AIDA-2020-SLIDE-2016-013

AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators

Presentation

Advanced cooling: air cooling

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02 November 2015

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This work is part of AIDA-2020 Work Package **9: New support structures and micro-channel cooling**.

Advanced cooling: air cooling and micro-channel cooling

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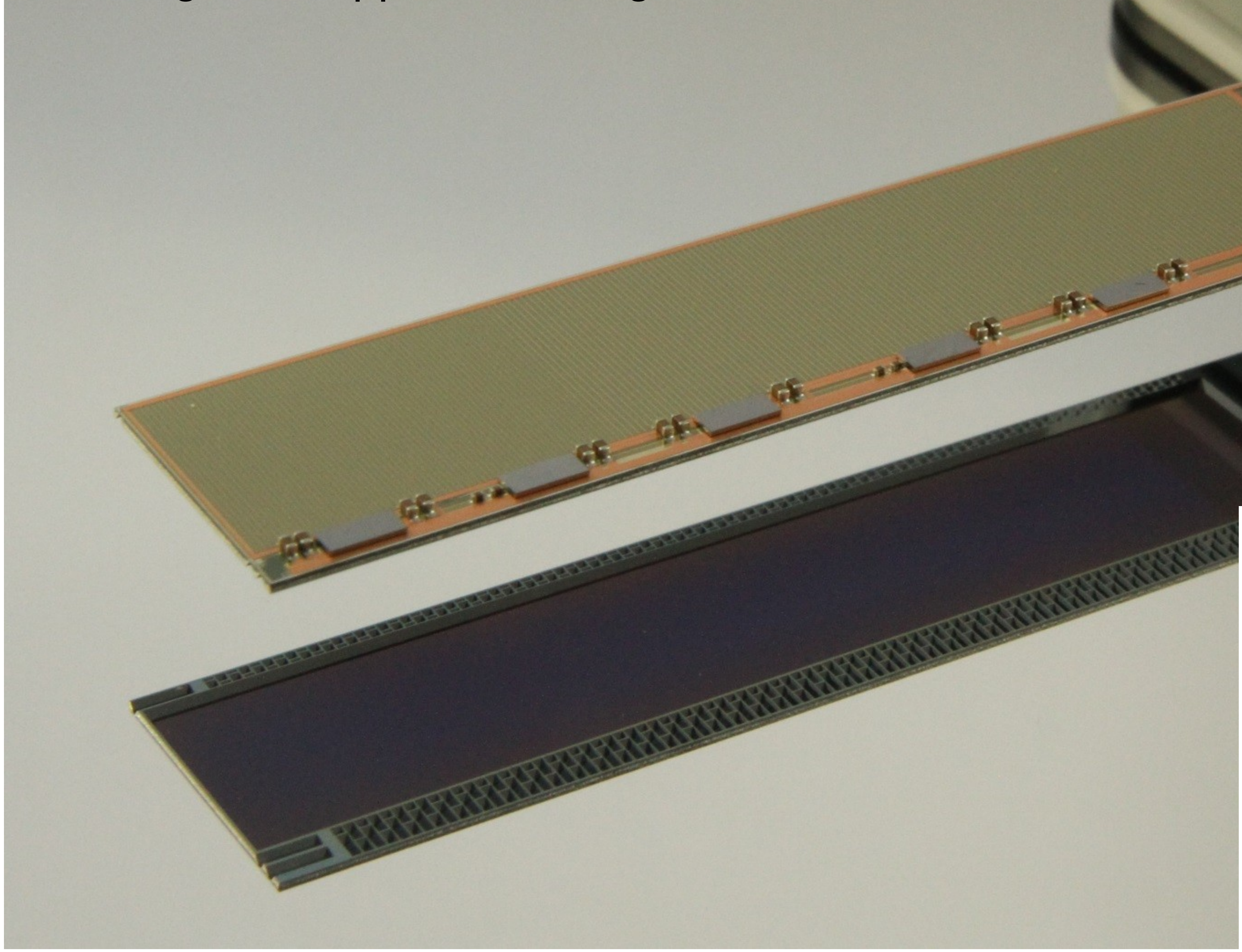
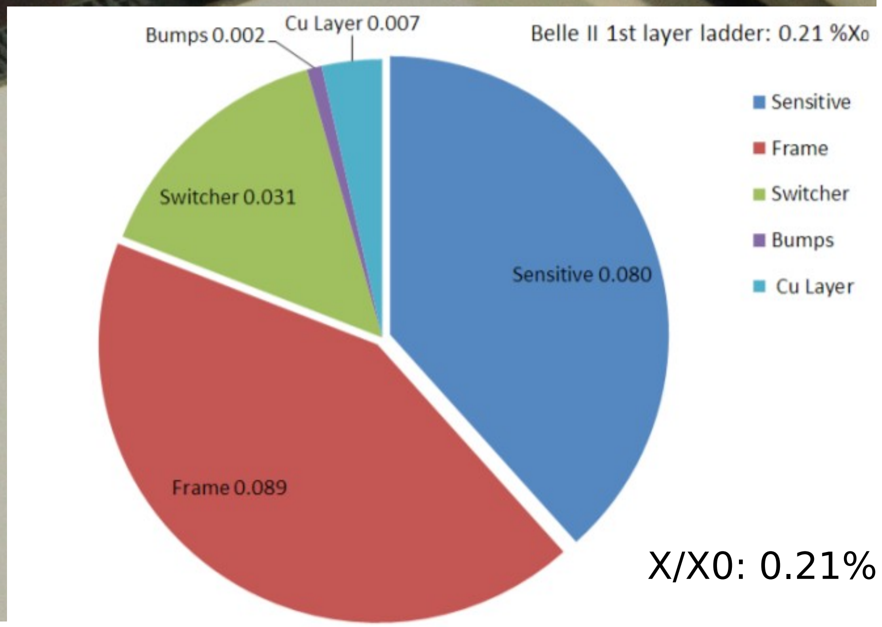
Thanks to AIDA H2020, CERN LCD

Ultra-thin and ultra-precise

Increasing precision and reducing material budget.
Challenge for supports, cooling and services.



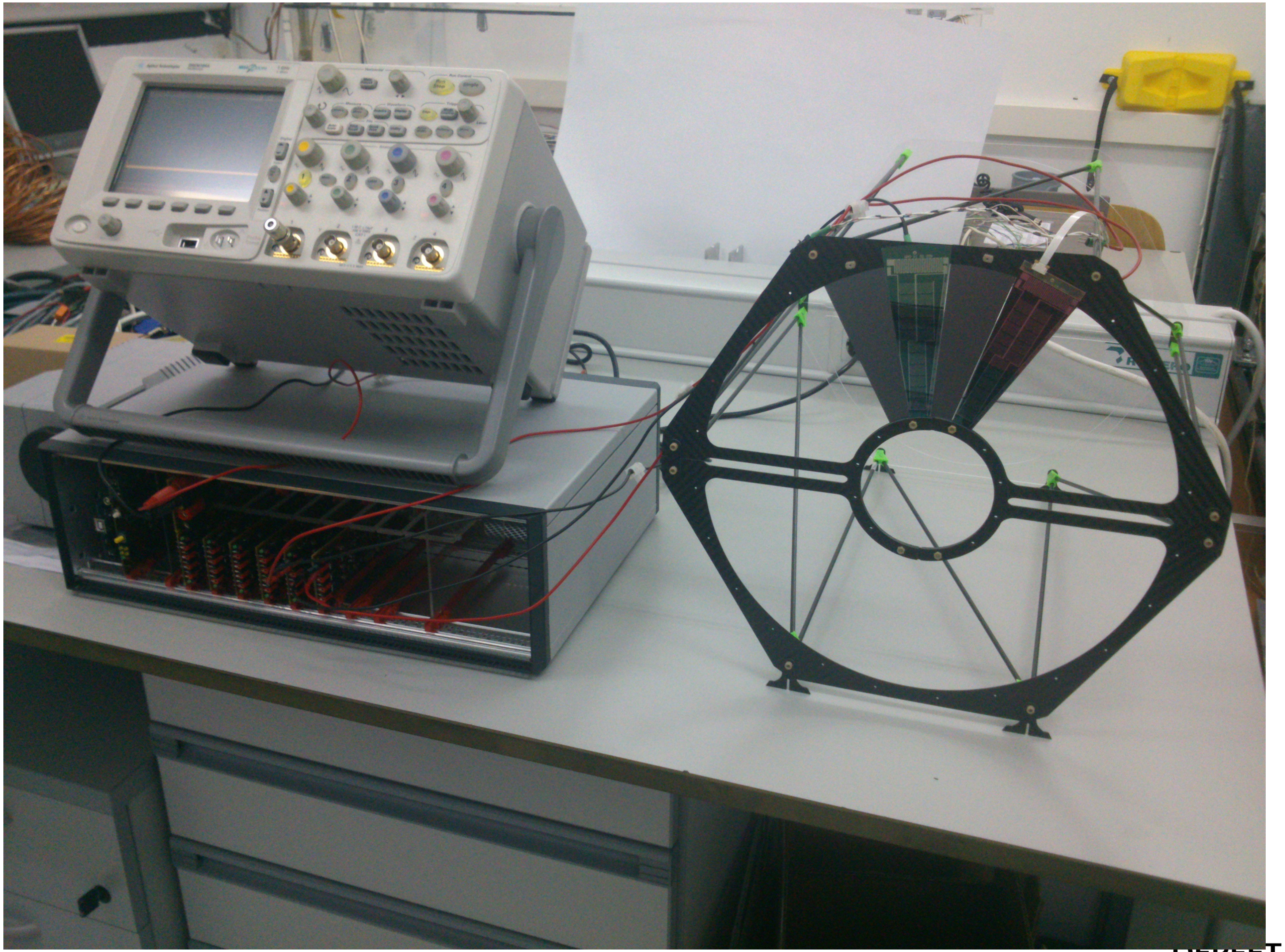


X/X0: 0.21%

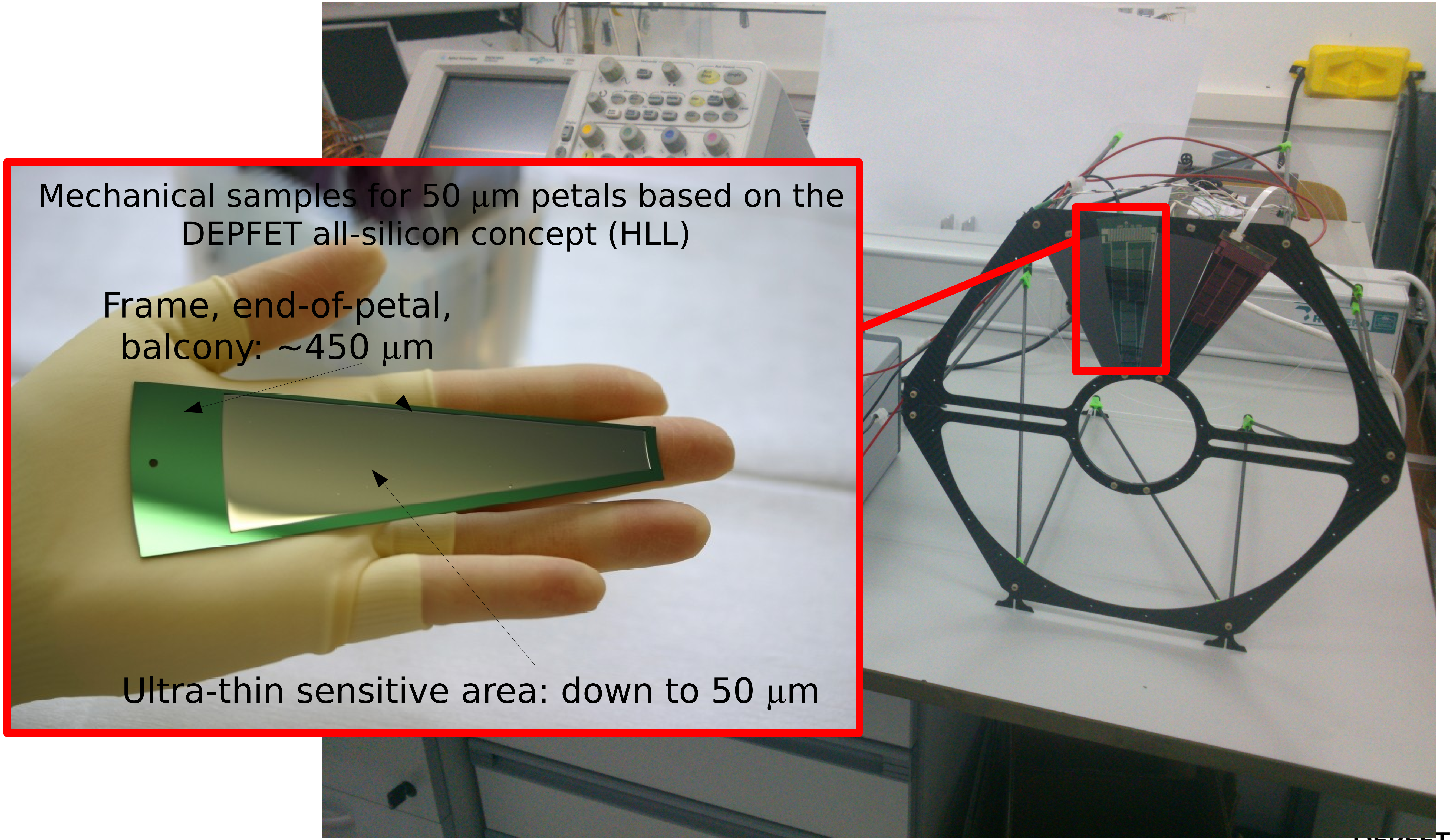
Belle II Module 0. See also: DEPFET overview in this track

