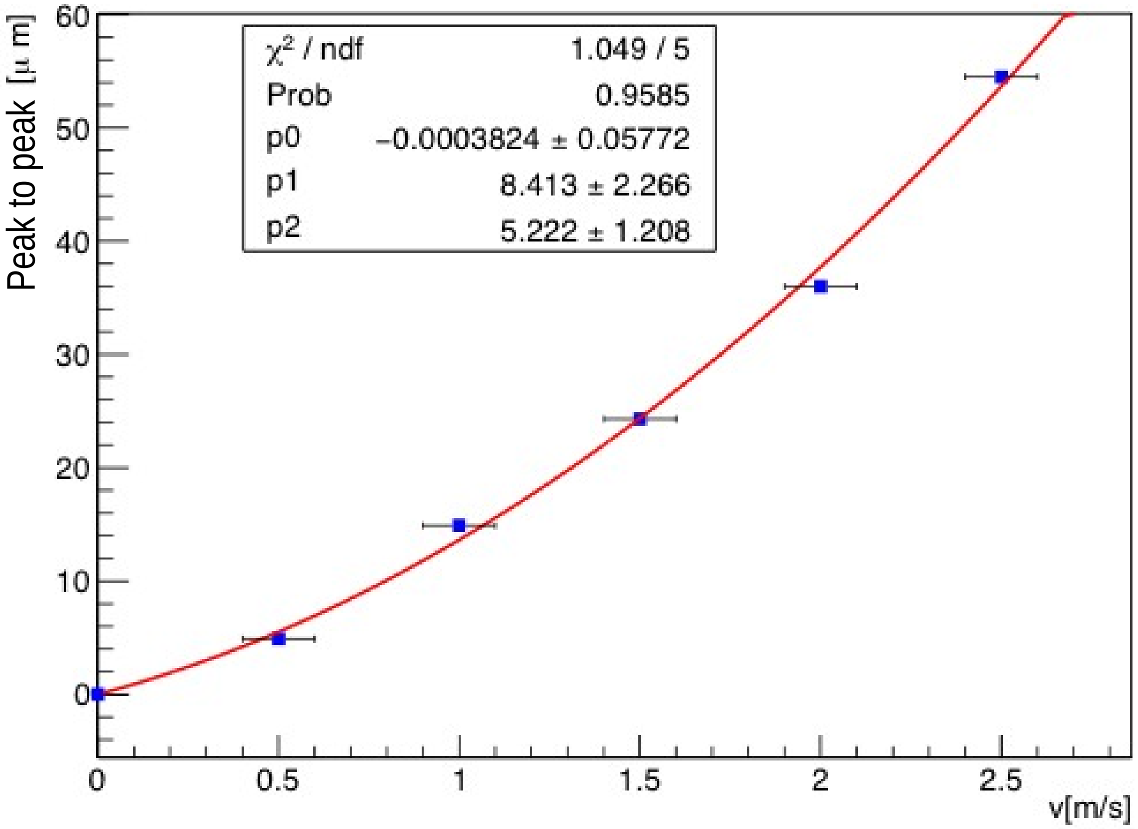




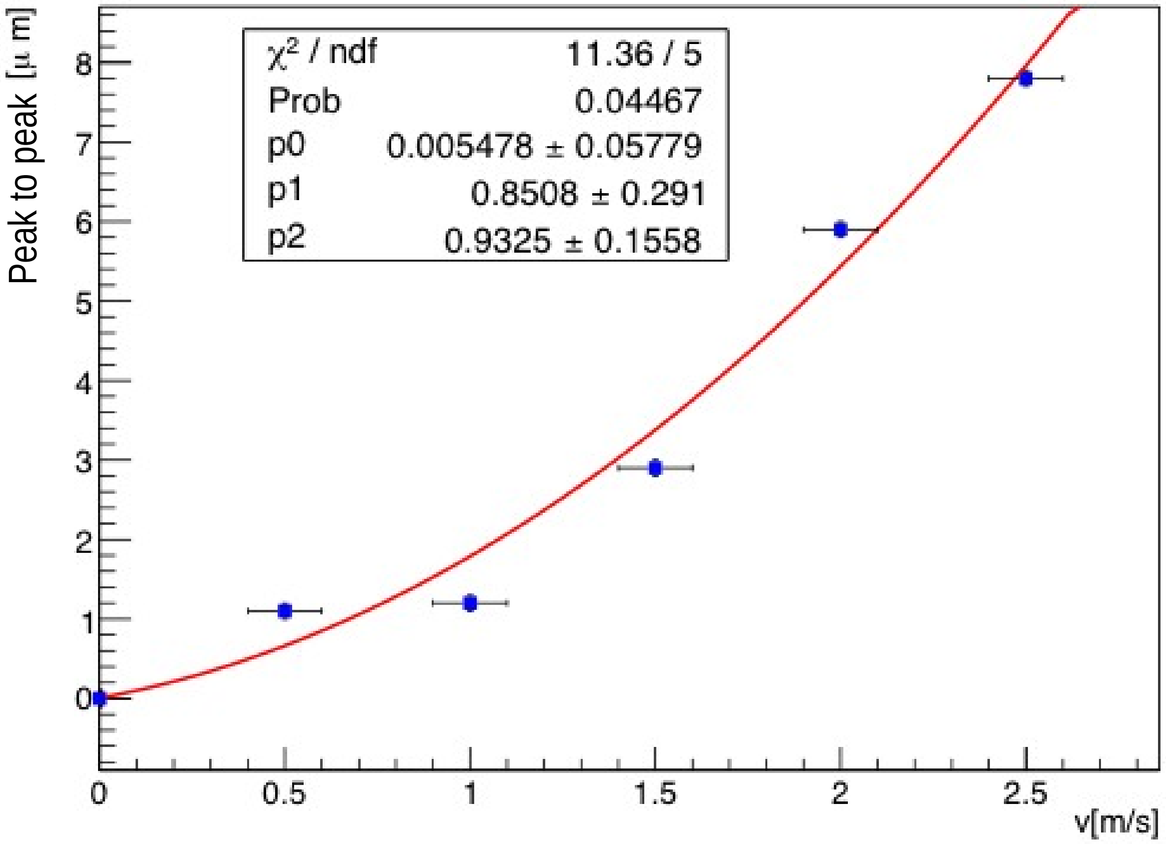
No fluid circulation and no air flowing	**Fluid circulation 1,47 l/h**	**Air flowing 3 m/s**
Peak to peak of the signal ~0,7 µm	Peak to peak of the signal ~0,1 µm	Peak to peak of the signal ~130 µm
RMS ~0,3 µm	**RMS ~0,4 µm**	**RMS ~57 µm**

MCC has no significant impact on mechanical stability in the clamped-free configuration but air deformations are more than 100 µm if v=3m/s (could be reduced a factor 10 for velocities under ≤0.5m/s)

Amplitude vs v_{air}



Clamped-Free



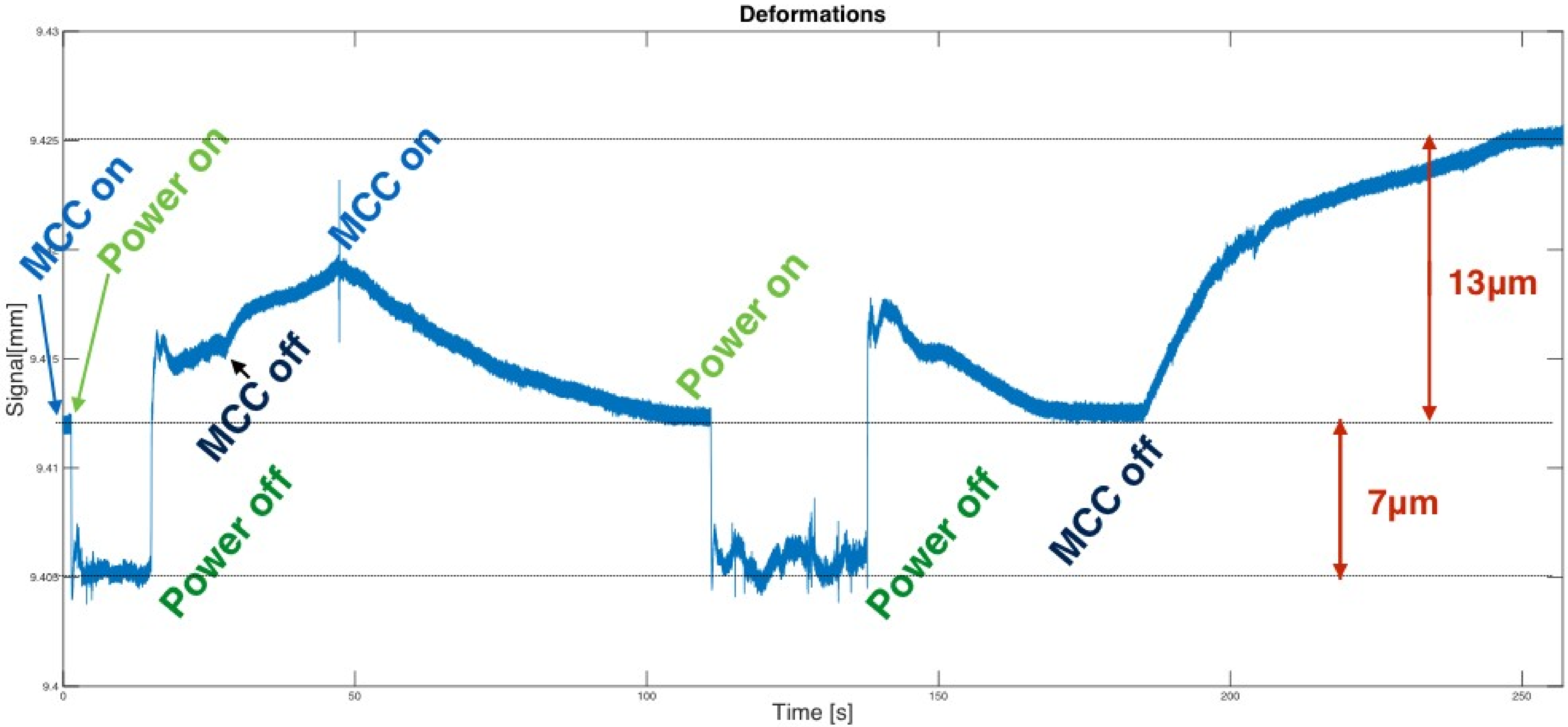
Clamped-Clamped

- *Peak-to-peak amplitude is the change between peak (highest amplitude value) and trough (lowest amplitude value)*