First generation mock-up

IFIC copy of the AIDA pulsing power supply



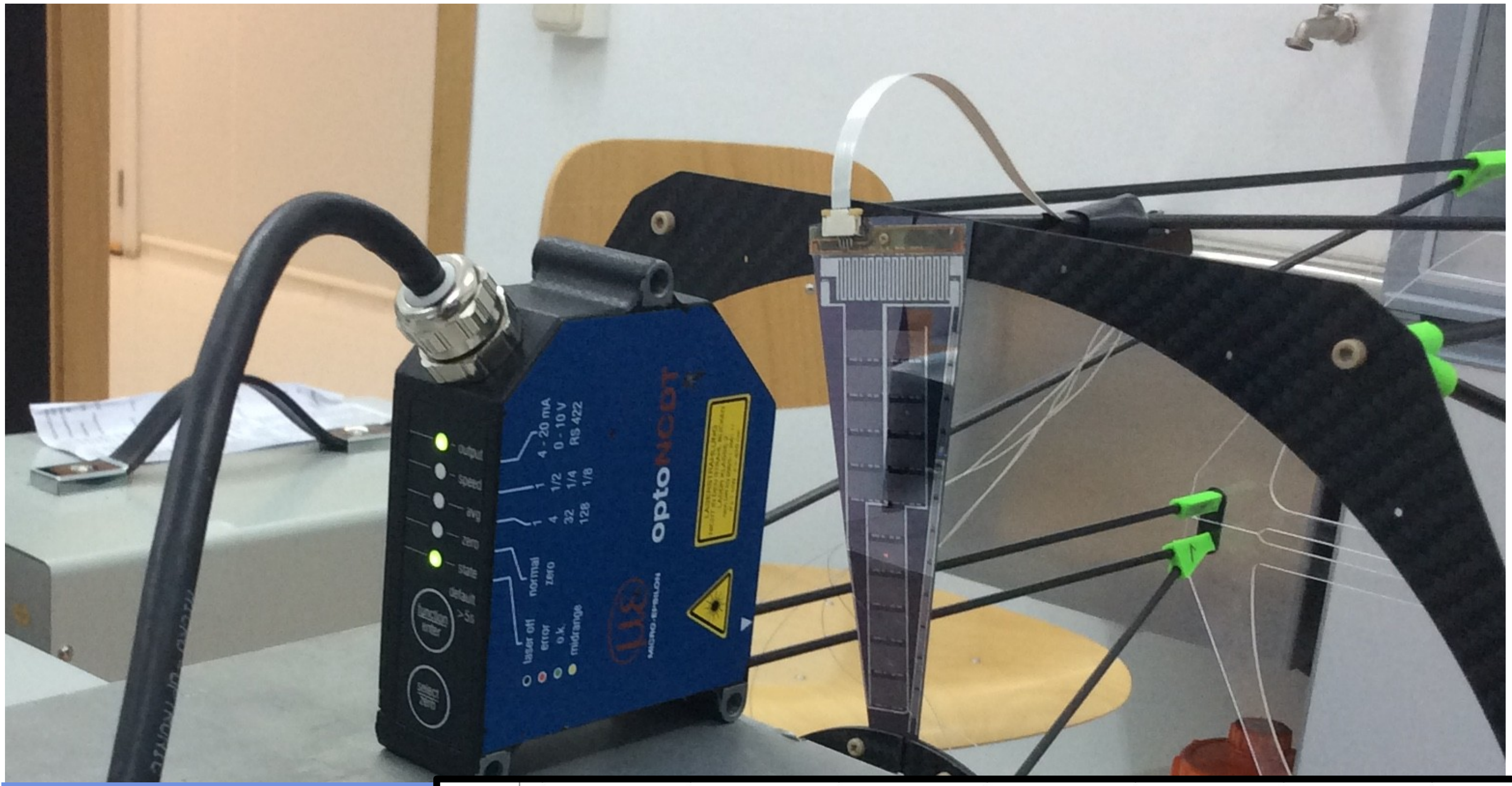
First generation mock-up

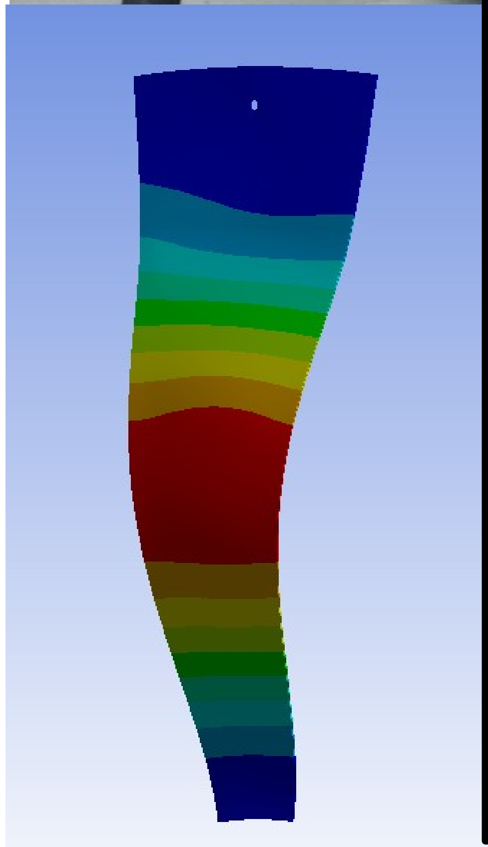


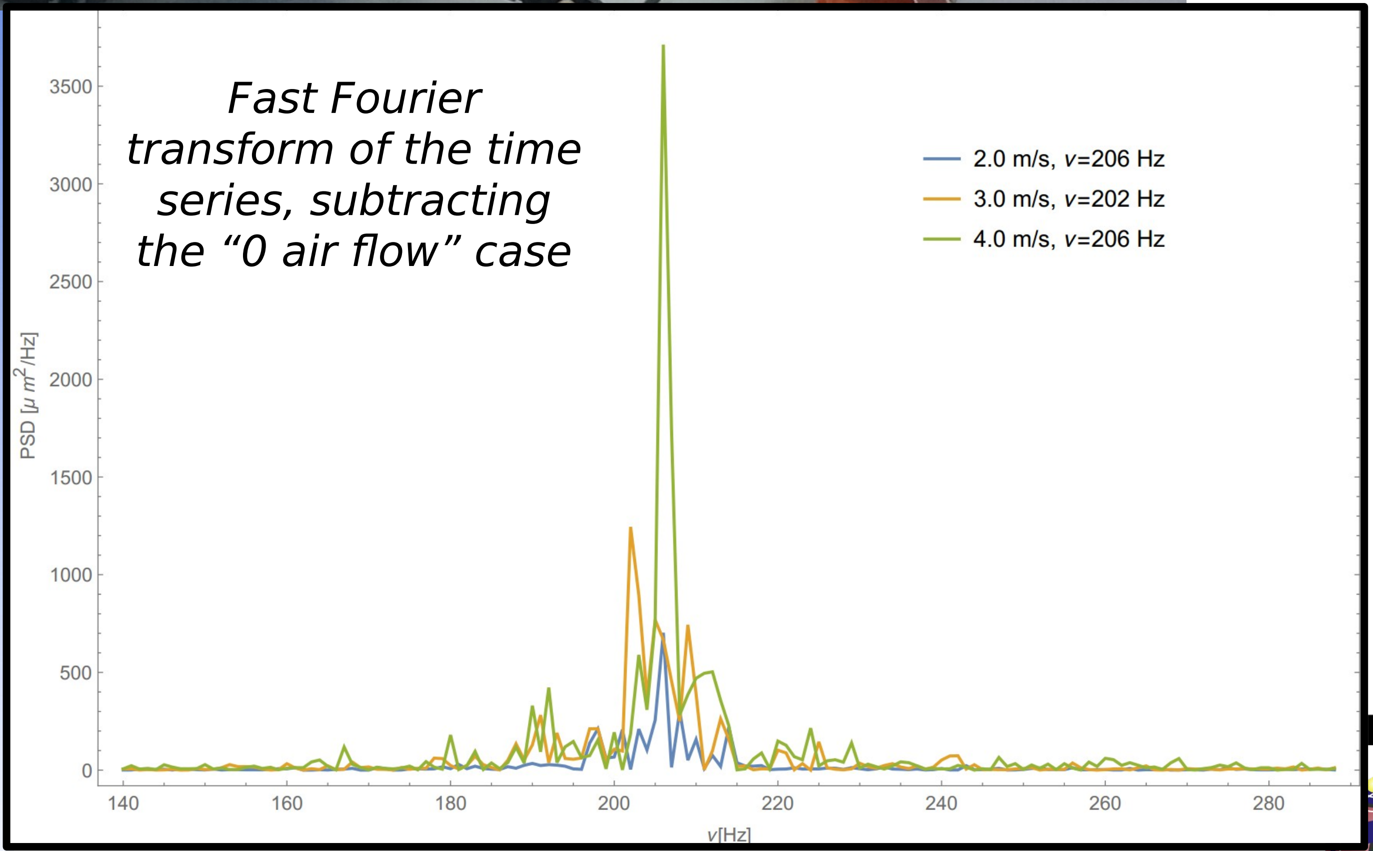
Air flow & deformation

Vibrations induced by air are at 200 Hz. Finite-element simulation of just the petal predict 300 Hz.

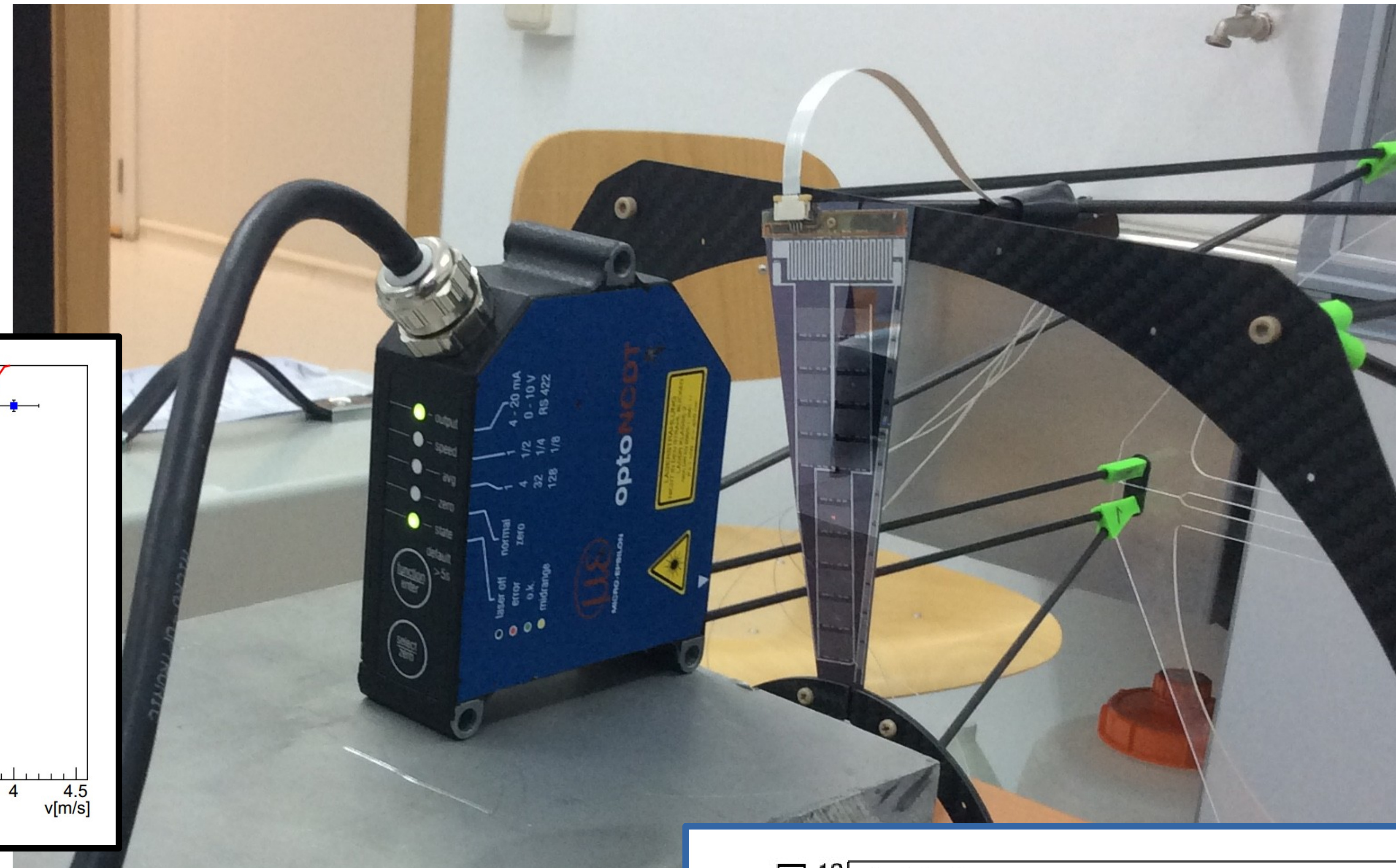
Work on petal design and CF support to raise the lowest eigenfrequency



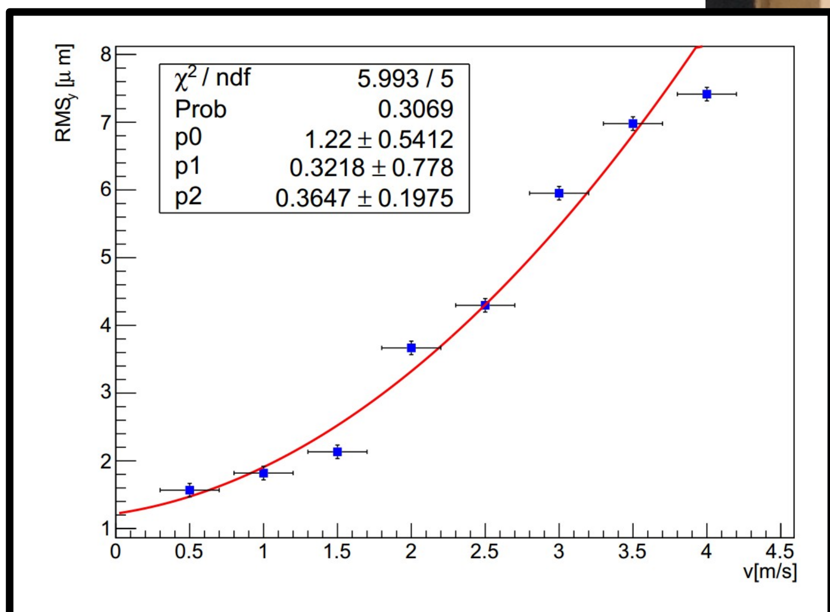




Air flow & deformation

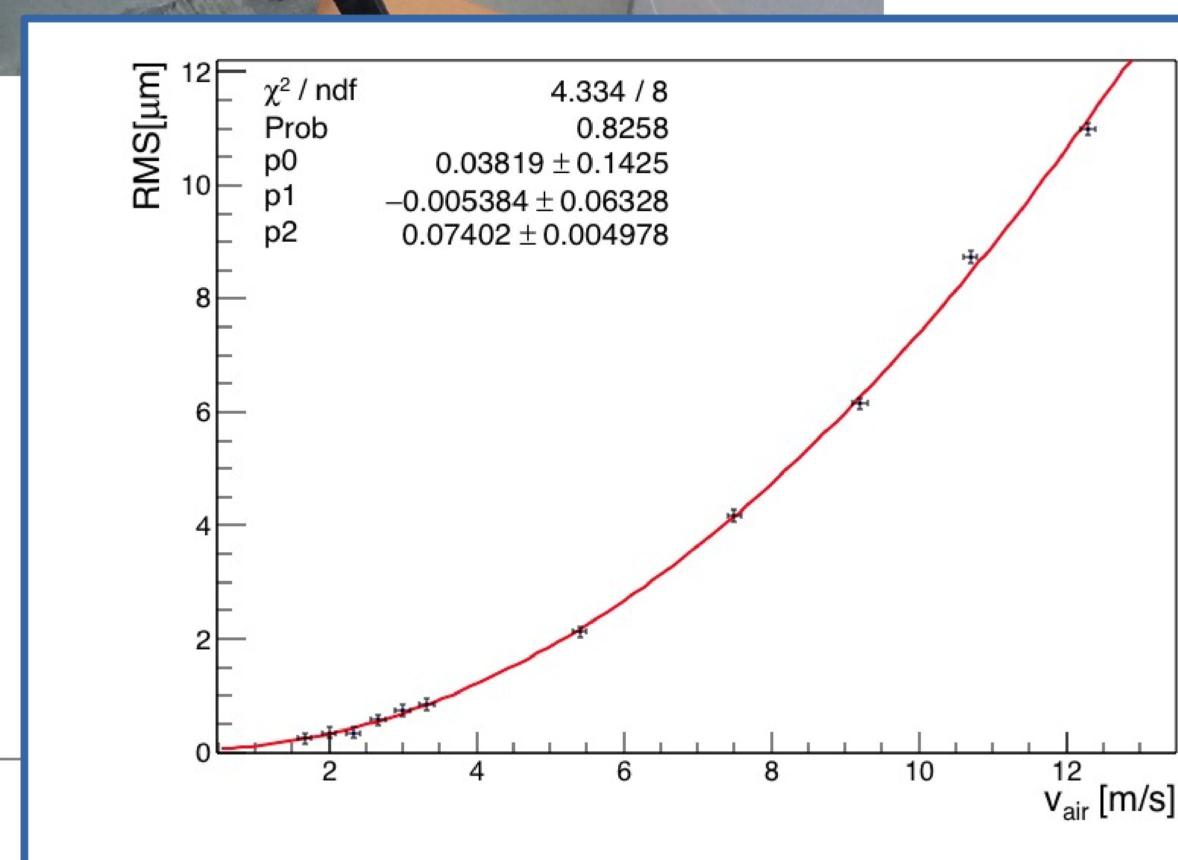


IFIC measurements



Air flow does introduce slight vibrations.
For large air speed these become sizeable wrt the intrinsic resolution.