- RMS ≃(PeaktoPeak/2) * 0.707 (approximation)

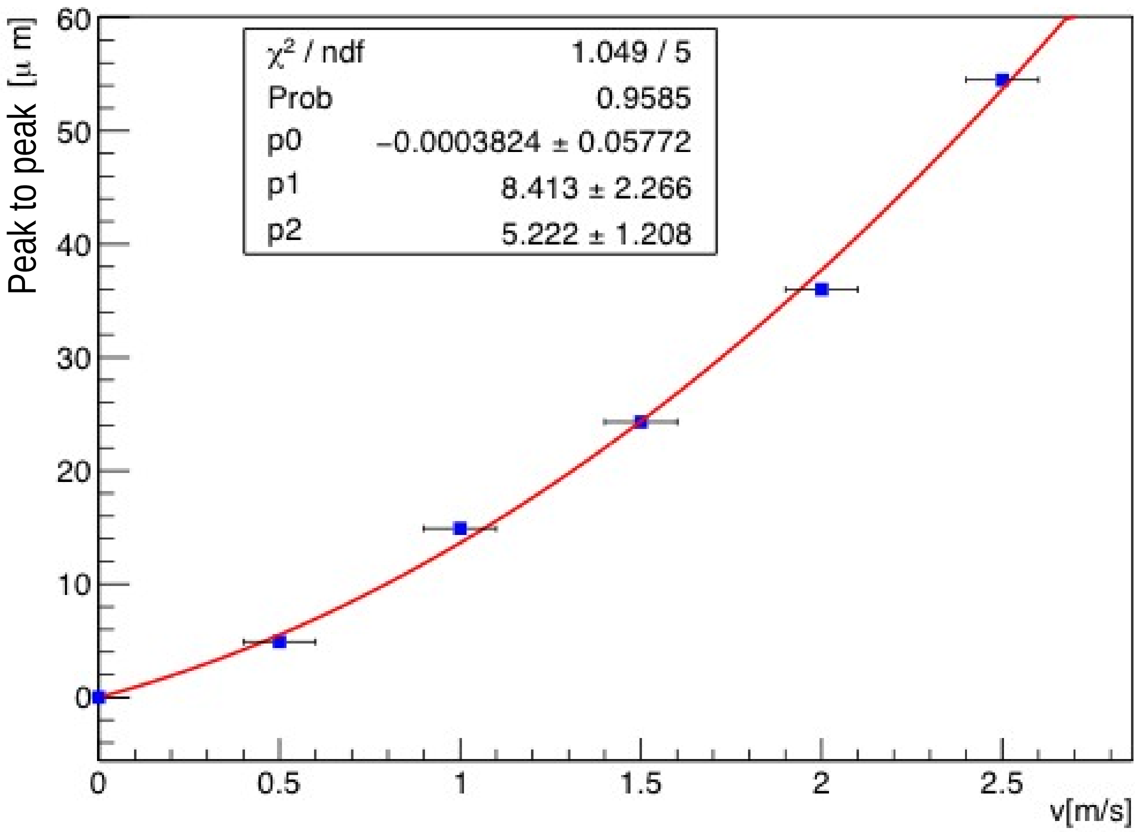
- For **v= 2.5 m/s** the amplitude of vibration is:
  - **~19 μm for clamped-free configuration**
  - **~2.8 μm for clamped-clamped configuration**

Vibrations and deformations

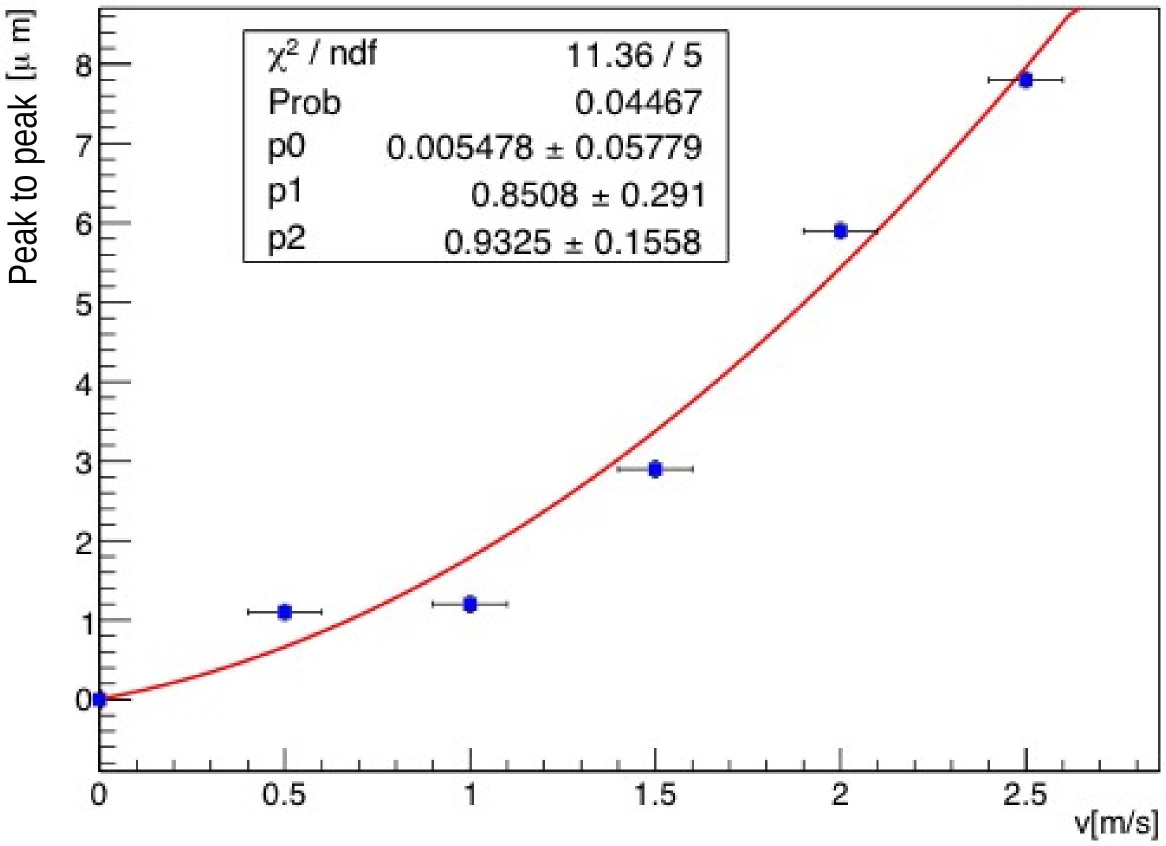


- Minor deformations observed in transitions regions
- Mechanical stability after cycles
- Maximum deformation ~20 µm

Amplitude vs v_{air}



Clamped-Free



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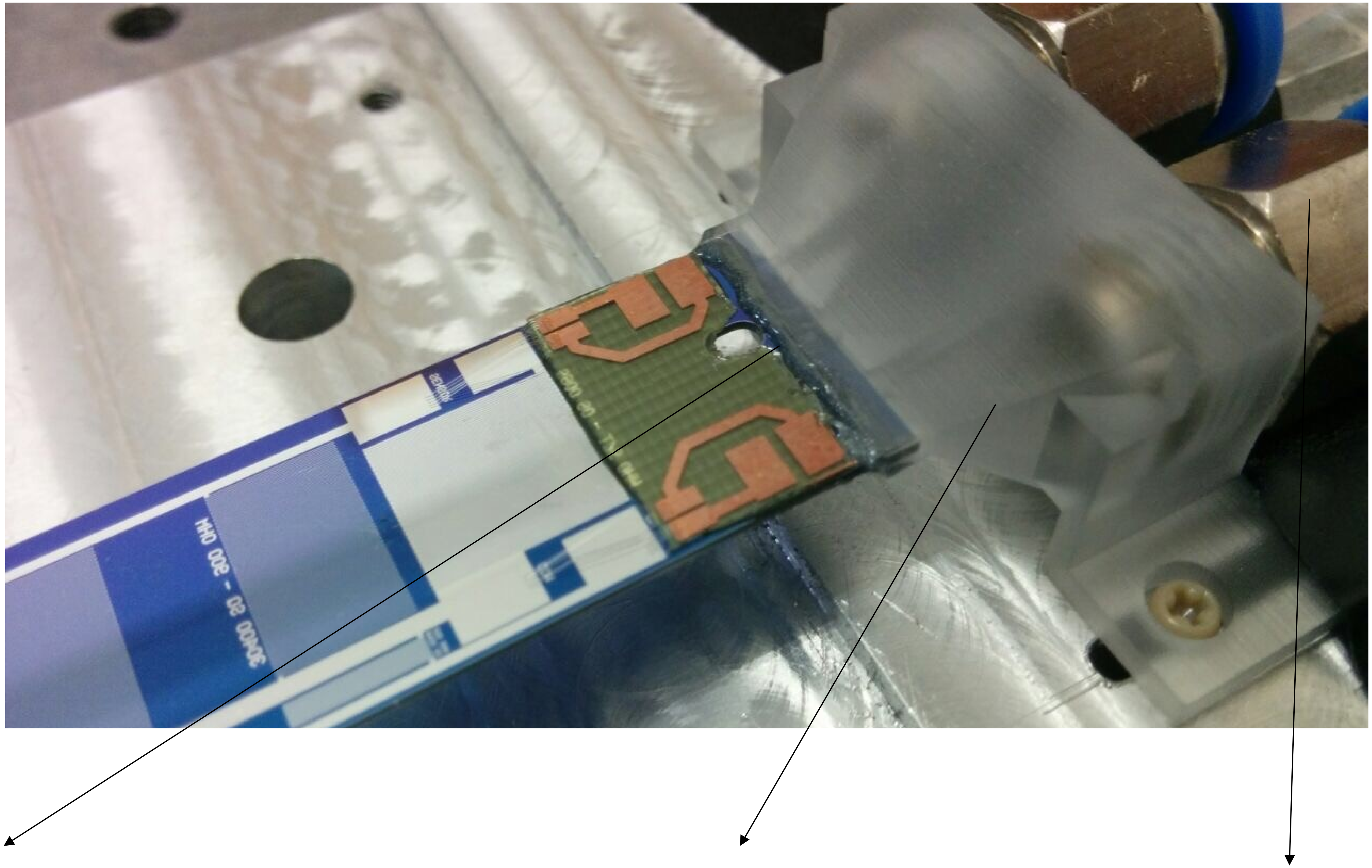
Past results: design issues



Glue: leaks

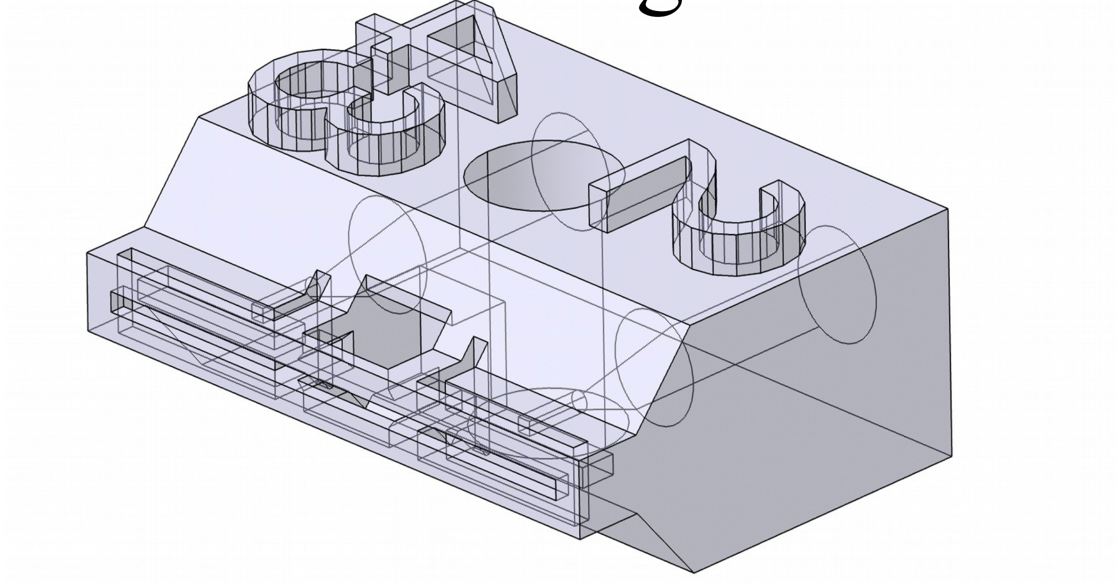
3D printed part: massive→ X/X0=0,81%

Connectors: space and massive

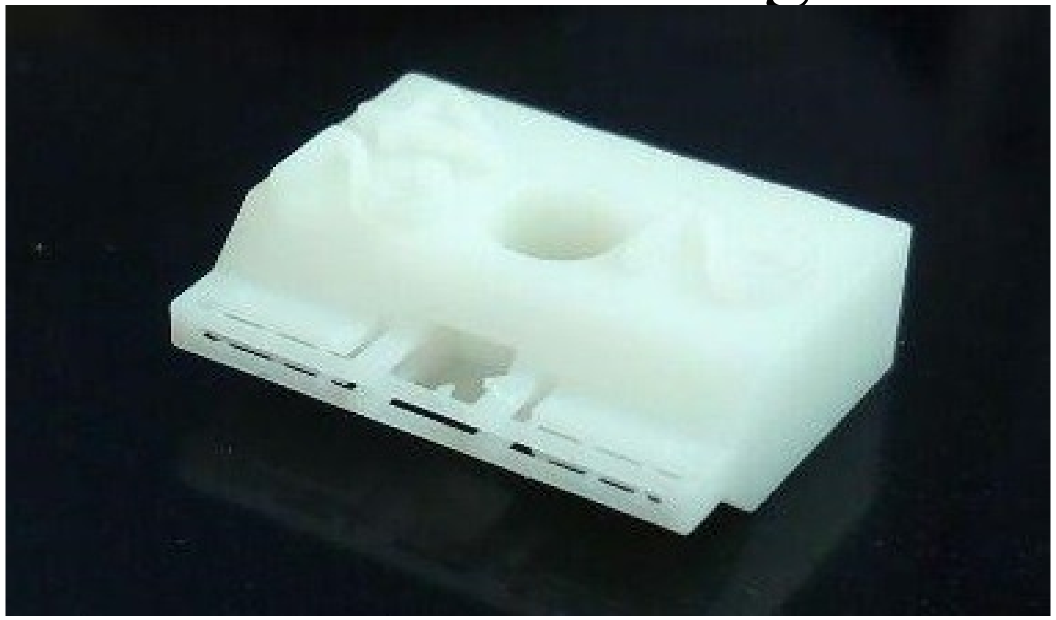
Present design and very next steps

3D-printed adaptor CURRENT design

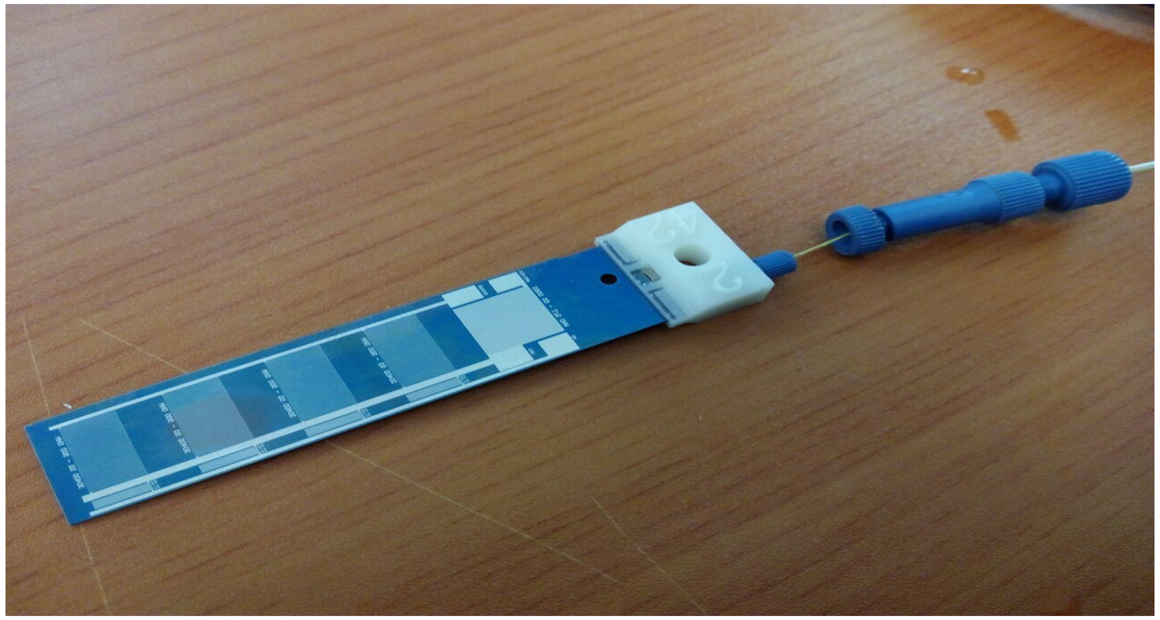
Design



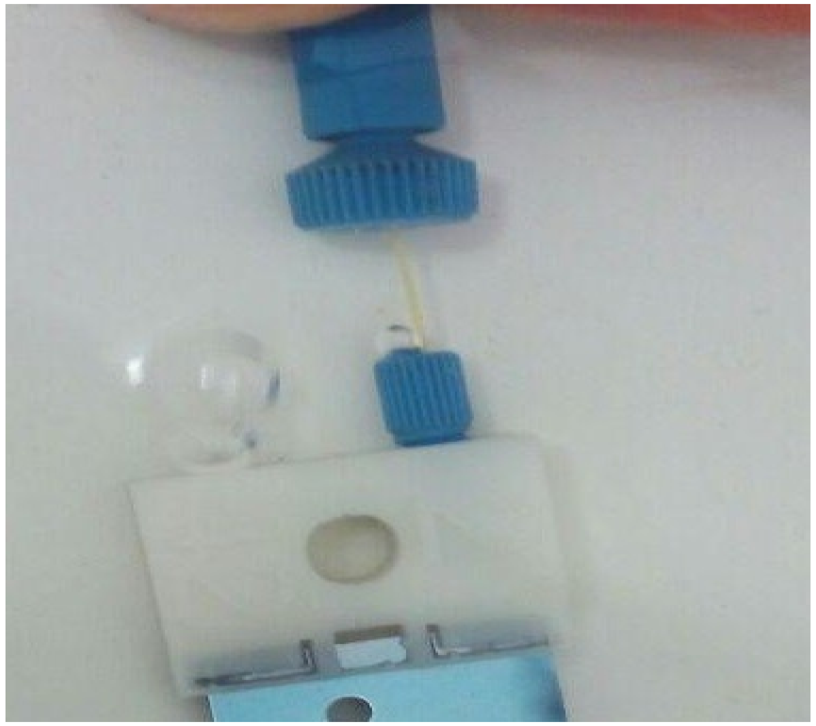