CERN LCD “wind tunnel”



LC thermo-mechanics of thin sensors

Thermo-mechanical performance of silicon sensors studied with thinned mechanical samples

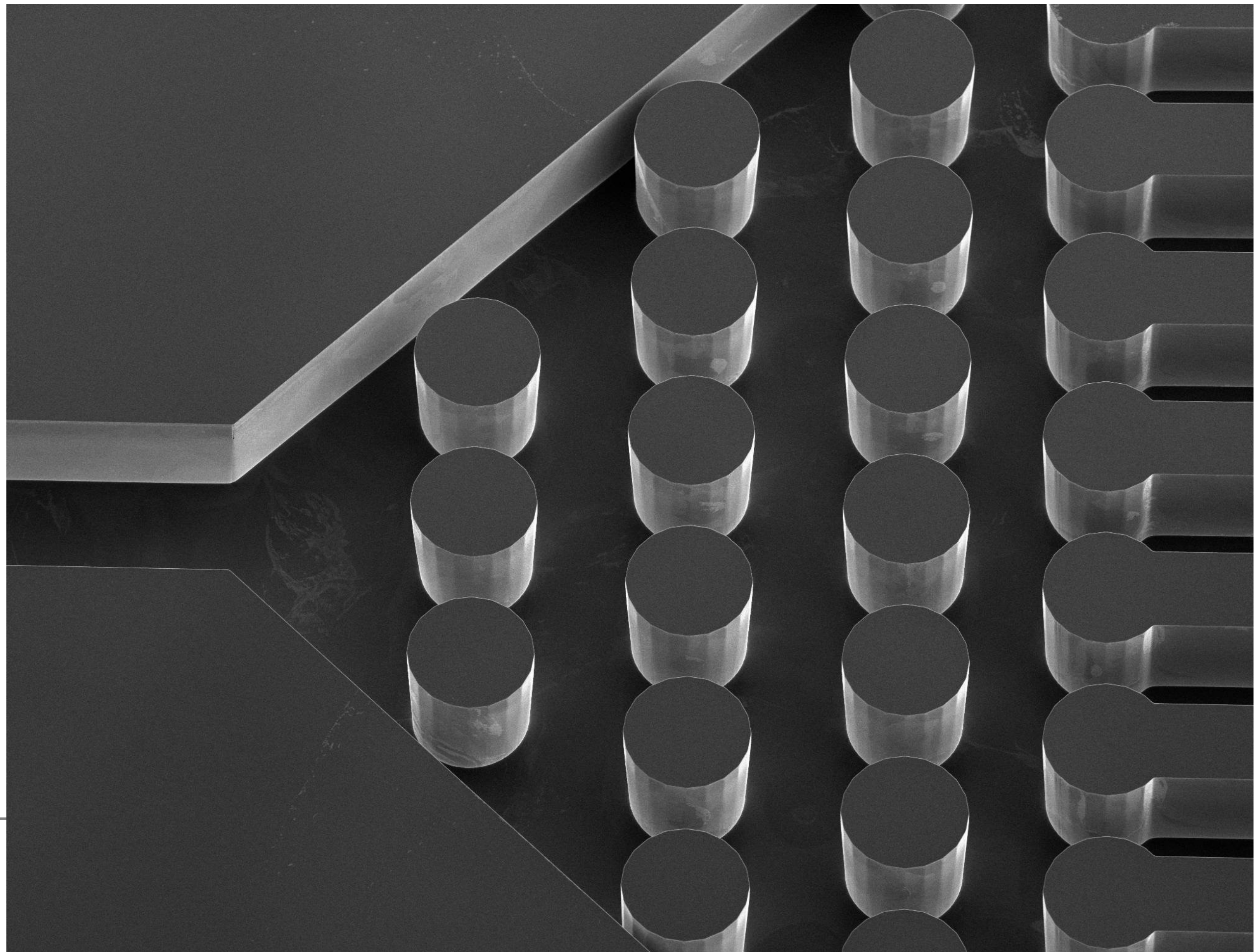
Study of power pulsing & air cooling very encouraging:
- Power pulsing has no impact on mechanical stability (but still without B-field!)
- A laminar air flow in front of the disk, with a moderate speed of 1m/s, is sufficient to remove the nominal DEPFET heat load (assuming 1/25 duty cycle for power pulsing, IEEE TNS 60-2-2, arXiv:1212.2160
- Air flow of greater than "a few m/s" must be avoided

The challenge is to bring in the air and establish a gentle, laminar air flow

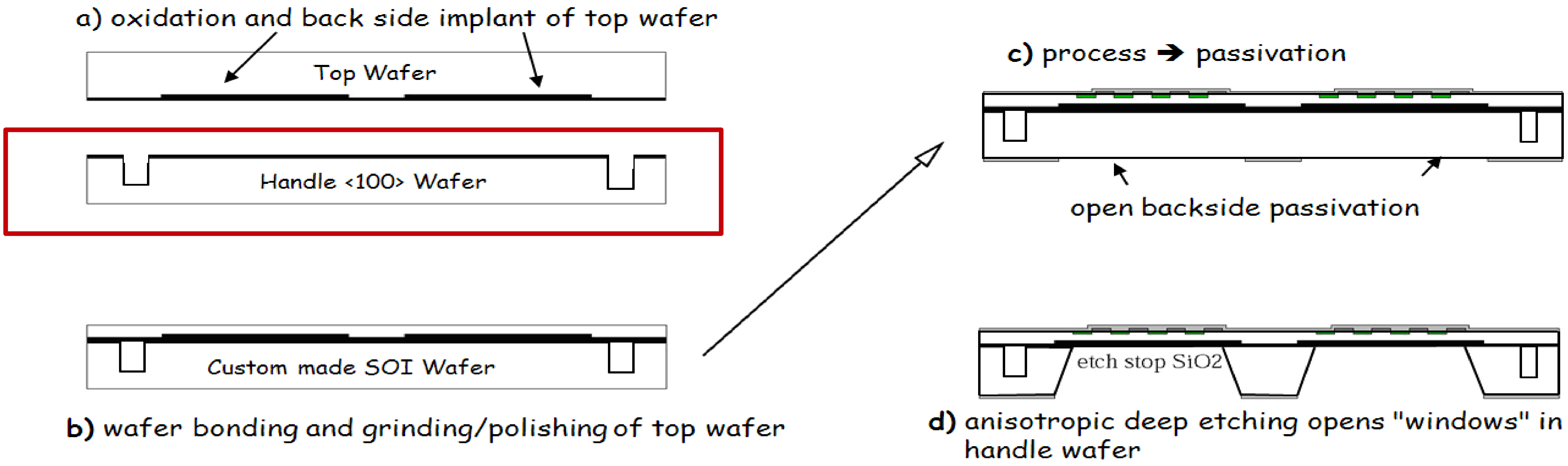
Micro-channel cooling, our take...

- Liquid cooling provides excellent temperature control, but is too bulky
- Industry is exploring micro-channel cooling (and, to some extent, high energy physics; LHCb, NA62, ALICE)
- DEPFET, with localized power dissipation and SOI process, provides an interesting application → integrate cooling in all-silicon ladder
- Compared to existing effort, aim at relatively high temperature, low pressure
- Keep it simple: mono-phase

- Small team at University of Bonn MPG-HLL Munich and IFIC Valencia
- Embedded in larger effort AIDA2020 (P. Petagna CERN)



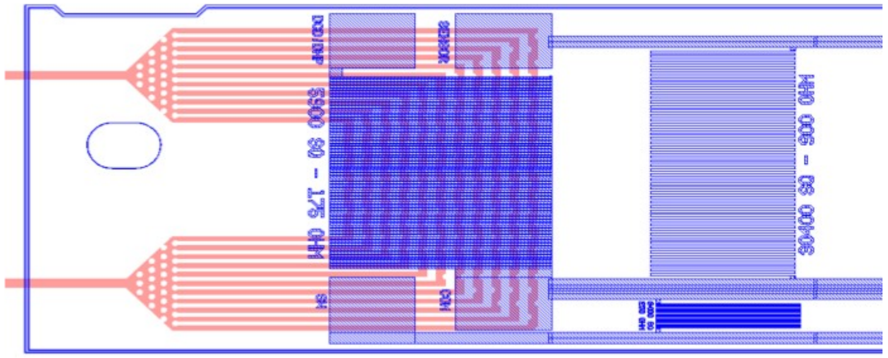
All-silicon ladder with integrated cooling

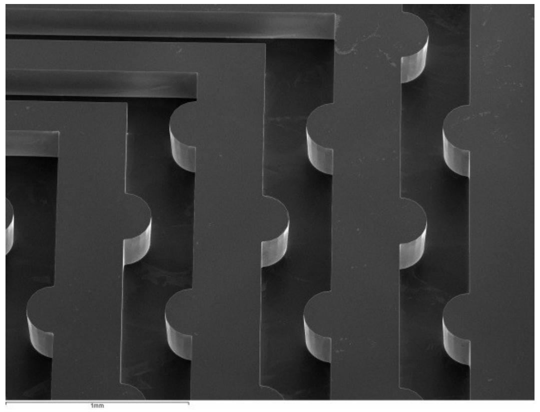


thinned all-silicon module with integrated cooling channels

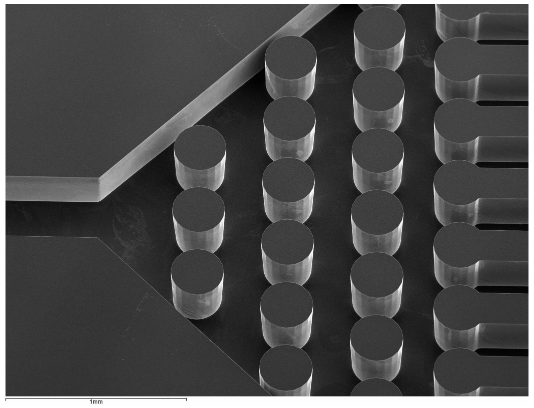
:- integrate channels into handle wafer beneath the ASICs
:- channels etched before wafer bonding → cavity SOI (C-SOI)
:- full processing on C-SOI, thinning of sensitive area
:- micro-channels accessible only after cutting (laser)