3D-Printing



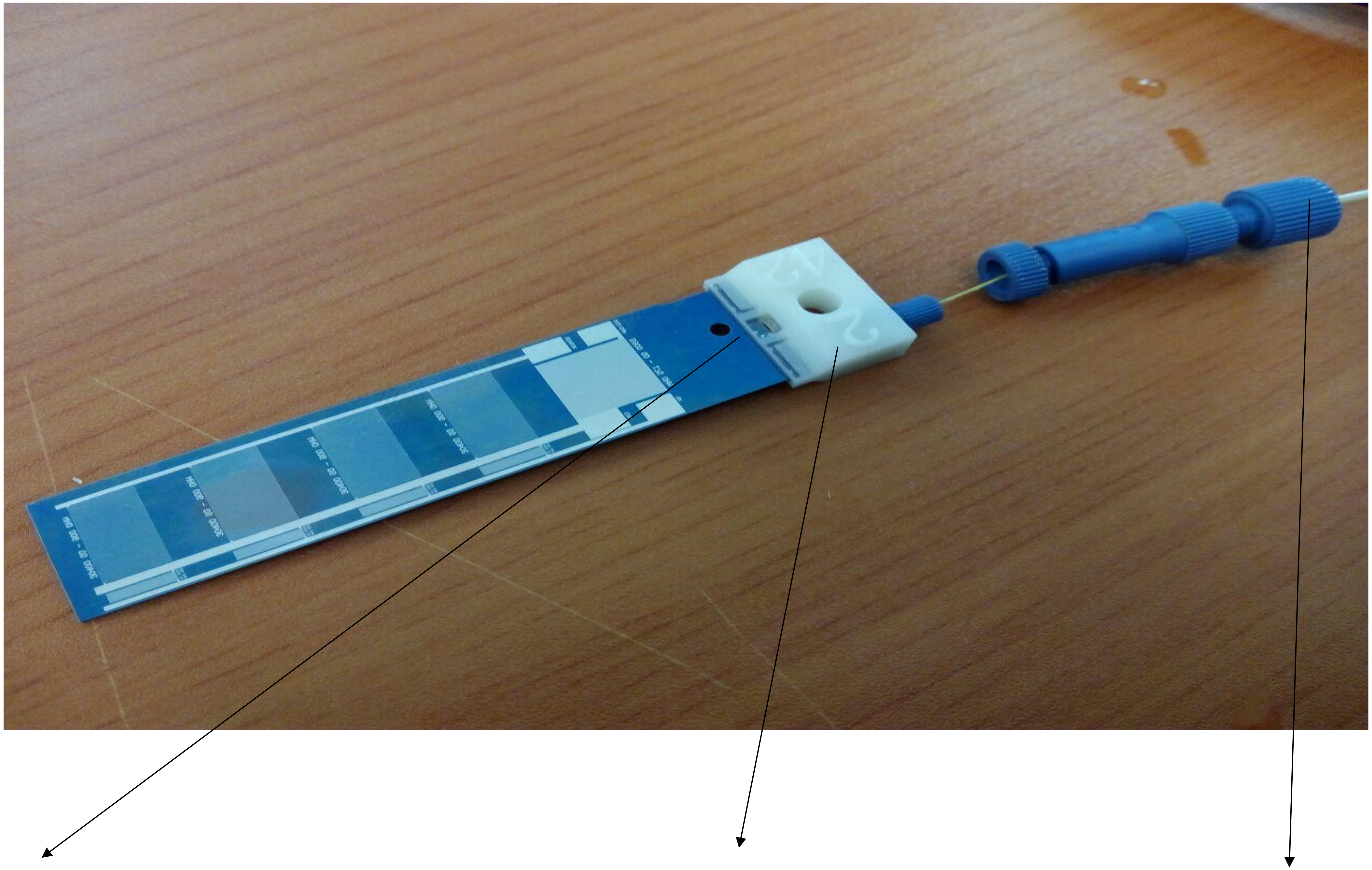
Gluing



Test



3D-printed adaptor CURRENT design: Characteristics

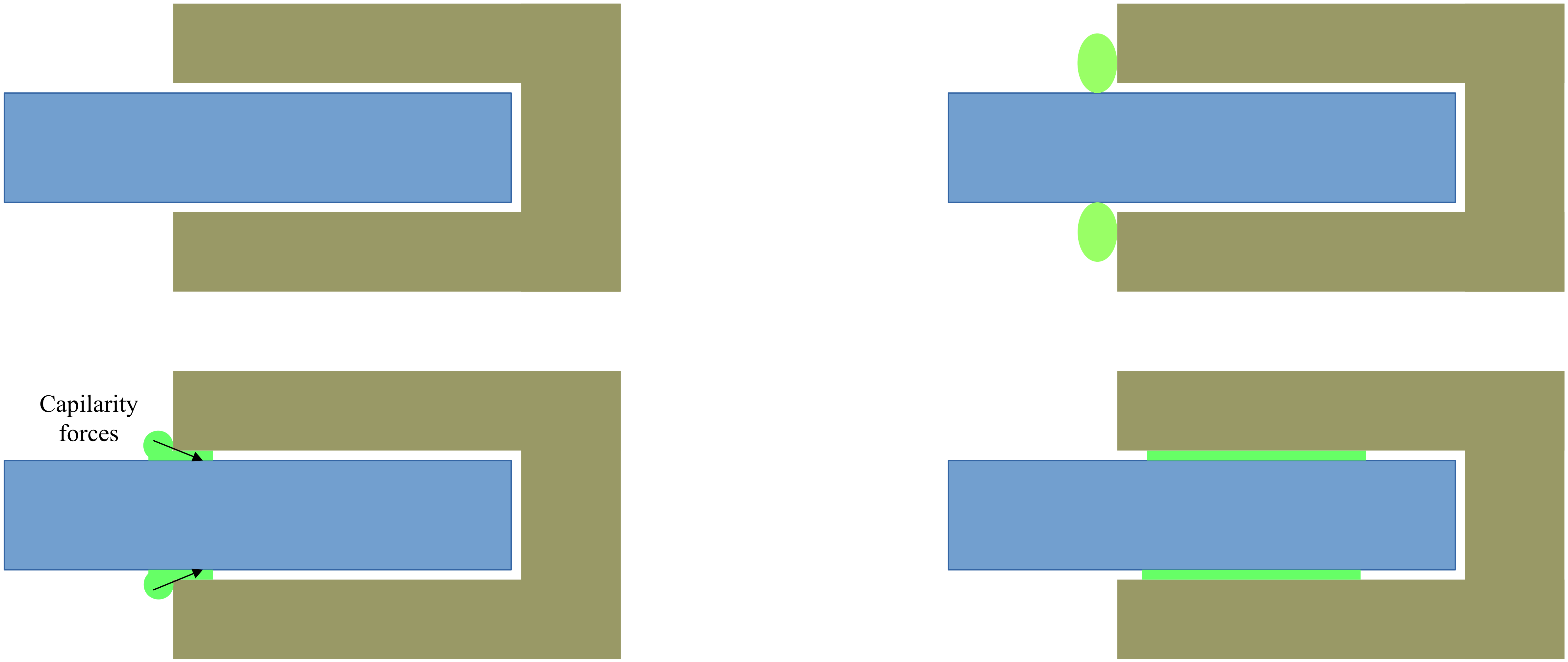


Glue: Araldite2020

3D printed part: less massive→ X/X0=0,21%

Connectors: far from VX region

3D-printed adaptor CURRENT design: Glue issue