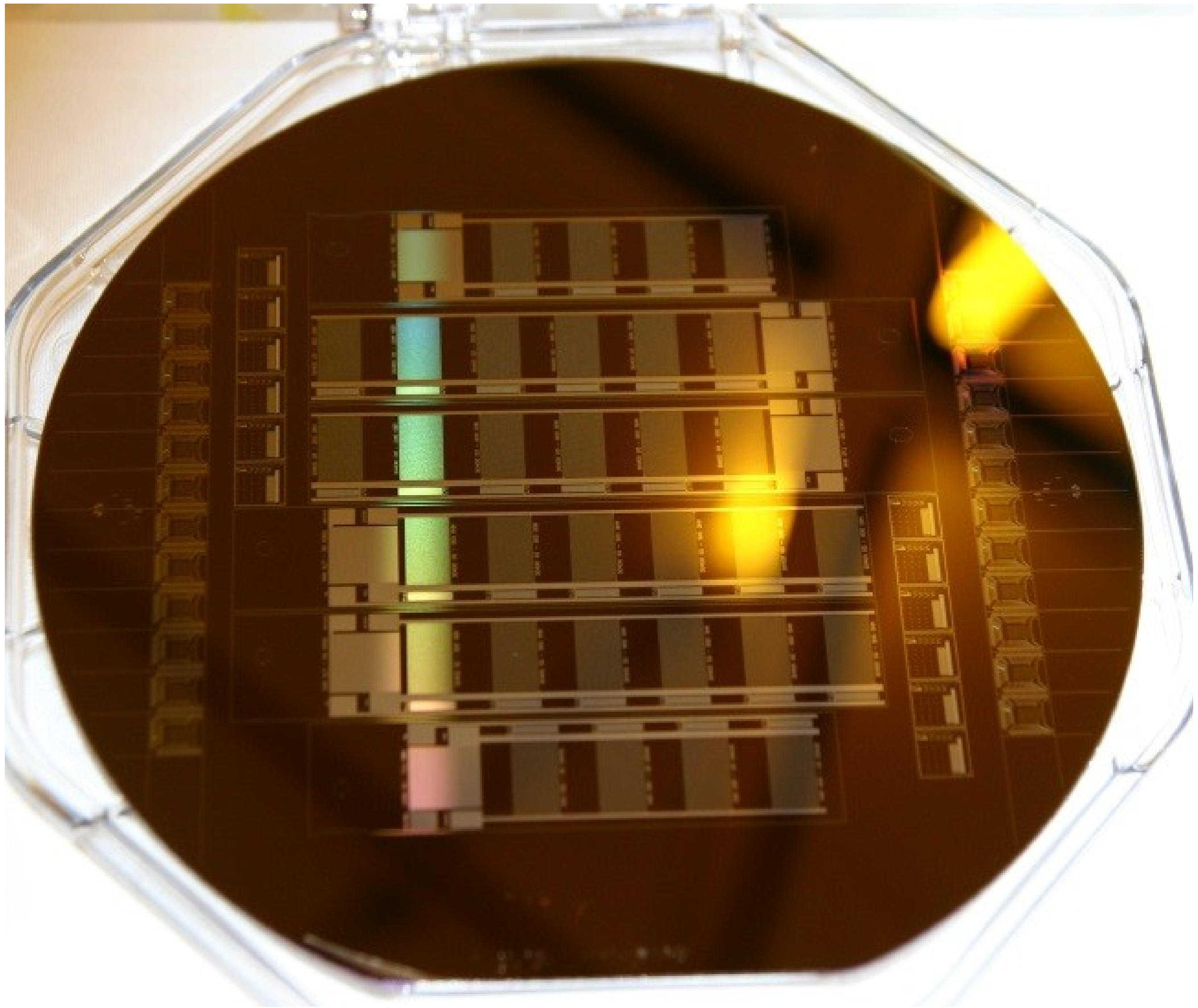
MCC prototypes





Micro-channel pattern in handle wafer

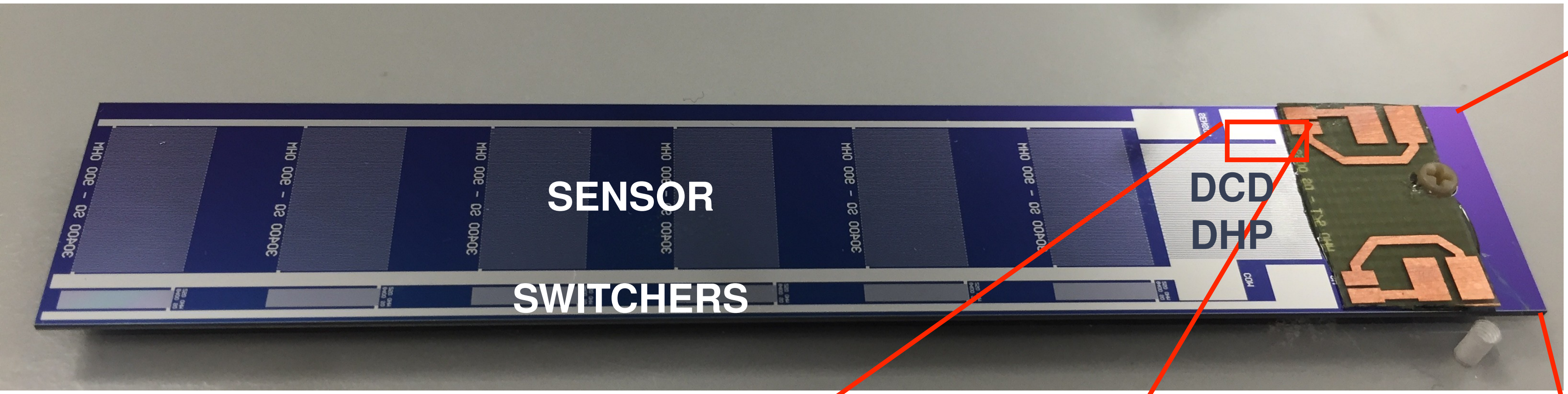


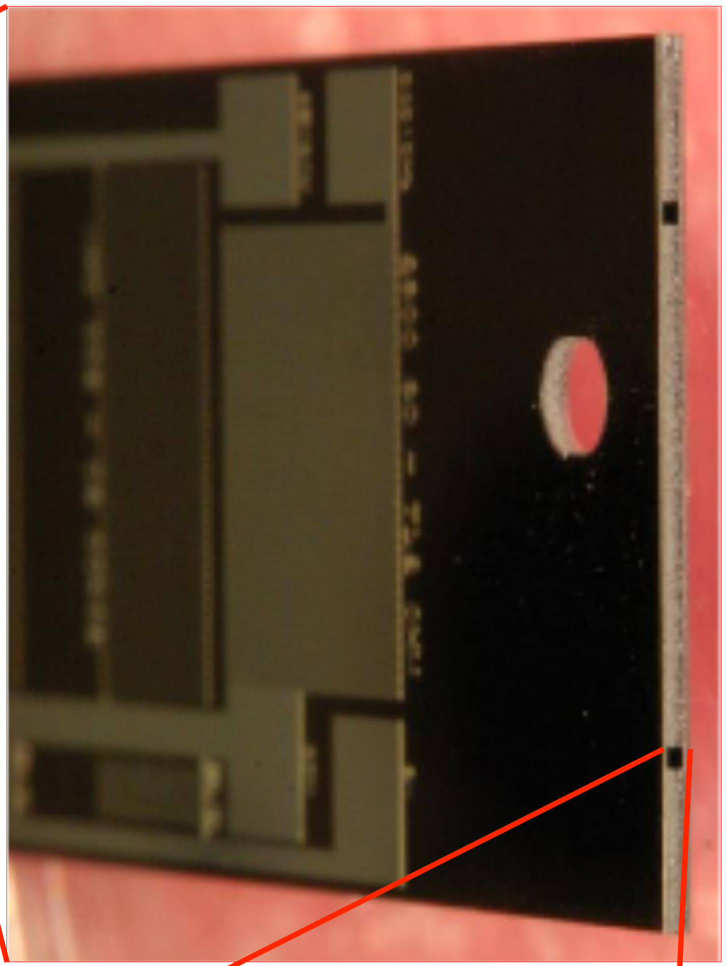


6 ladders with integrated MCC manifolds on a wafer

DEPFET Active Pixel Detector

All-silicon ladder with integrated cooling

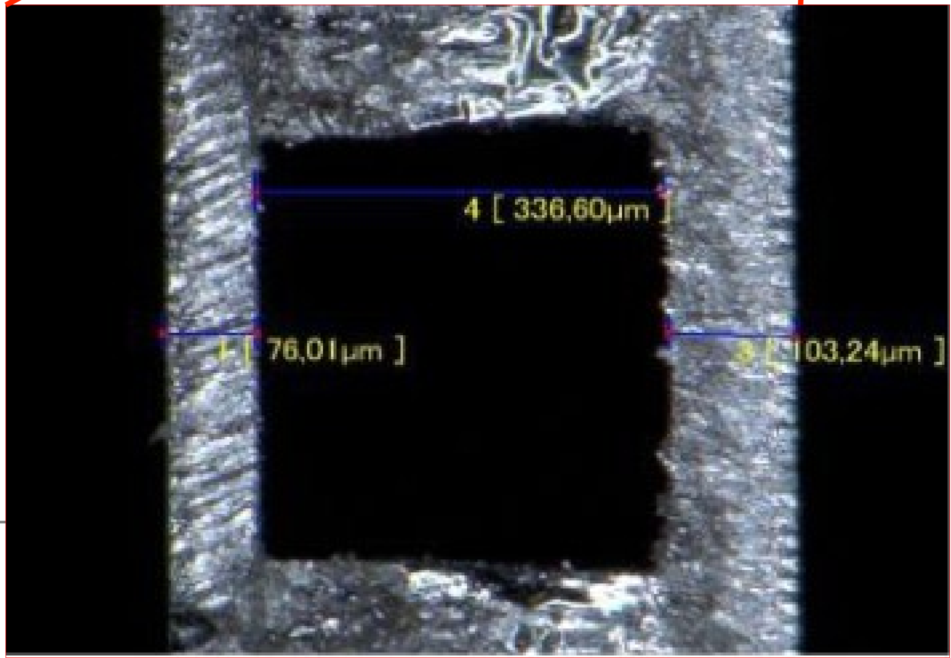




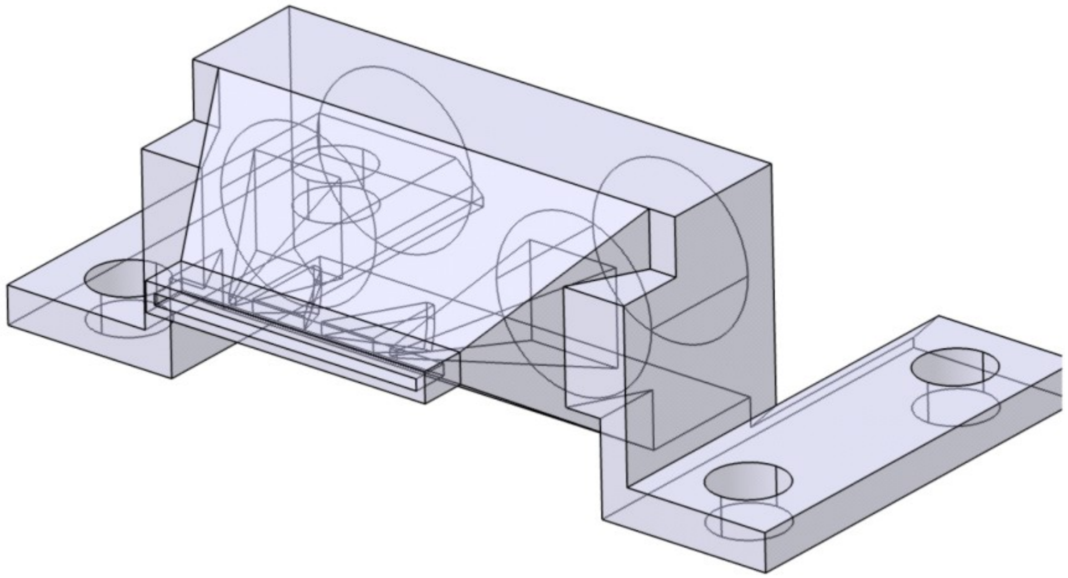
Resistor circuits to mimic DEPFET power dissipation

Thermo-mechanical half-ladder for the LC inner vertex detector

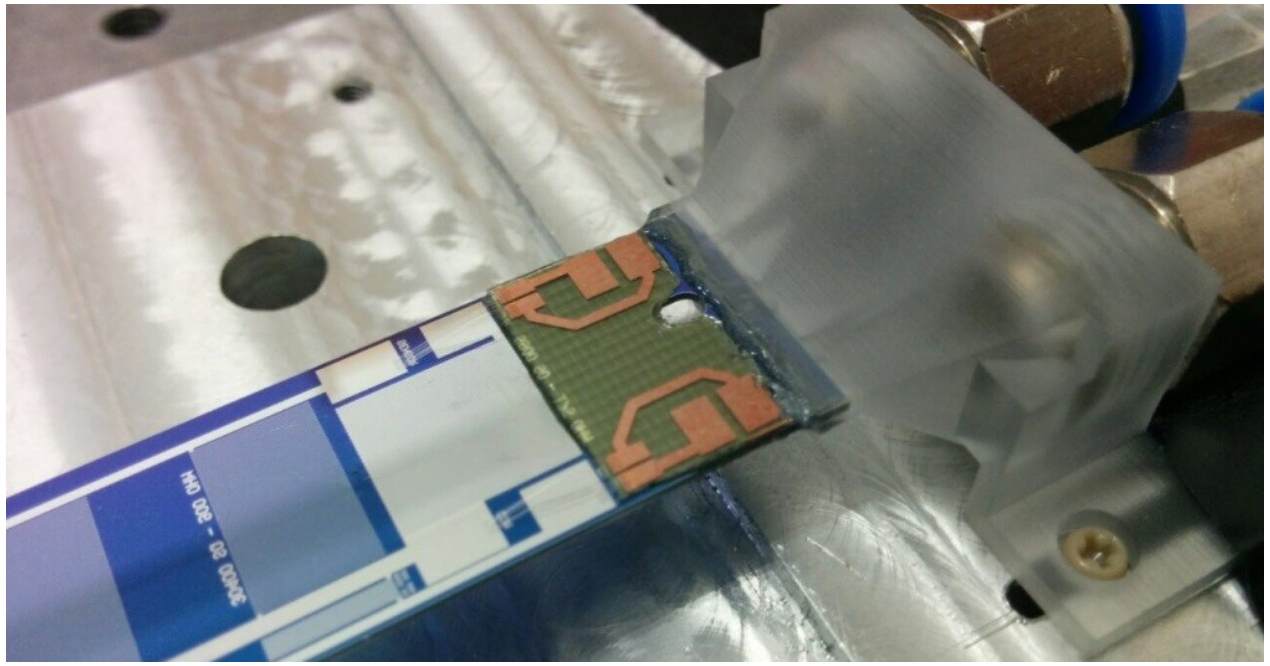
Inlet and outlet visible after wafer cutting

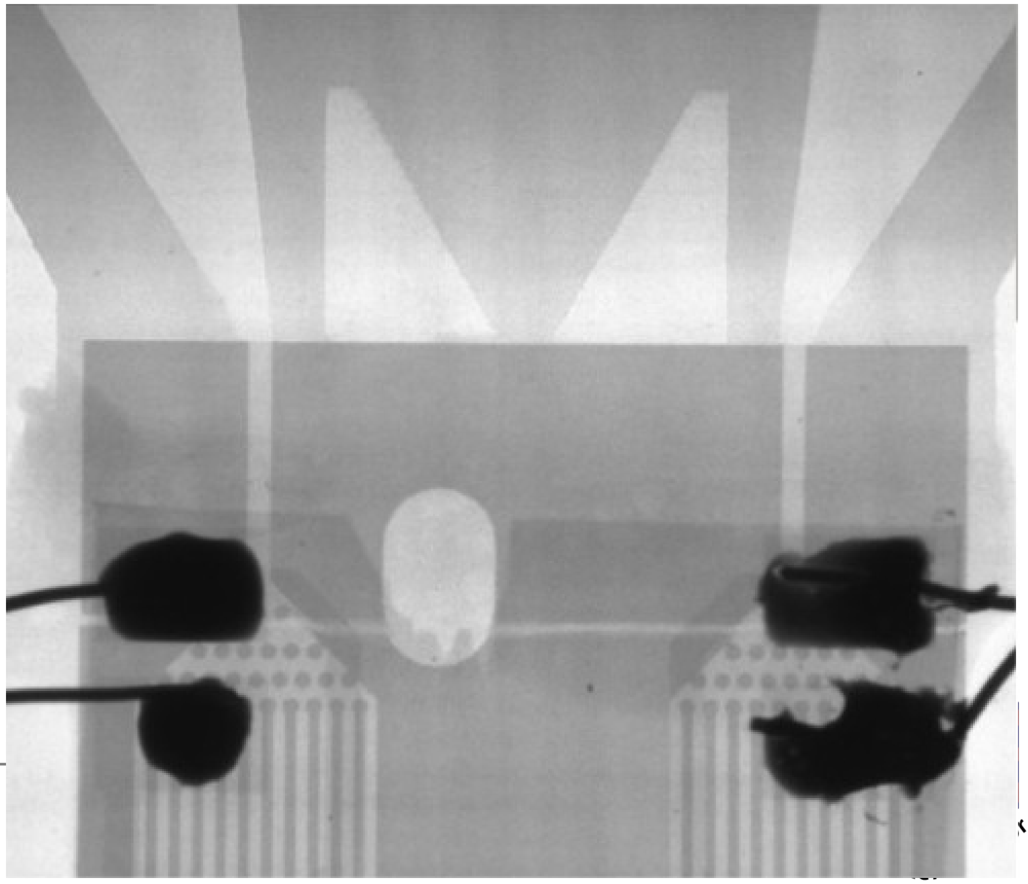


The interconnect challenge

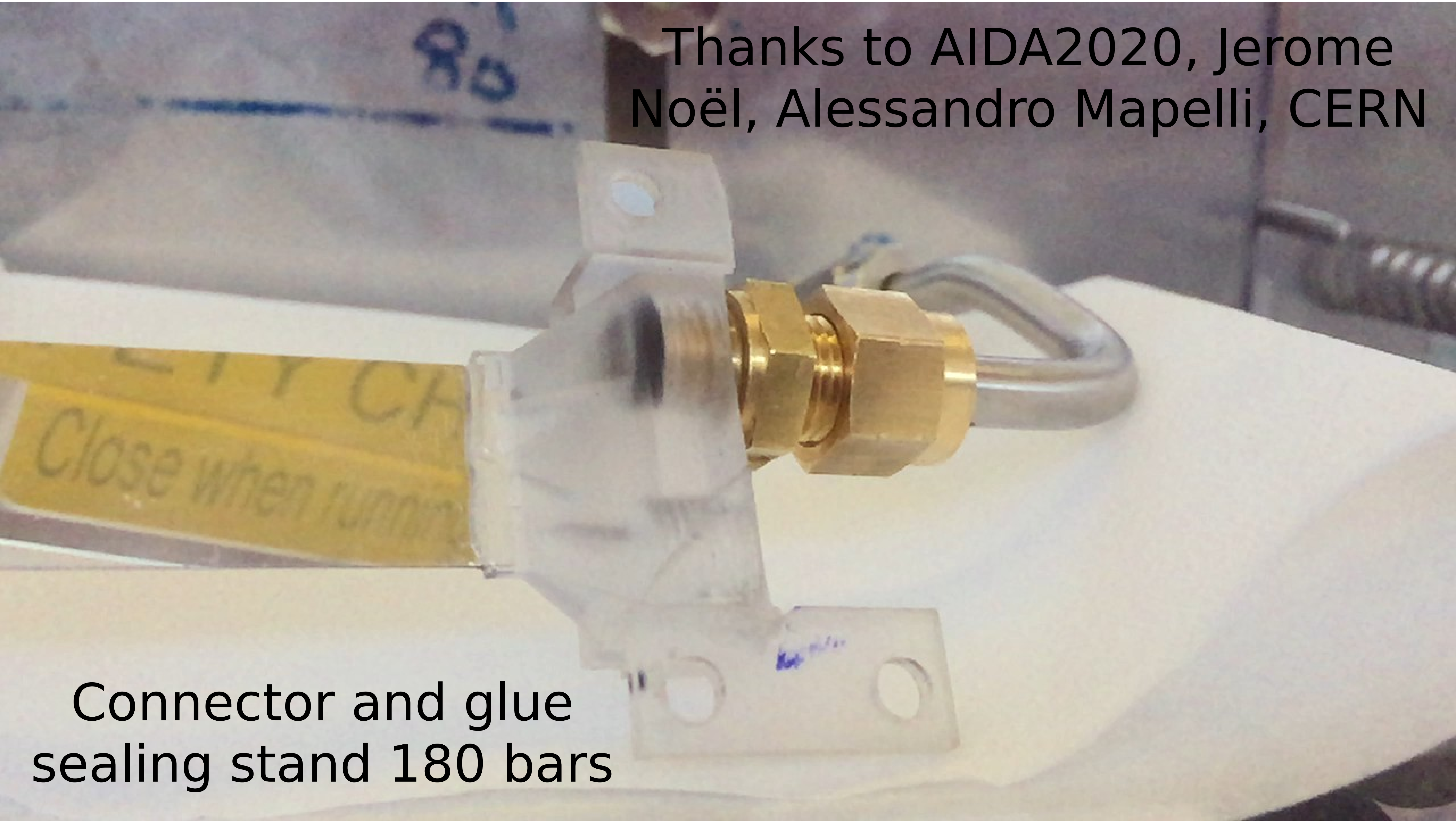


- ▷ Laboratory connector
  = interface to high-pressure Swagelok
- ▷ 3D-printed (stereo-lithography)
  15 µm precision → self-aligning
- ▷ Sealed with glue (Araldite)