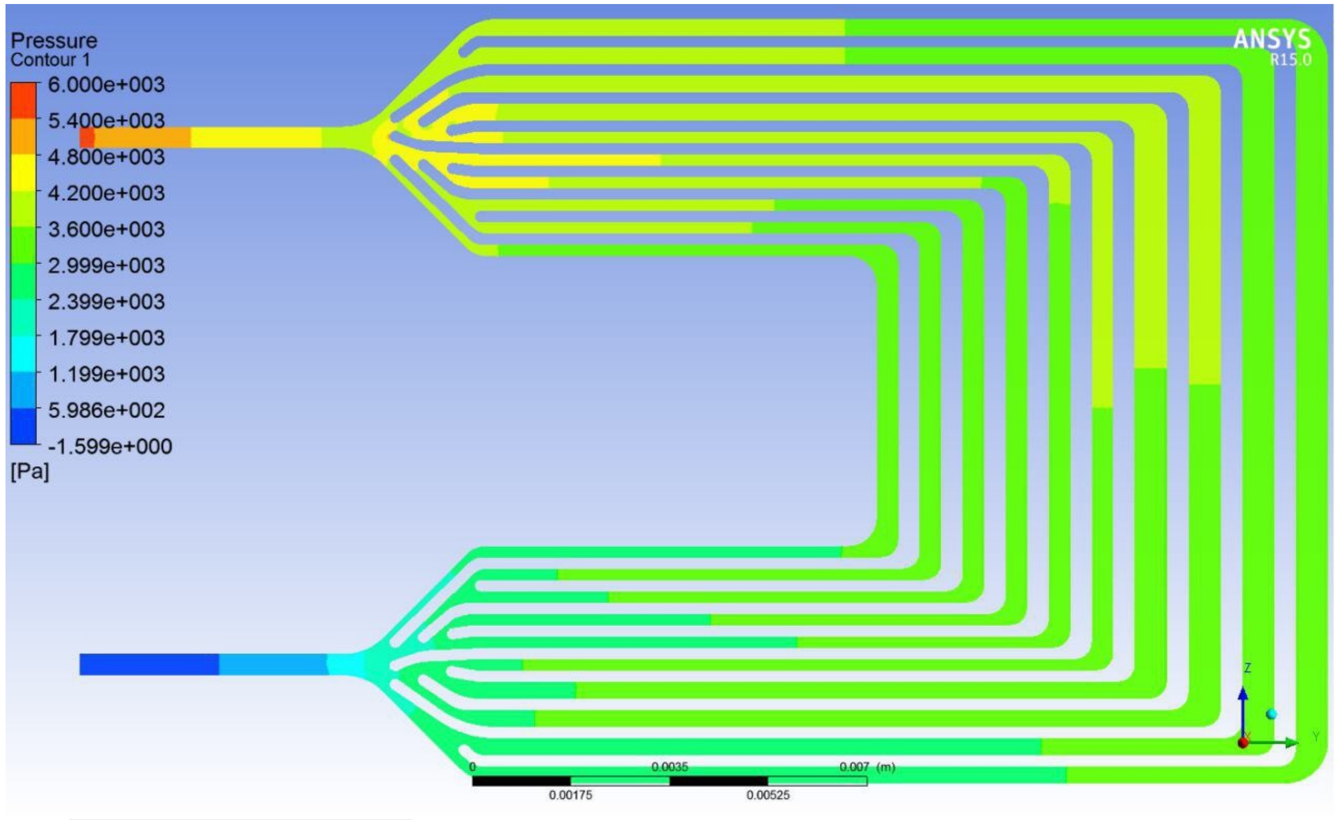
Glue: Araldite2020

Expected max. pressure: 150bar

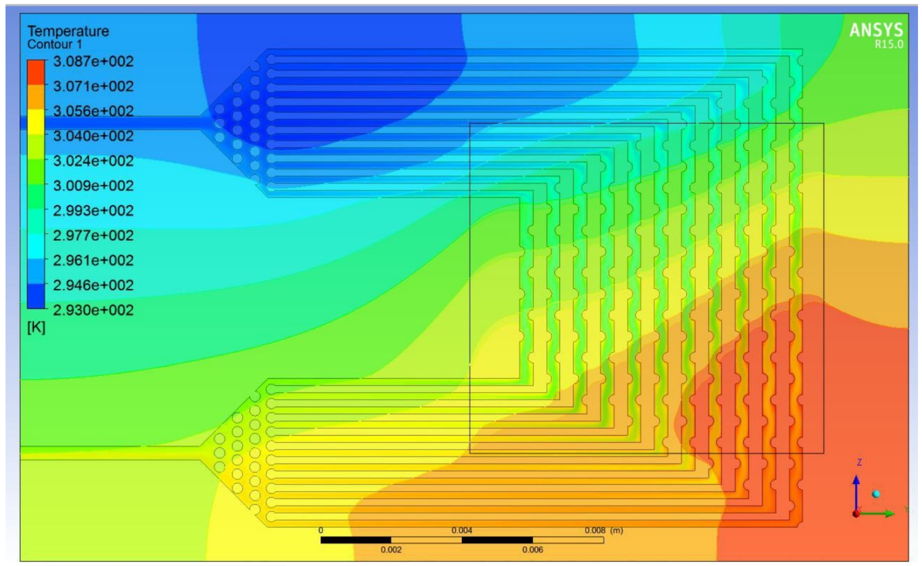
Possible problem: Clog of MC

Future designs

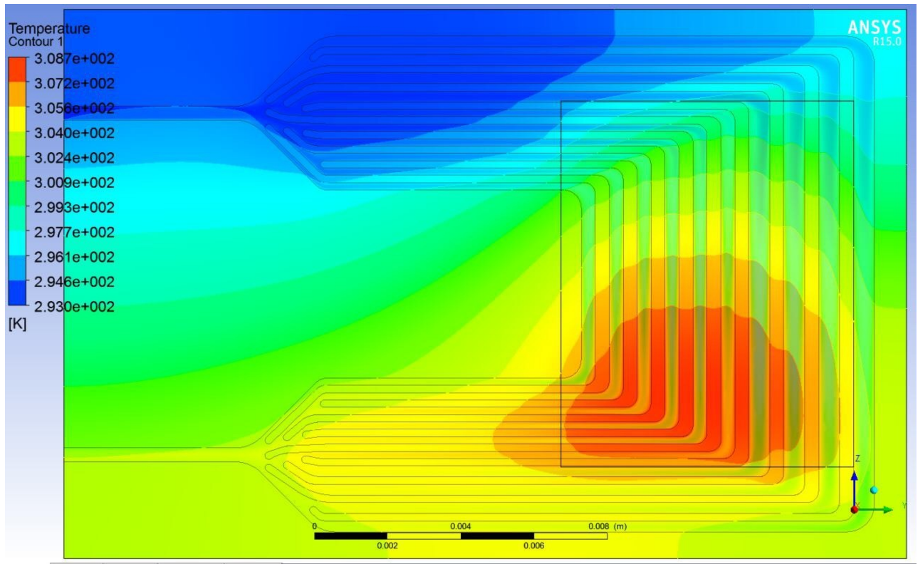
Optimized MCC geometry



- More homogenous flow
- Reduce pressure gradients
- Minimize and confine the heat spread



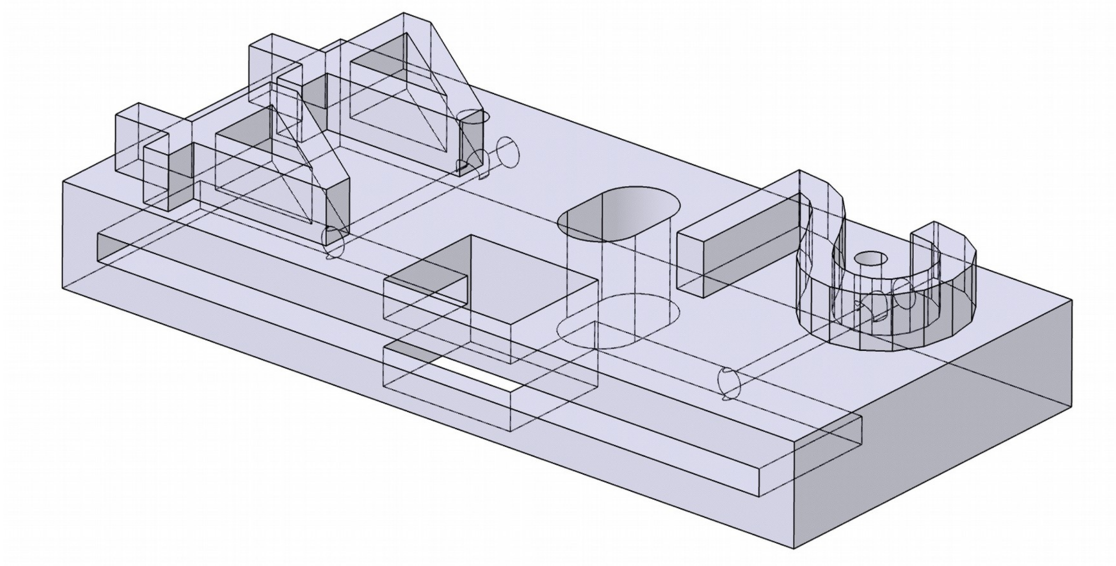
Recent geometry



Optimized geometry

3D-printed adaptor FUTURE design

Design



3D-Printing

X/X0=0,05%

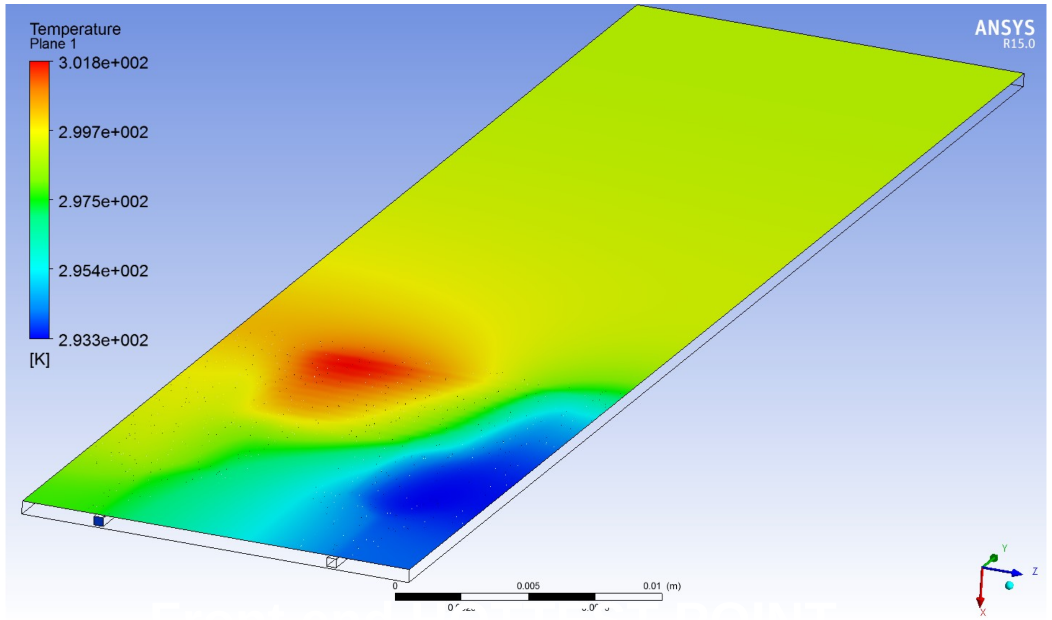
Gluing

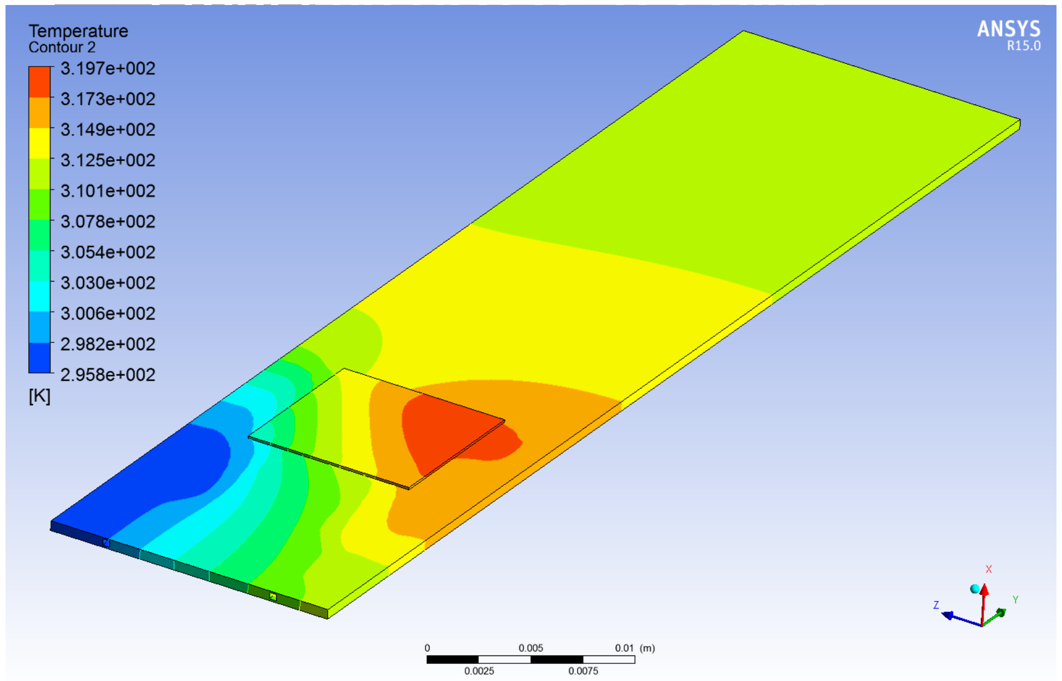
Test

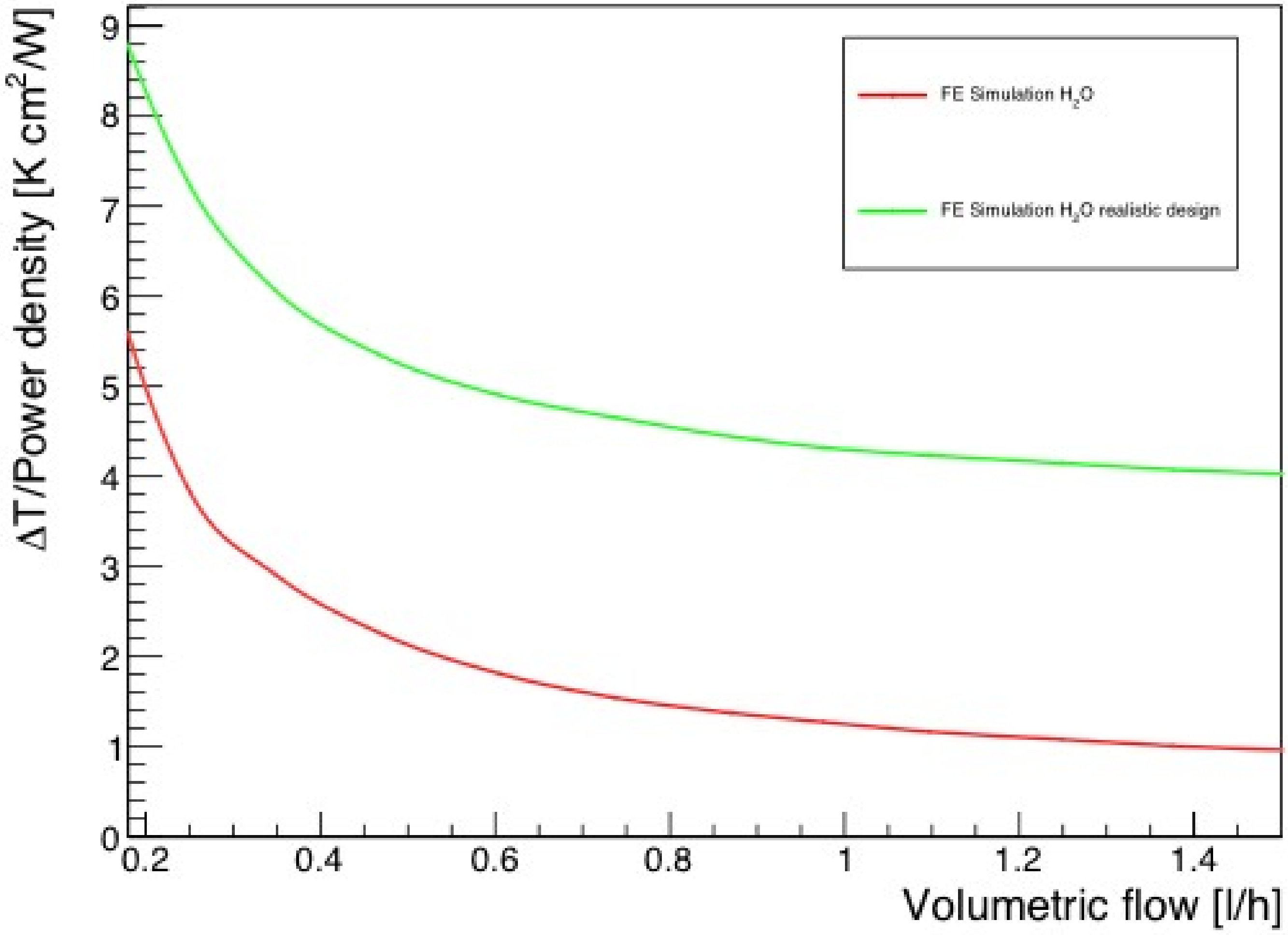
To try different
types of glue:
2020
2011
Epolite

Possibility to include:
1) Bumpboundings (next slides)
2) Thermorresistors (next slides)
3) New MC layout (next slides)
4) Automatize gluing process