Pressure test

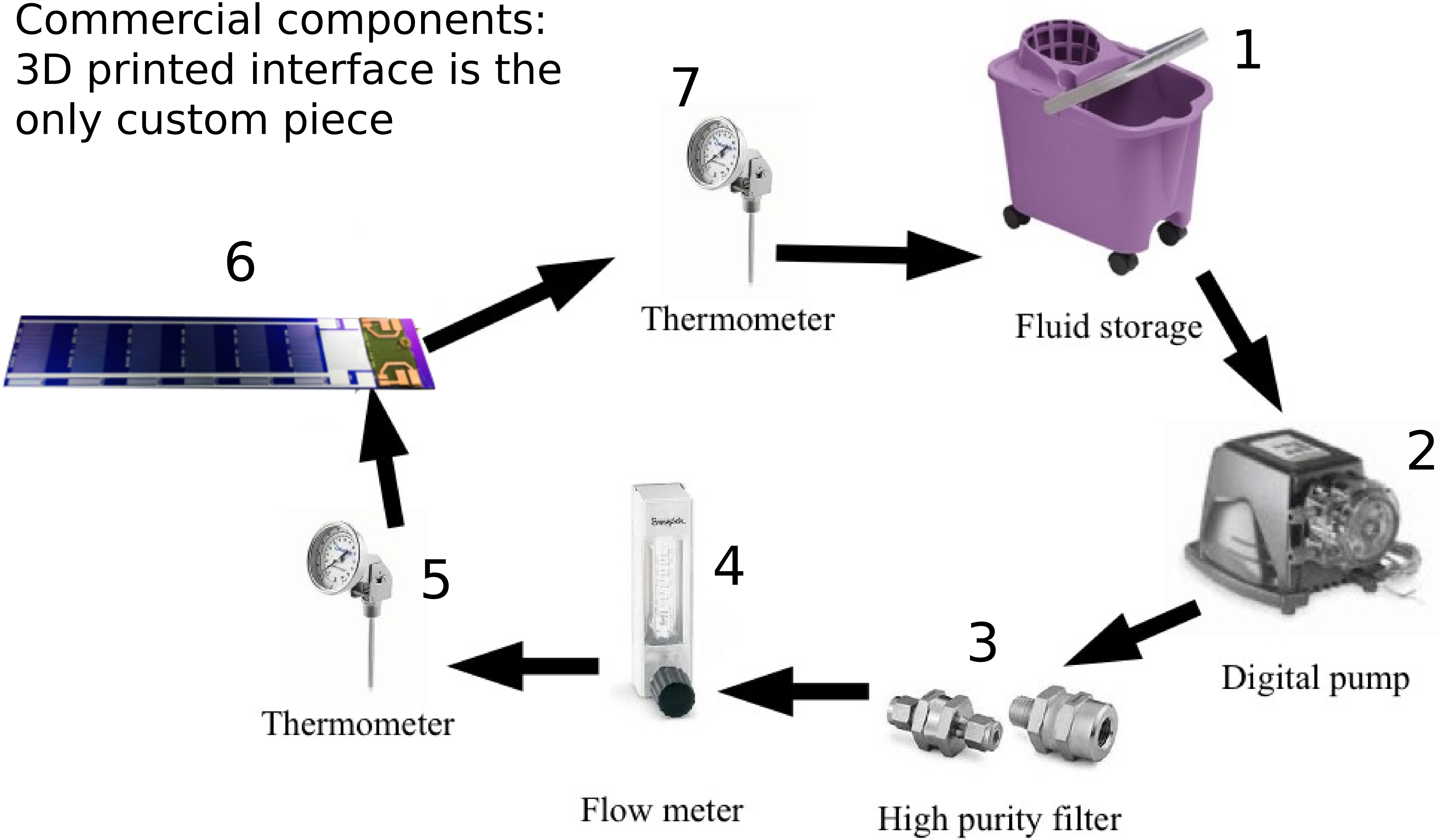


Thanks to AIDA2020, Jerome Noël, Alessandro Mapelli, CERN

Connector and glue sealing stand 180 bars

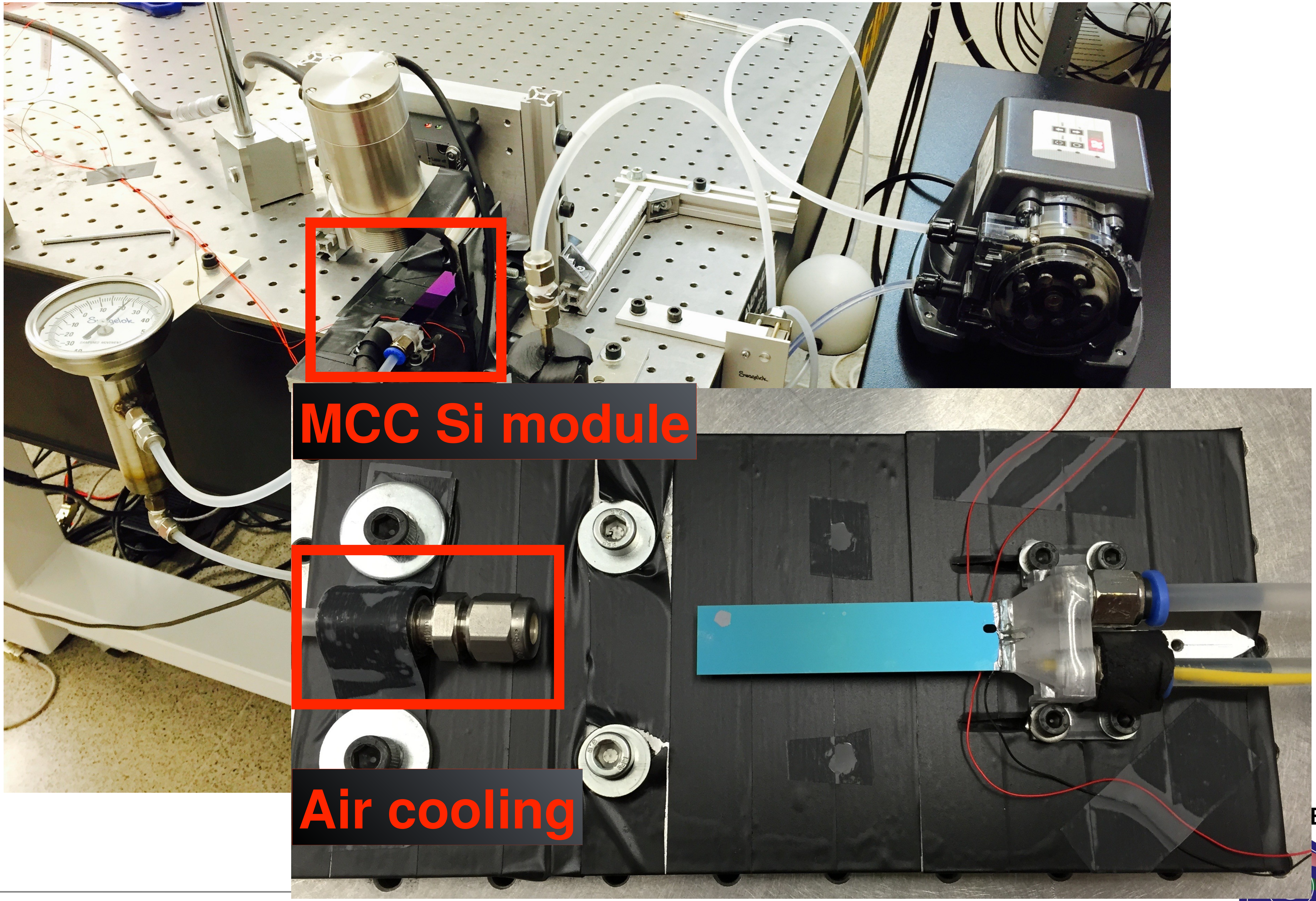
Experimental setup

Commercial components:
3D printed interface is the only custom piece

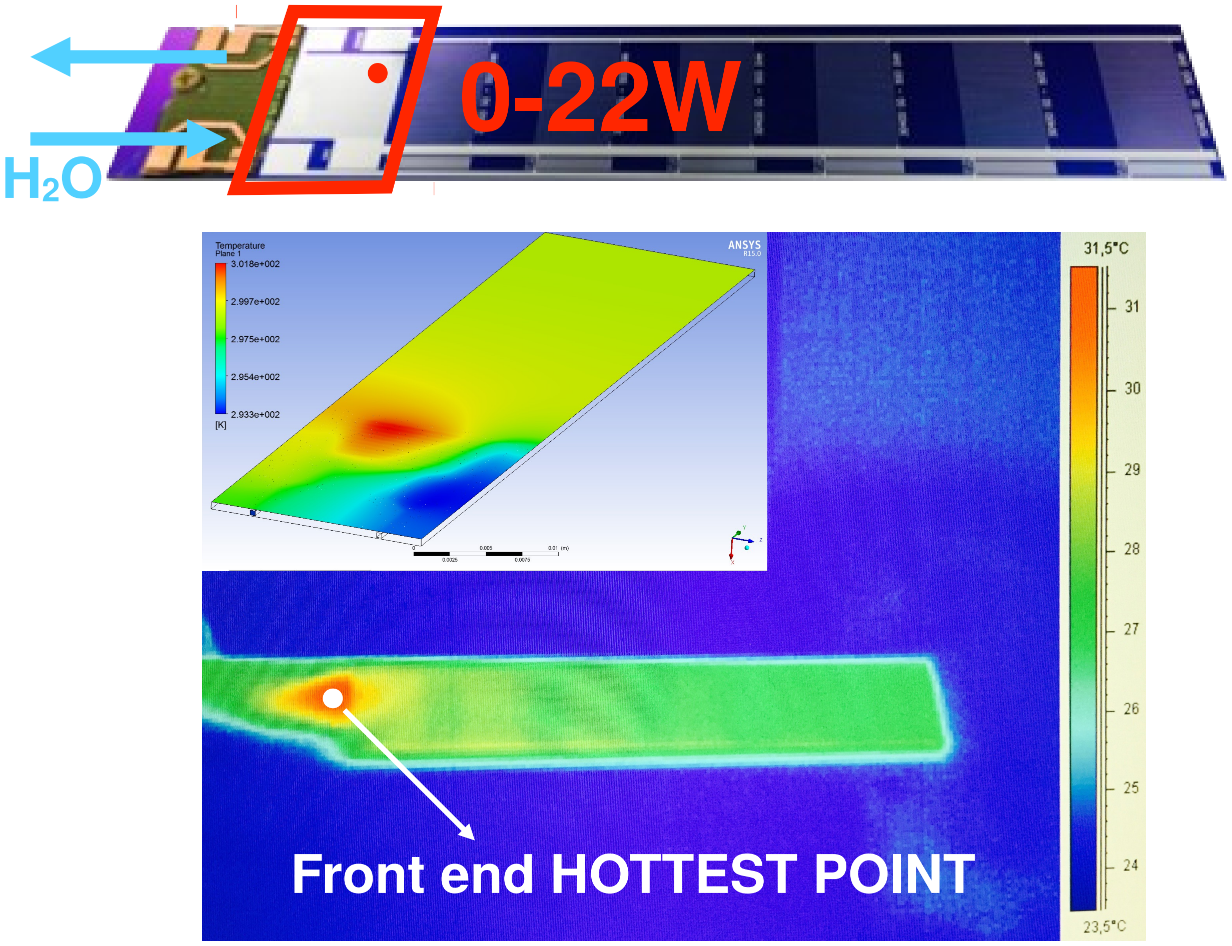


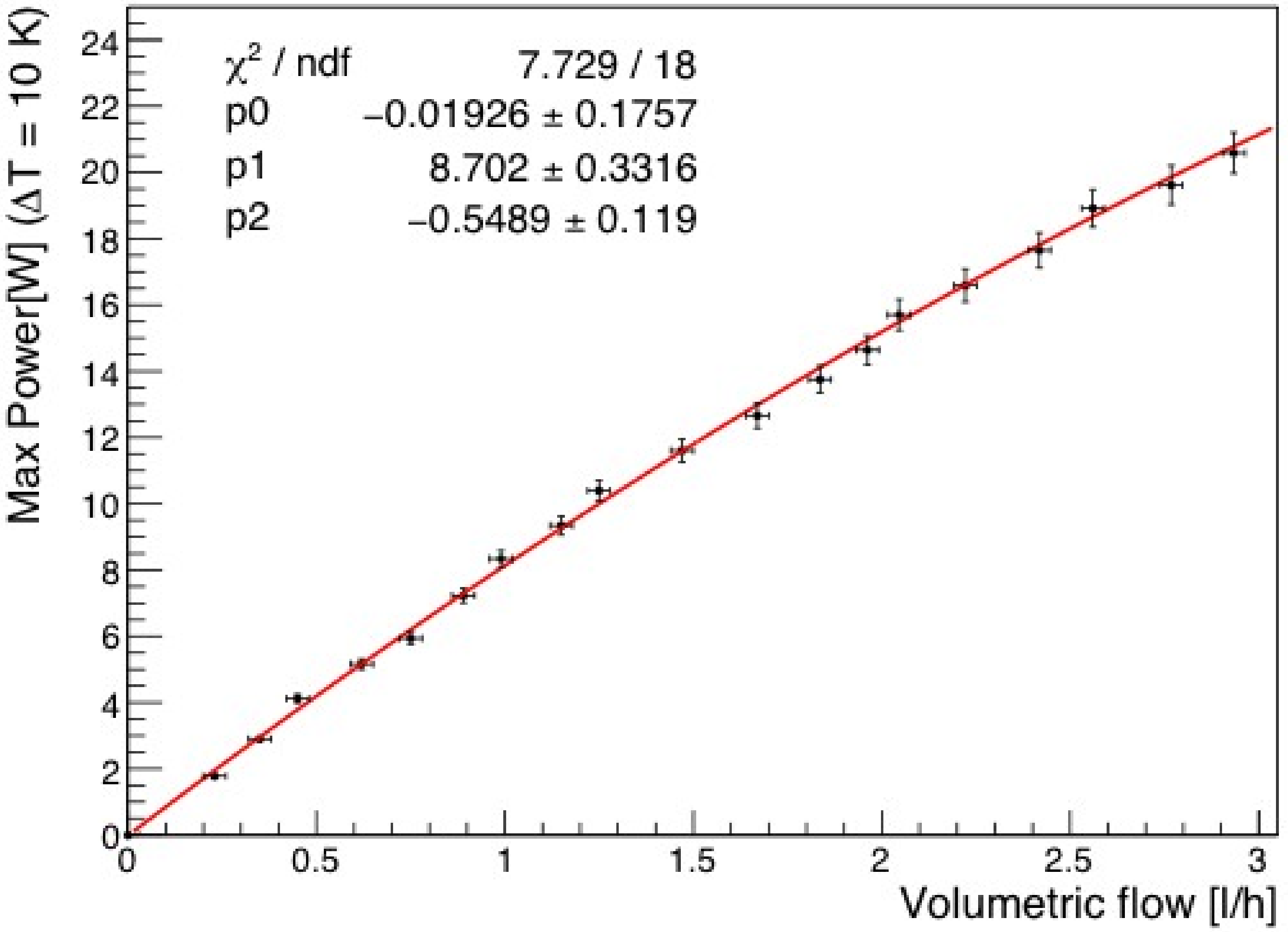
Experimental setup

For operation above 0°C **mono-phase liquid cooling** with (**H_2O**)



Thermal measurements: Maximum Power vs Volumetric flow



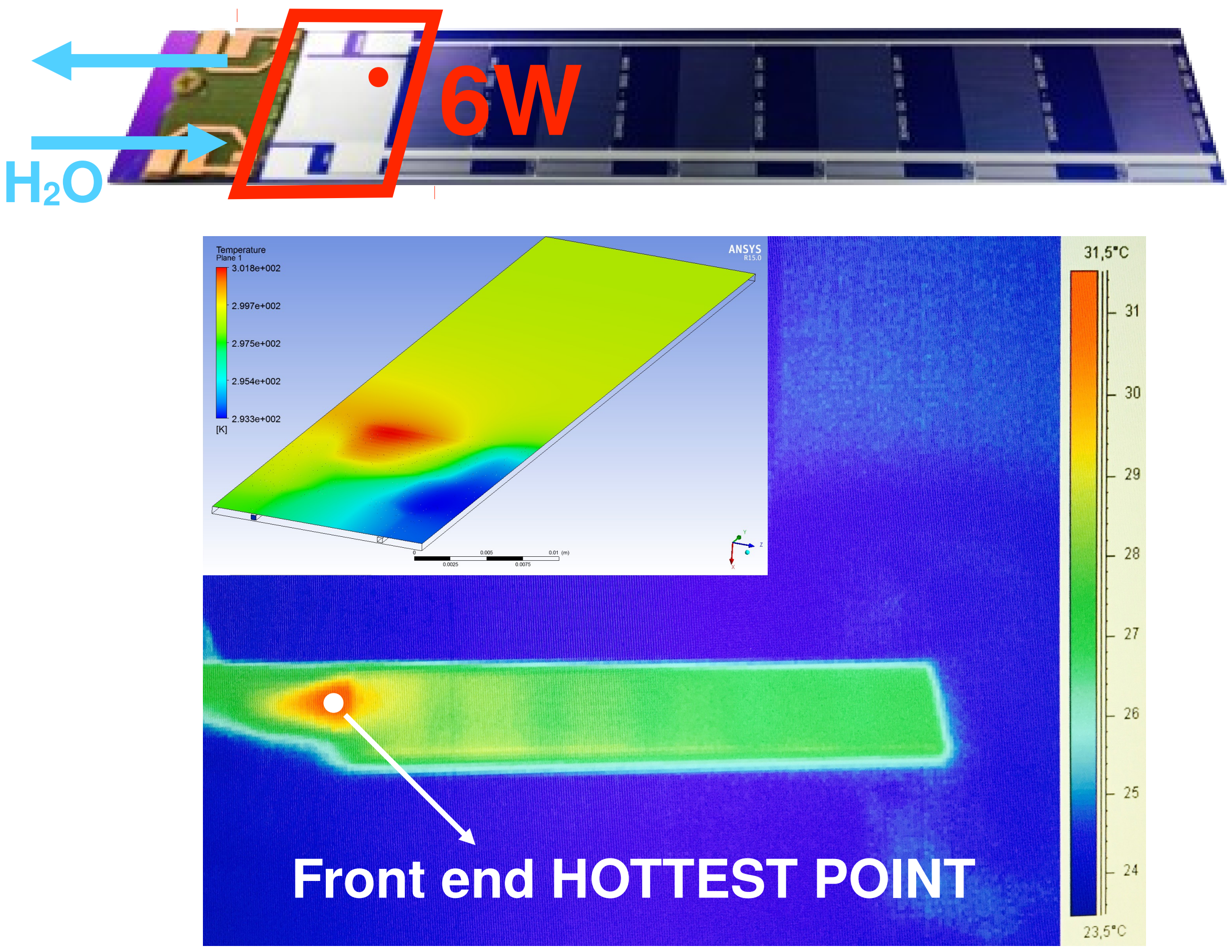


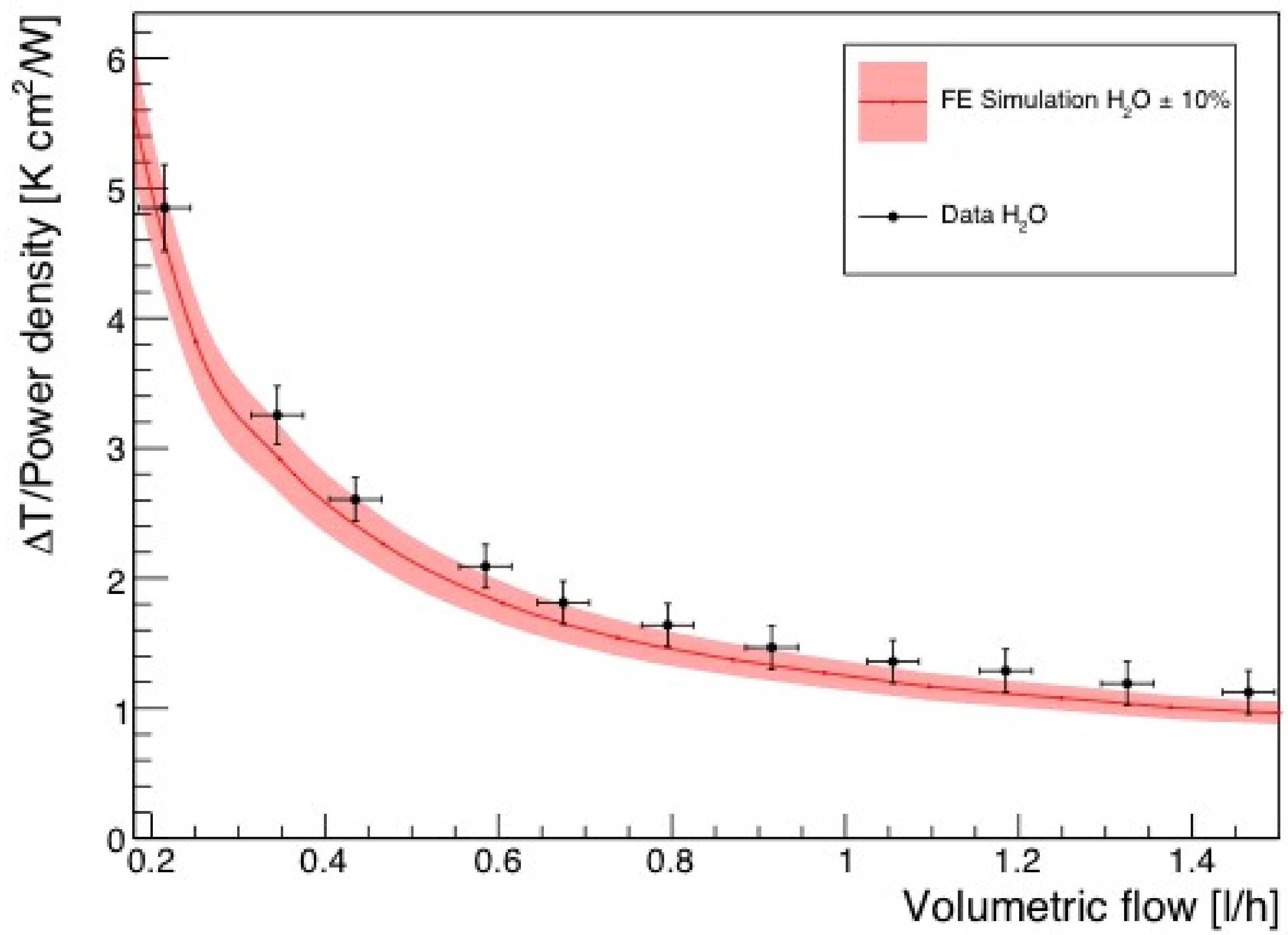
Maximum power supported for a ΔT of 10 ºC as a function of the volumetric flow

- **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

Extremely powerful: MCC removes many times the instantaneous with very small temperature gradient

Thermal measurements: MCC



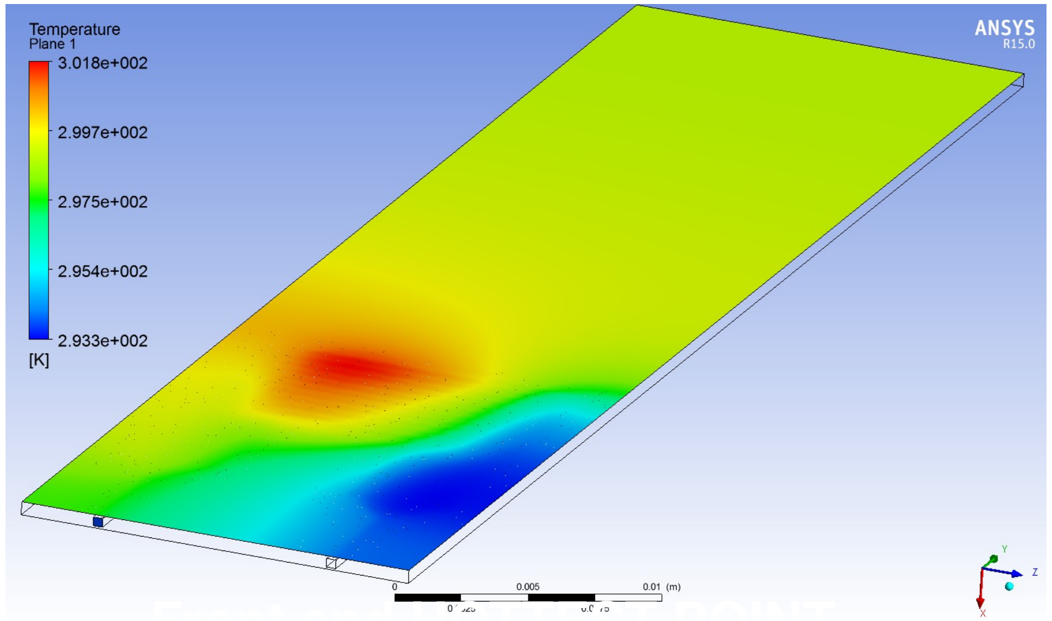


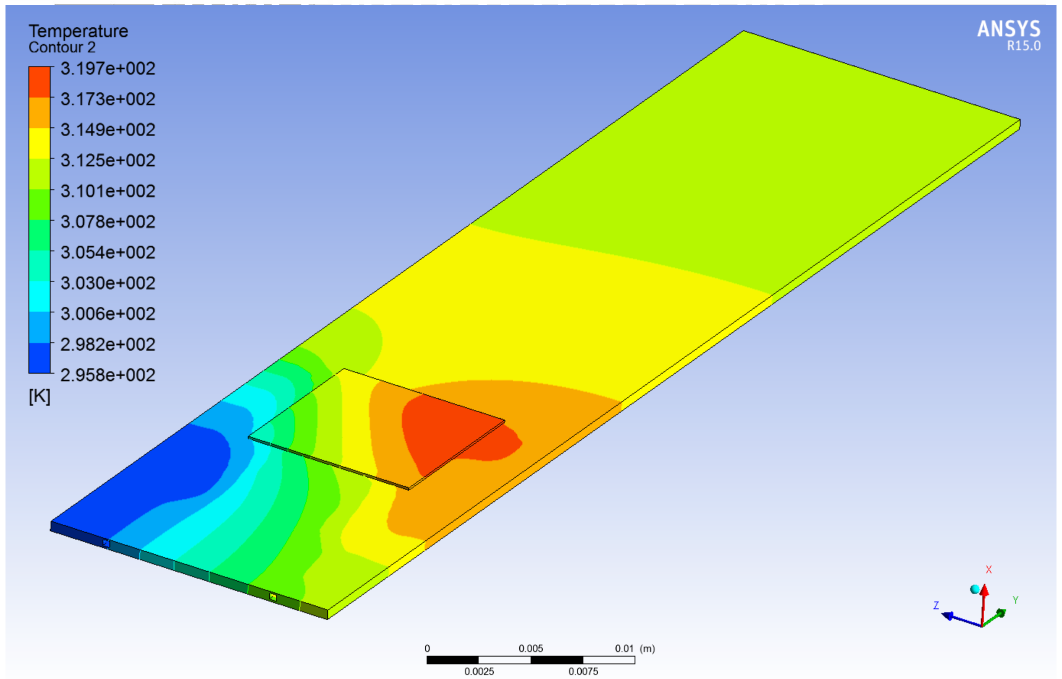
Measurement data errors

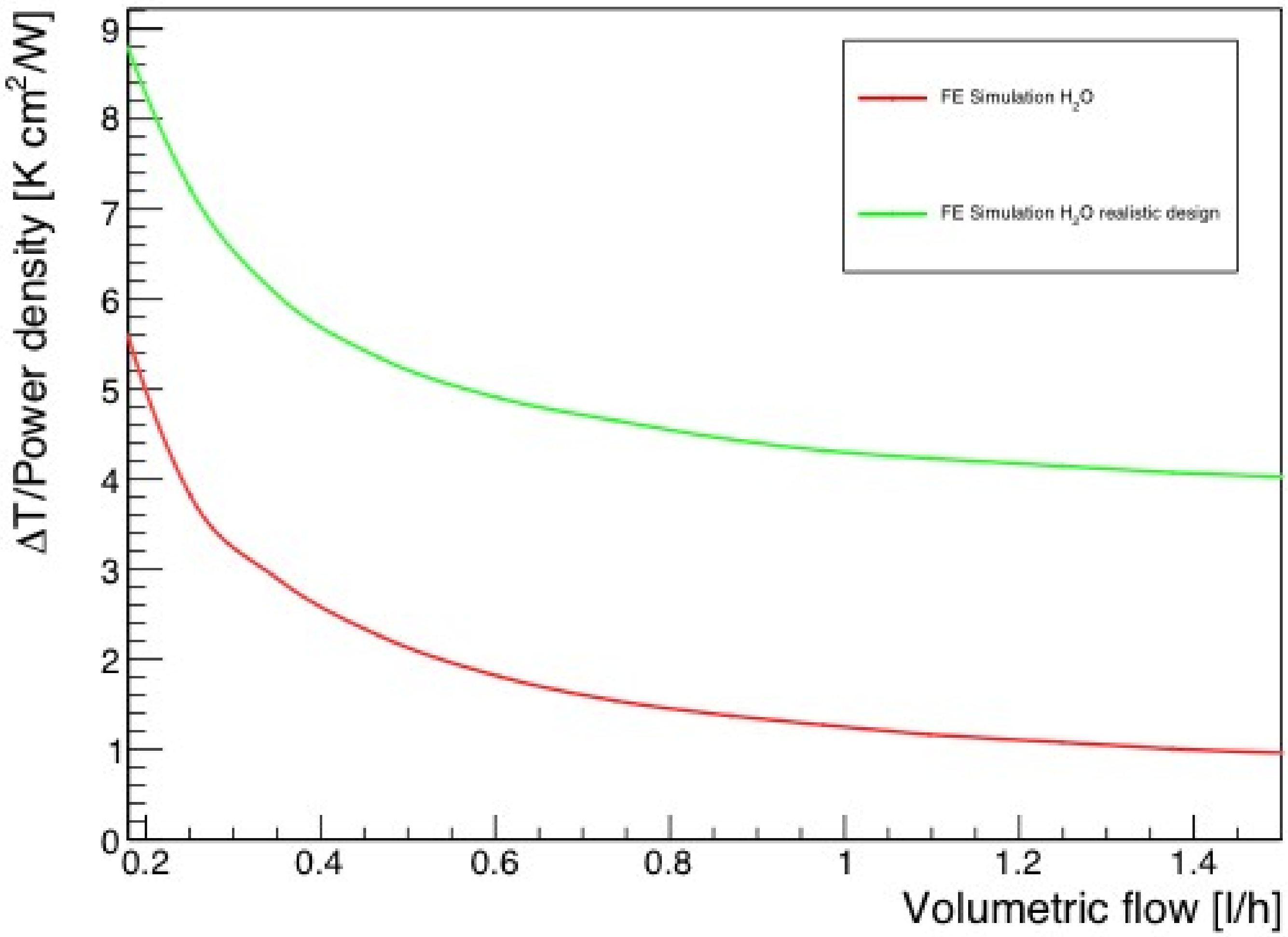
- P ±1% W
- T ± 1 ºC
- ΔT/Power density ± 0,14 ºC/W
- flow ± 0,03 l/h

Good agreement with the **FE simulation** within 10%

Thermal simulations: MCC

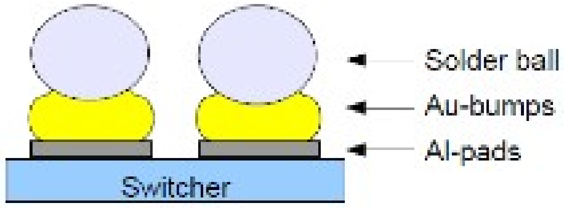






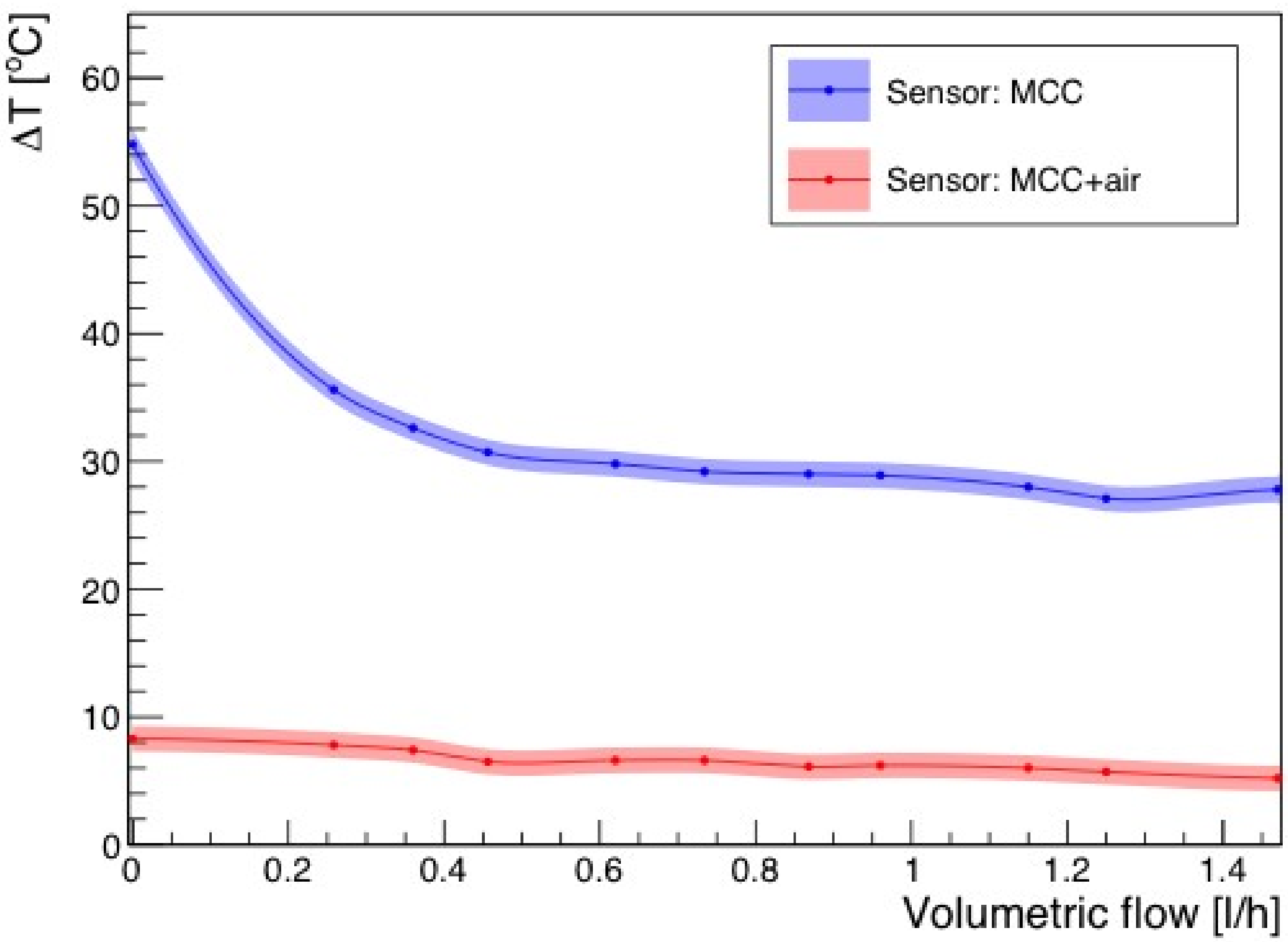
Realistic design

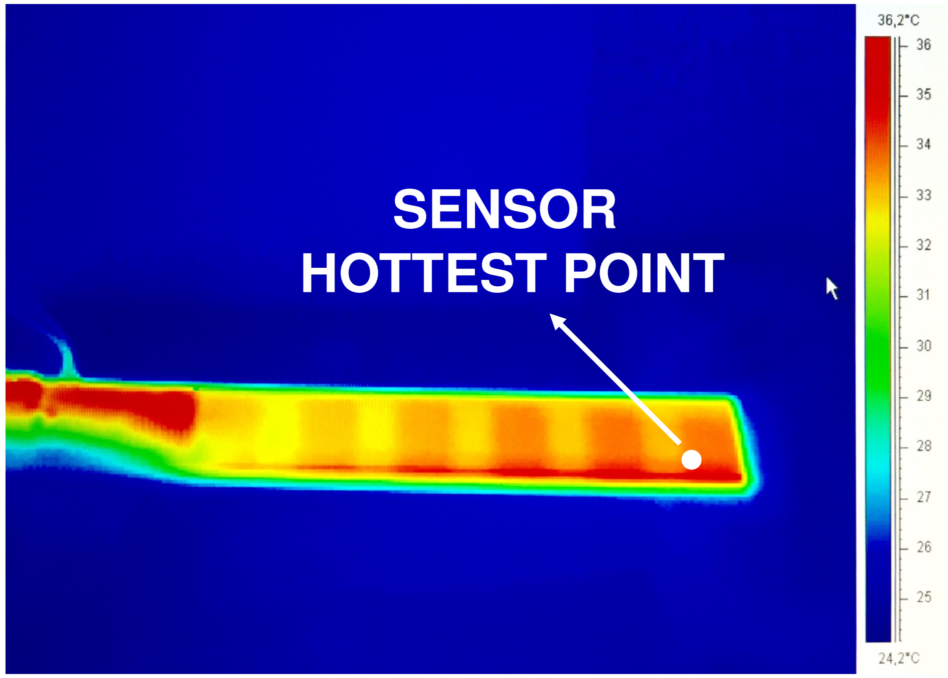
300 µm Si ASICS +
100 µm Bump-boundings
thermal resistivity of 6 W/m·K