Thermal simulations: MCC





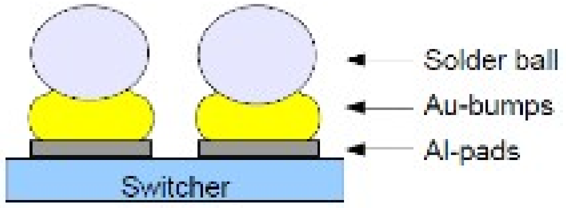


Realistic design

300 µm Si ASICS +

100 µm Bump-boundings

thermal resistivity of 6 W/m·K

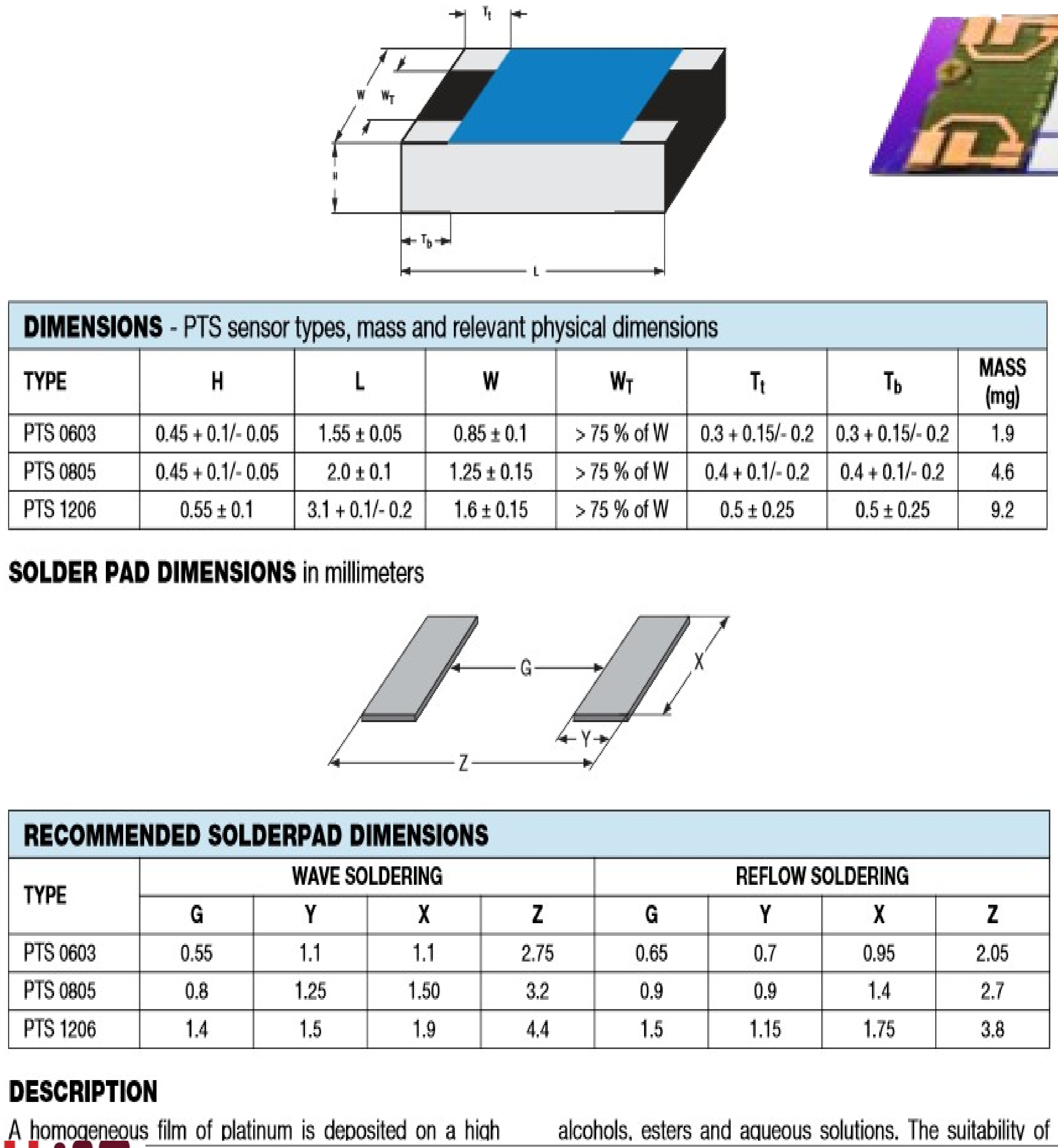


C.Mariñas PhD thesis

http://digital.csic.es/bitstream/10261/41942/1/Carlos%20Mari%C3%B1as-Te
is.pdf

In the realistic design the power dissipation is degraded

Thermal measures: SMD pt1000 along the ladder



DIMENSIONS - PTS sensor types, mass and relevant physical dimensions

TYPE	H	L	W	W_T	T_t	T_b	MASS (mg)
PTS 0603	0.45 + 0.1/- 0.05	1.55 ± 0.05	0.85 ± 0.1	> 75 % of W	0.3 + 0.15/- 0.2	0.3 + 0.15/- 0.2	1.9
PTS 0805	0.45 + 0.1/- 0.05	2.0 ± 0.1	1.25 ± 0.15	> 75 % of W	0.4 + 0.1/- 0.2	0.4 + 0.1/- 0.2	4.6
PTS 1206	0.55 ± 0.1	3.1 + 0.1/- 0.2	1.6 ± 0.15	> 75 % of W	0.5 ± 0.25	0.5 ± 0.25	9.2

SOLDER PAD DIMENSIONS in millimeters

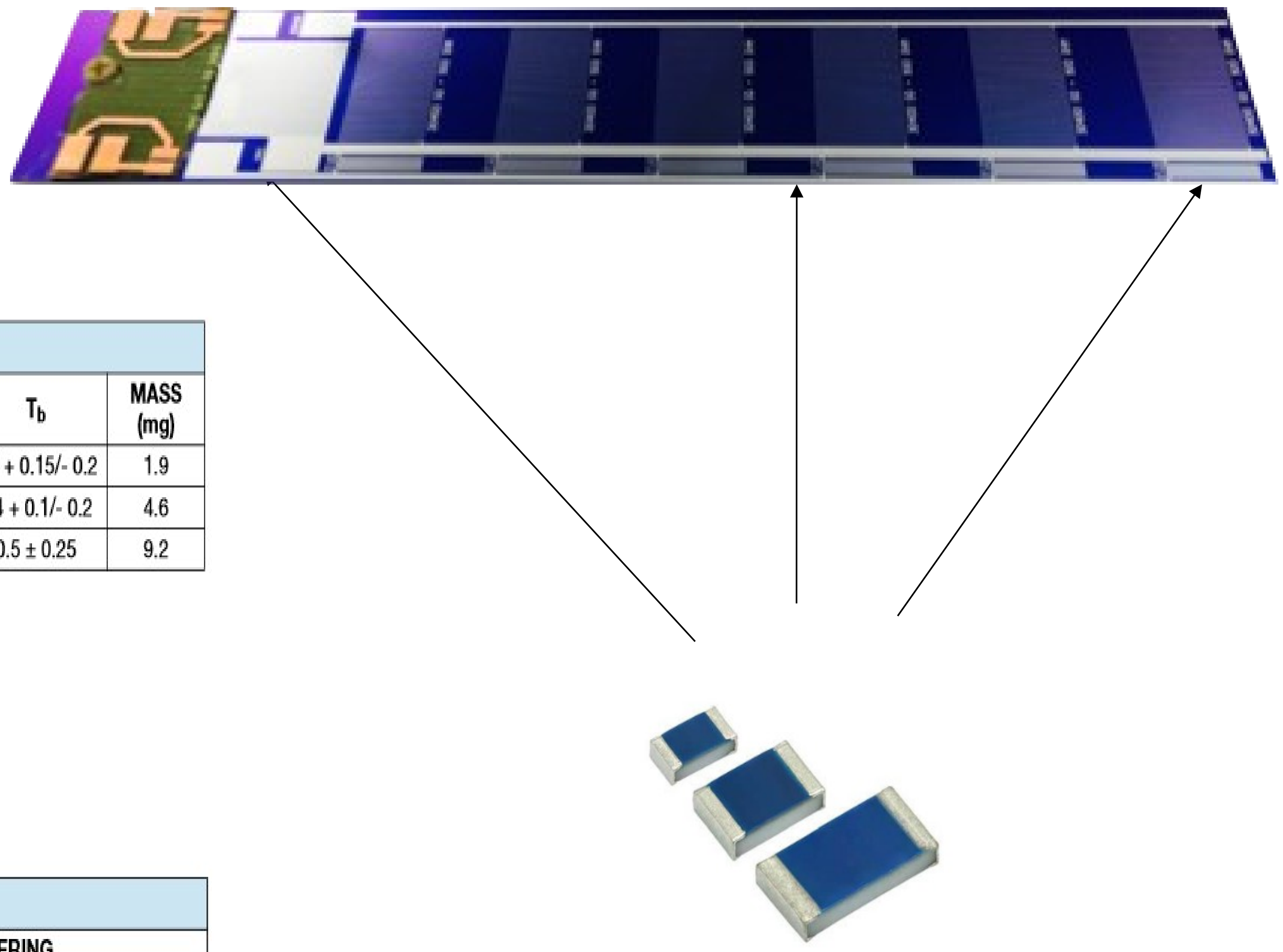
RECOMMENDED SOLDERPAD DIMENSIONS

TYPE	WAVE SOLDERING				REFLOW SOLDERING			
	G	Y	X	Z	G	Y	X	Z
PTS 0603	0.55	1.1	1.1	2.75	0.65	0.7	0.95	2.05
PTS 0805	0.8	1.25	1.50	3.2	0.9	0.9	1.4	2.7
PTS 1206	1.4	1.5	1.9	4.4	1.5	1.15	1.75	3.8