C.Mariñas PhD thesis link

Thermal measurements: MCC + air

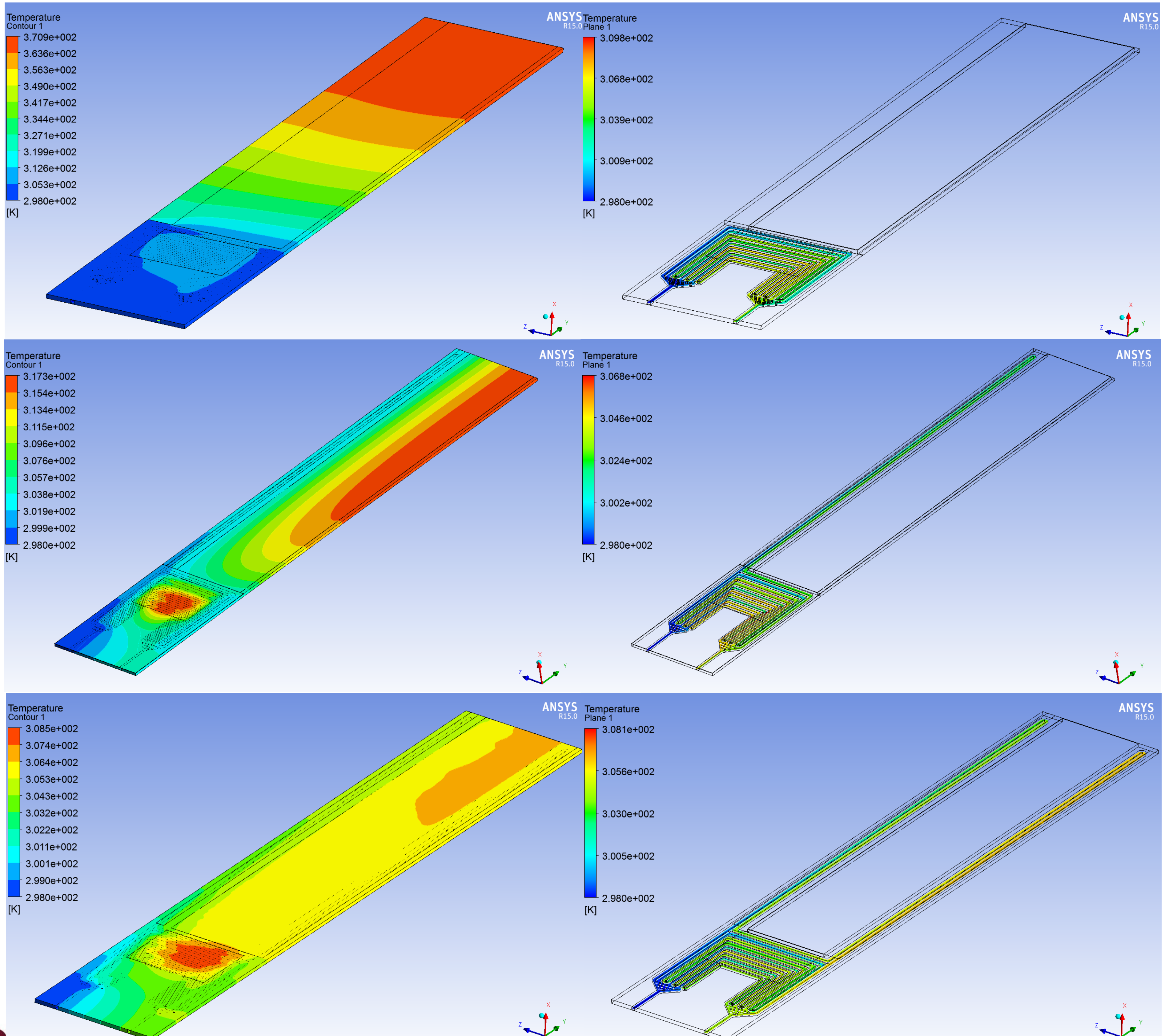




Cooling strategy: micro-channels running under the front end and gentle air flow on the sensor part

- **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**

Thermal simulations: MCC Layouts

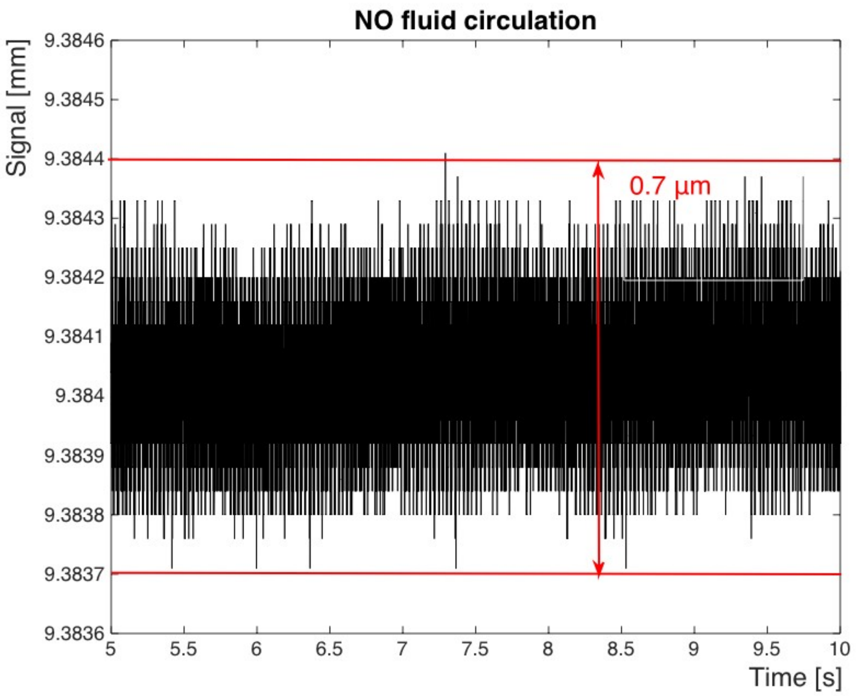


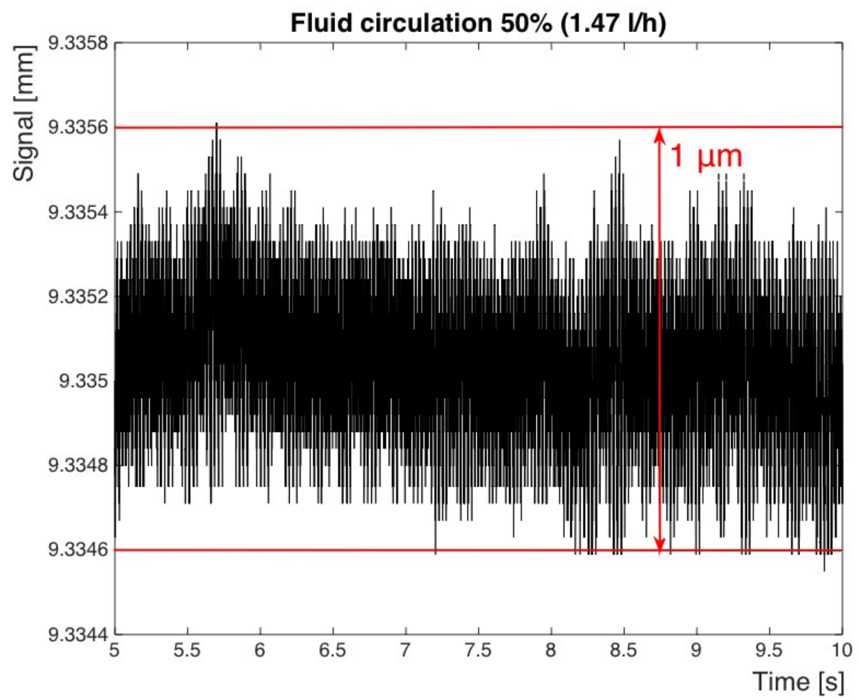
Standard MCC layout
ΔT = 73 K

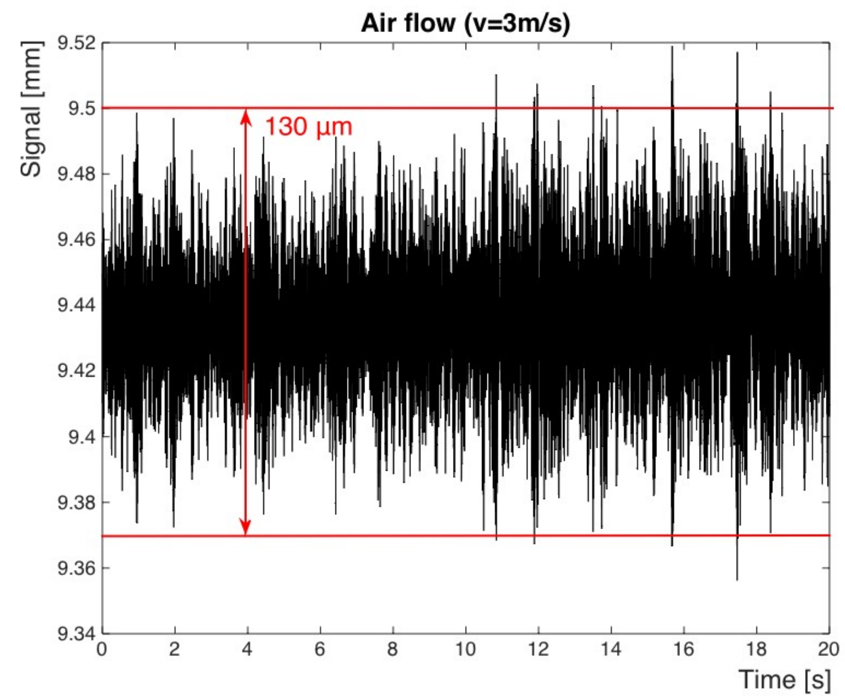
Standard MCC layout + channel below switchers
ΔT = 15 K

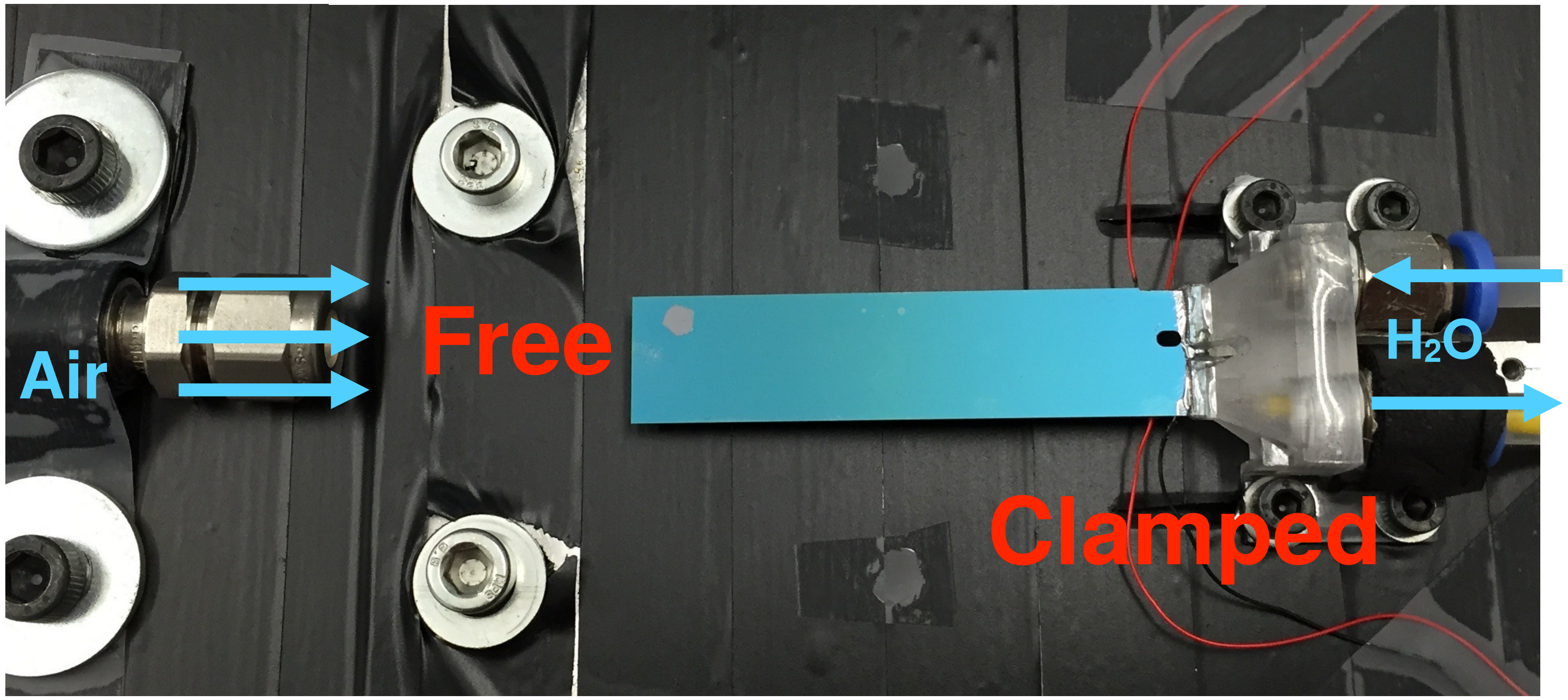
Standard MCC layout + channel below switchers + channel in the balcony
ΔT = 5 K