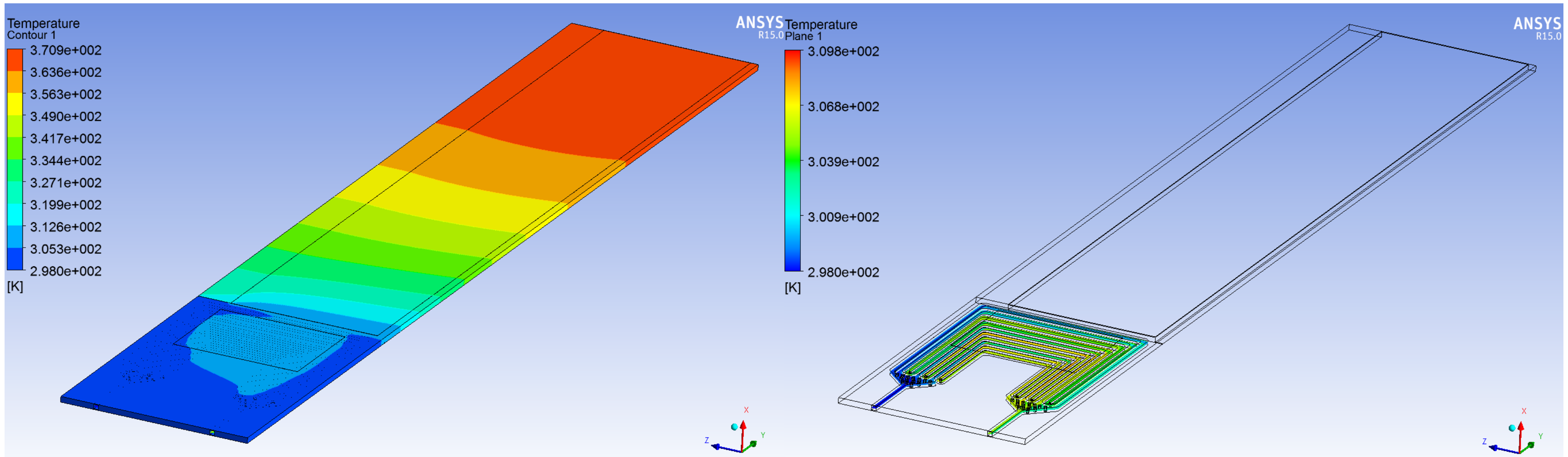
DESCRIPTION

A homogeneous film of platinum is deposited on a high

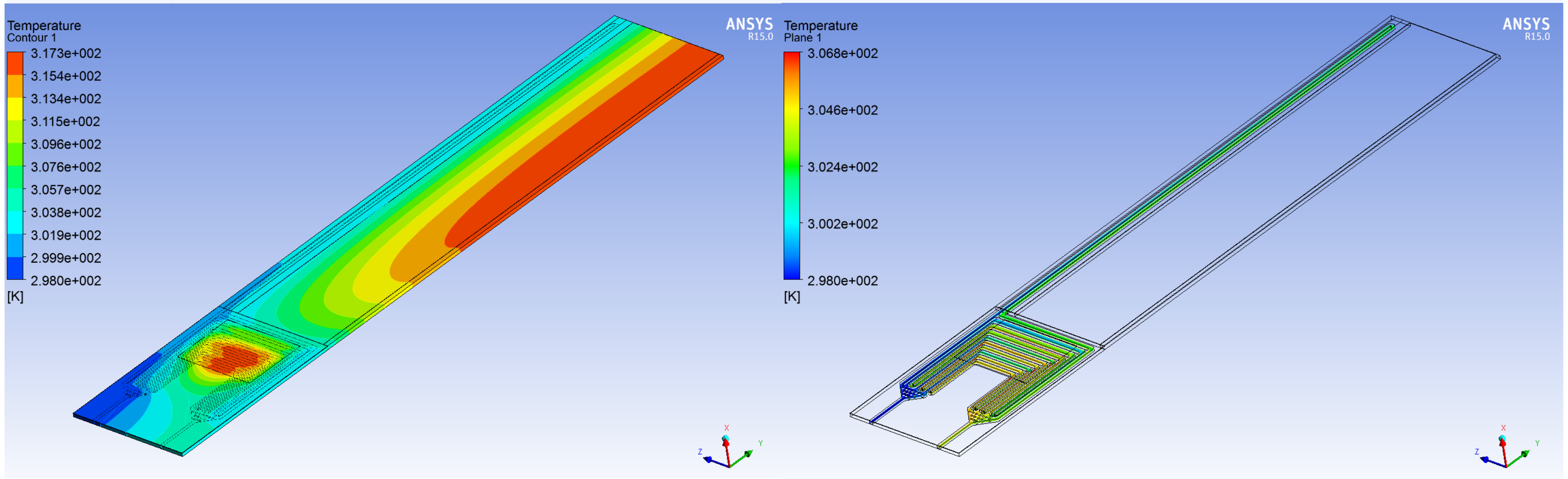
alcohols, esters and aqueous solutions. The suitability of



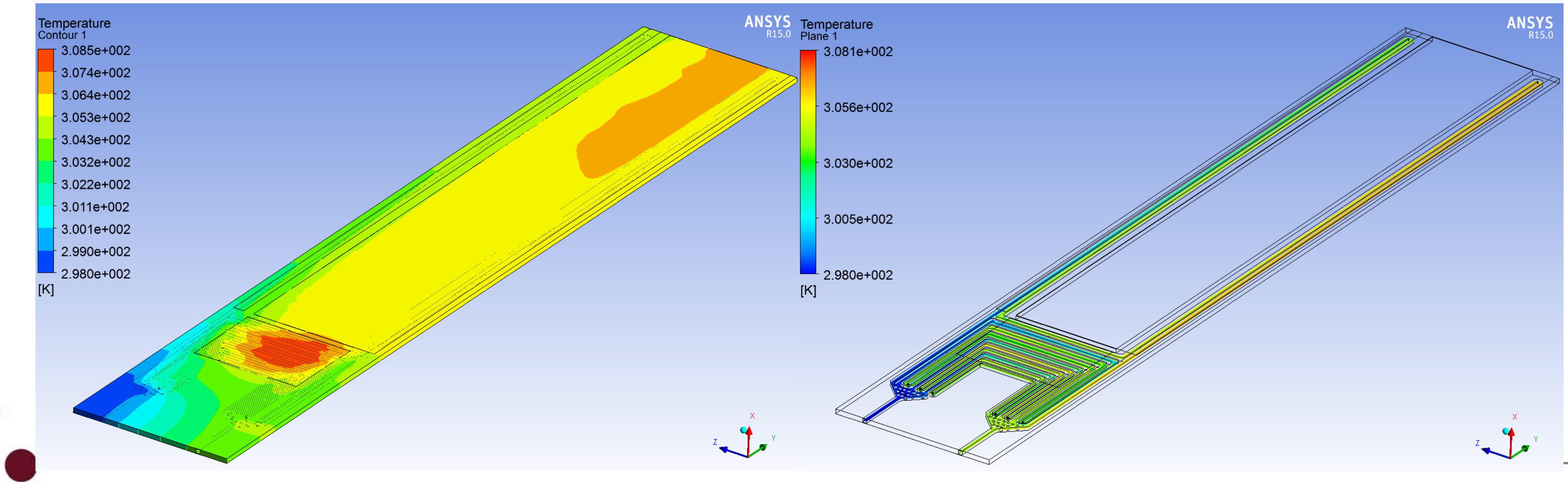
Thermal simulations: MCC Layouts



Standard MCC layout
ΔT = 73 K



Standard MCC layout + channel below switchers
ΔT = 15 K



Standard MCC layout + channel below switchers + channel in the balcony
ΔT = 5 K

Conclusions

MCC shows very efficient cooling, up to 25 W/cm² with minimal temperature increase (10ºC) even with a mono-phase fluid at low pressure

Thermal measurements are in good **agreement with the FE simulation**

MCC has a **minimal impact on the mechanical stability**

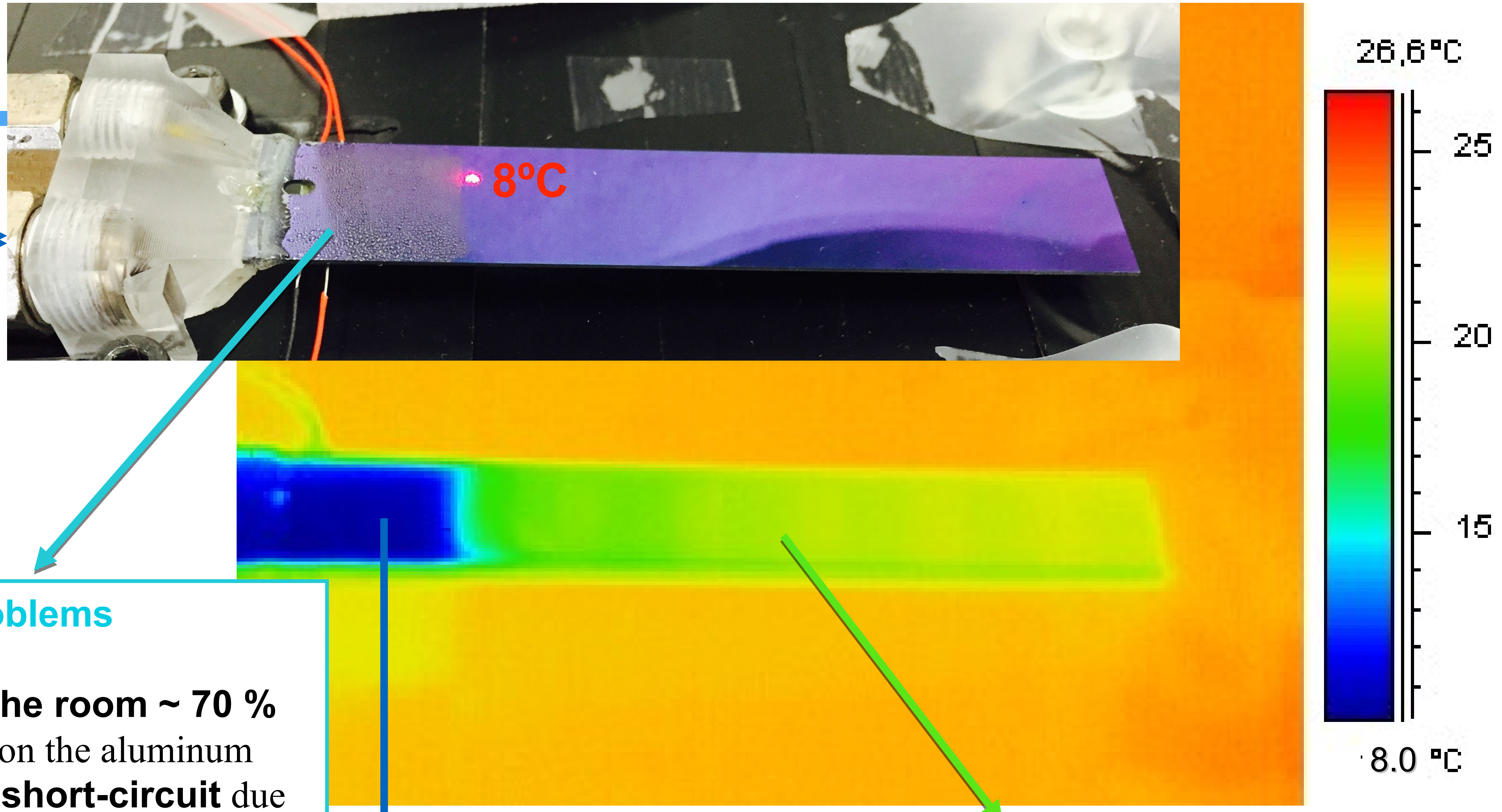
The assembly with the 3D-printed adaptor was done **successfully in 3/3**

MCC embedded in all-silicon ladders is a real option

3D-printed adaptor resistant to high pressure -> 183 bar

Pressure test

Thermal measurements: cold water



T_{out} ~ 10ºC

T_{in} ~ 5ºC

Condensation problems

High humidity in the room ~ 70 %
impossible to power on the aluminum resistances (possible **short-circuit** due to the water on the soldering)

In this region the effect of the MCC is quite less pronounced 5-10 ºC below

MCC region is cooled 18ºC below T_{Room}