Vibrations and deformations



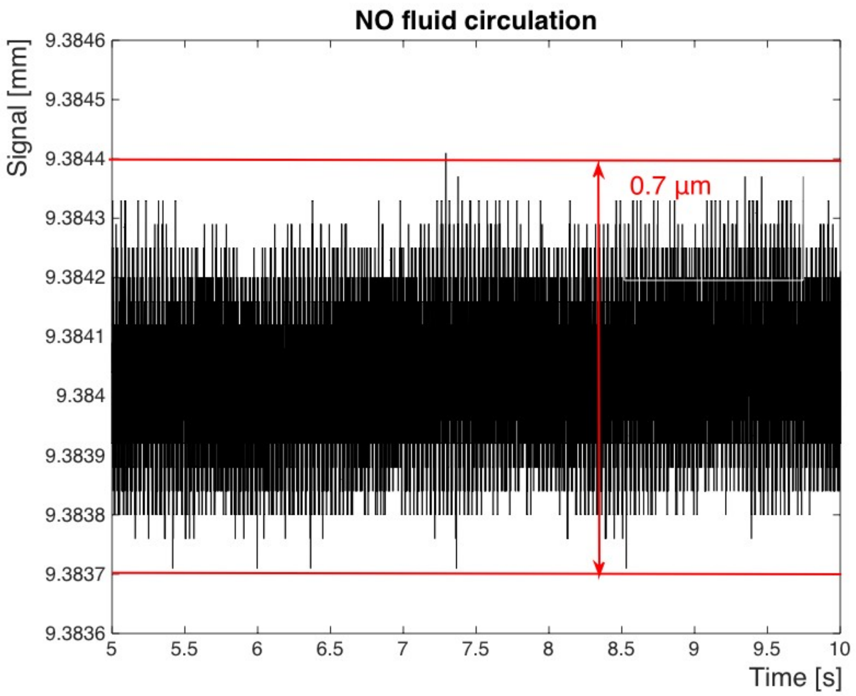


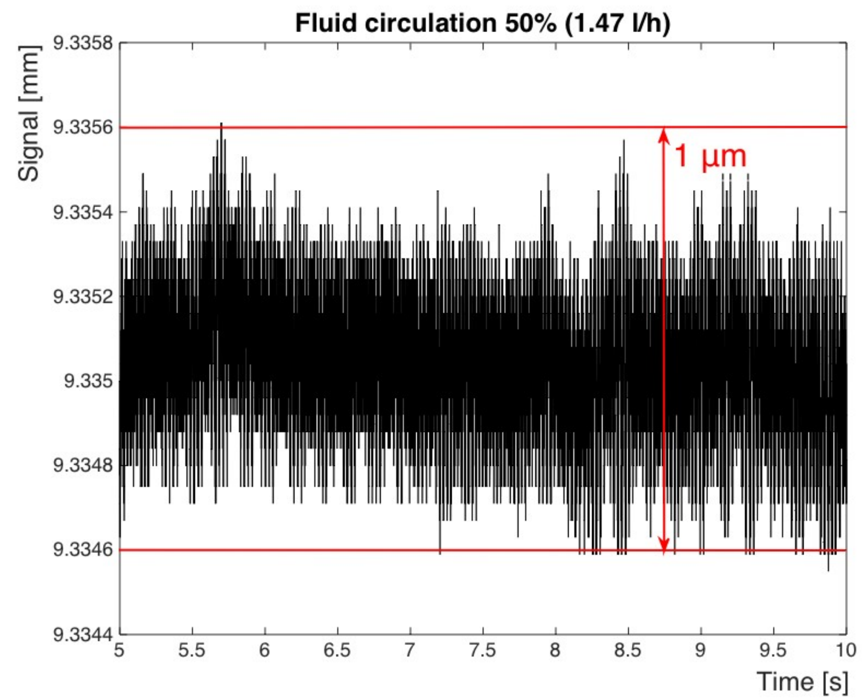


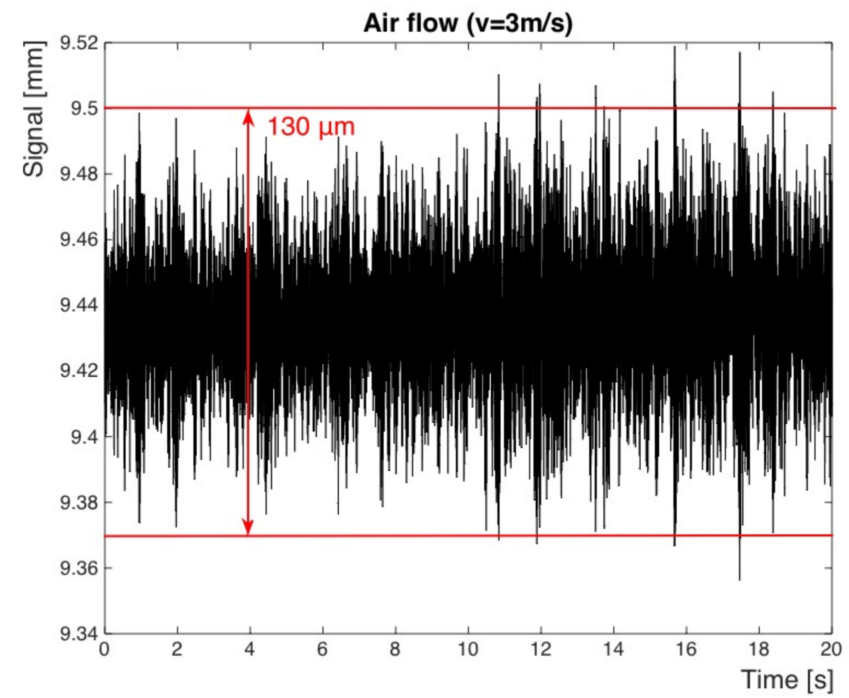


One extreme of the dummy is clamped to the 3D adaptor
→ amplifies vibrations

Vibrations and deformations







No fluid circulation and no air flowing

Peak to peak of the signal ~0,7 µm
RMS ~0,3 µm

Fluid circulation 1,47 l/h

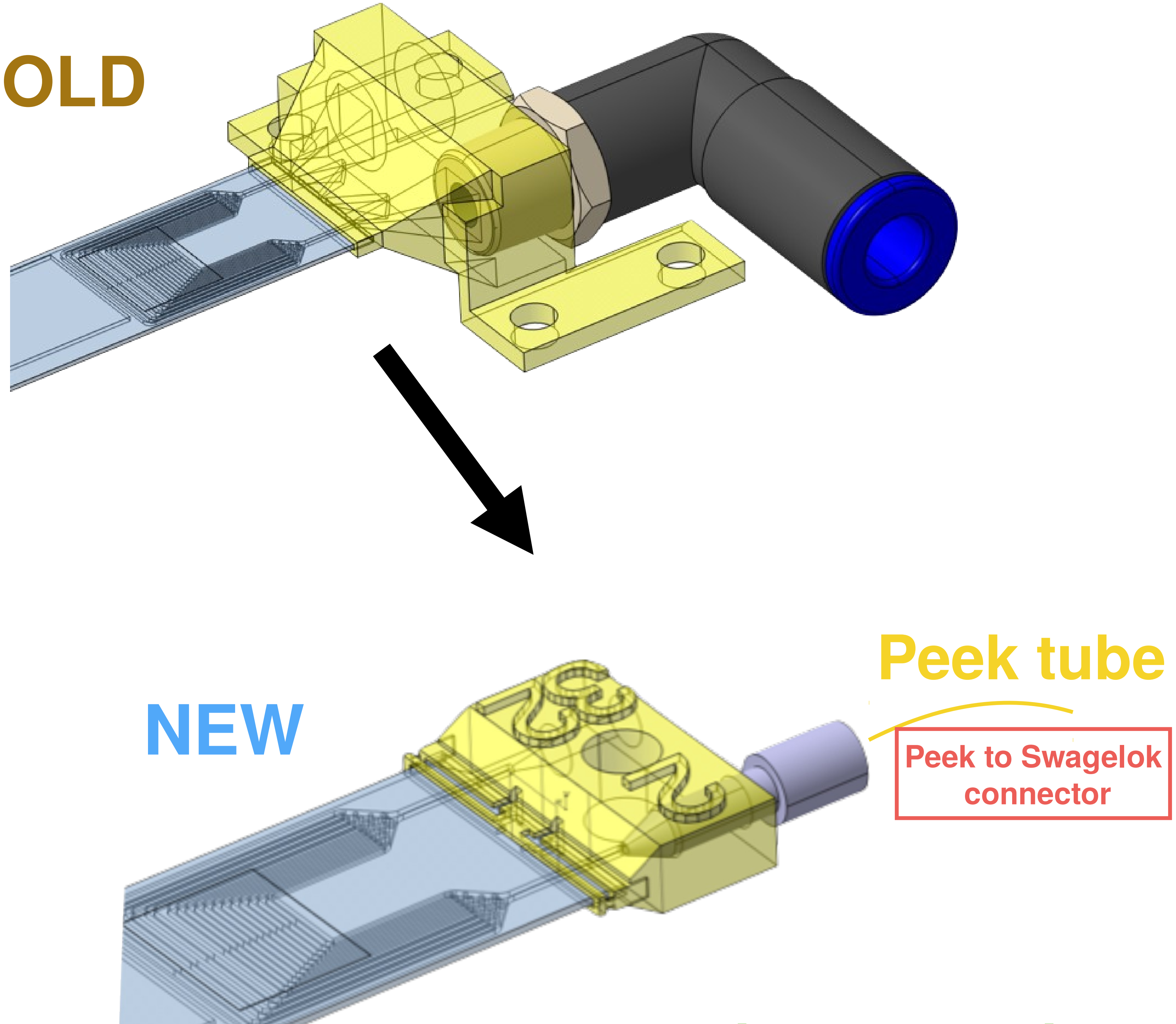
Peak to peak of the signal ~0,1 µm
RMS ~0,4 µm

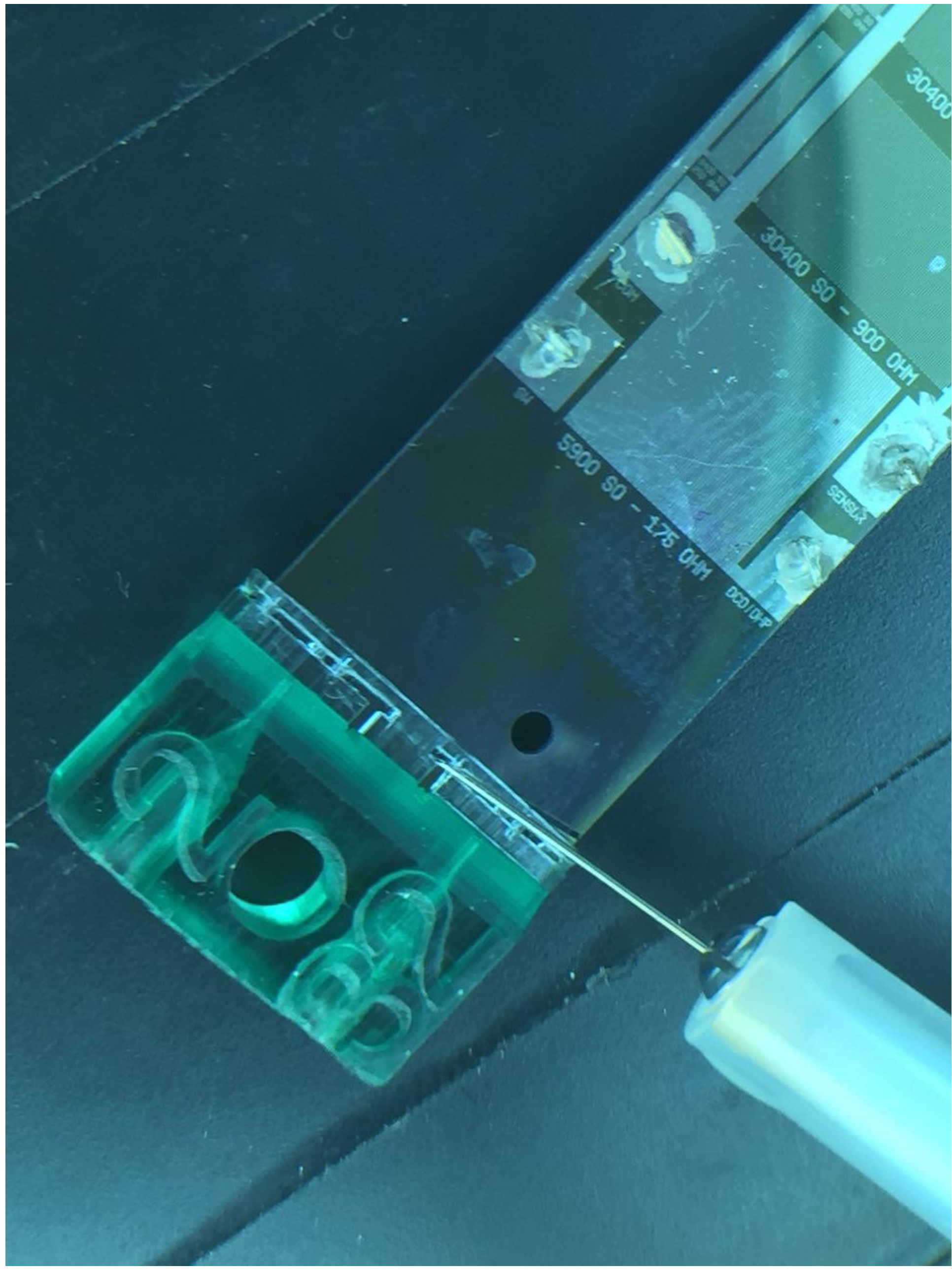
Air flowing 3 m/s

Peak to peak of the signal ~130 µm
RMS ~57 µm

MCC has no significant impact on mechanical stability

Towards a low mass interconnection





Material budget is reduced a factor ~4

1.5% X0 Still largely driven by connector

Conclusions

Measurements on mock-up and mechanical samples confirm that the combination power pulsing + air cooling can be made to work if care is taken to limit the air flow to several m/s

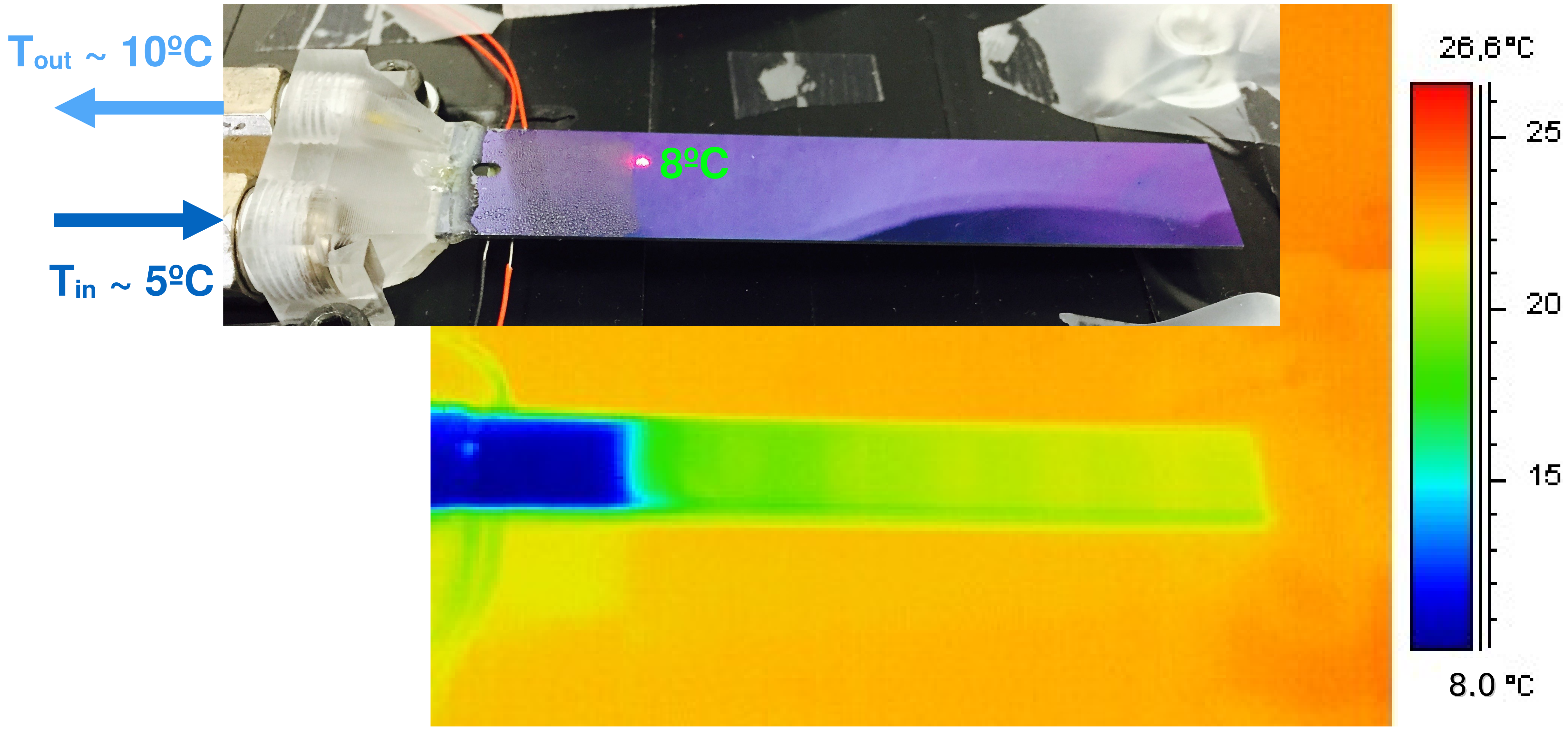
To be done: impact of the B-field, long term stability, viable way to set up air flow

For localized power dissipation, **up to many W/cm²** with, a minimalistic micro-channel cooling (mono-phase, low pressure) can provide excellent control and a modest temperature increase (10ºC)

To be done: miniature connector

Thank you for your attention

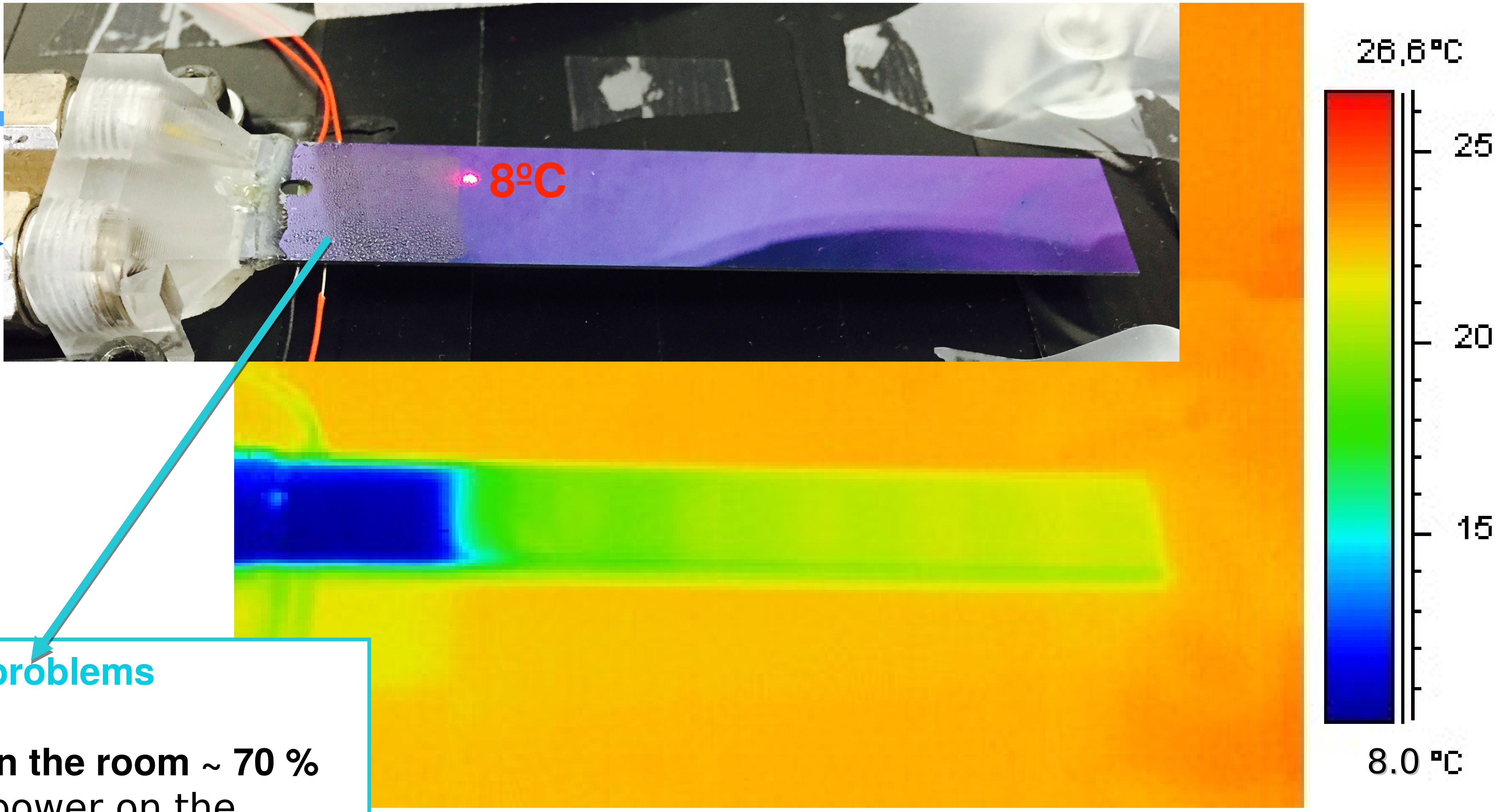
Thermal measurements: cold water



Thermal measurements: cold water

T_{out} ~ 10ºC

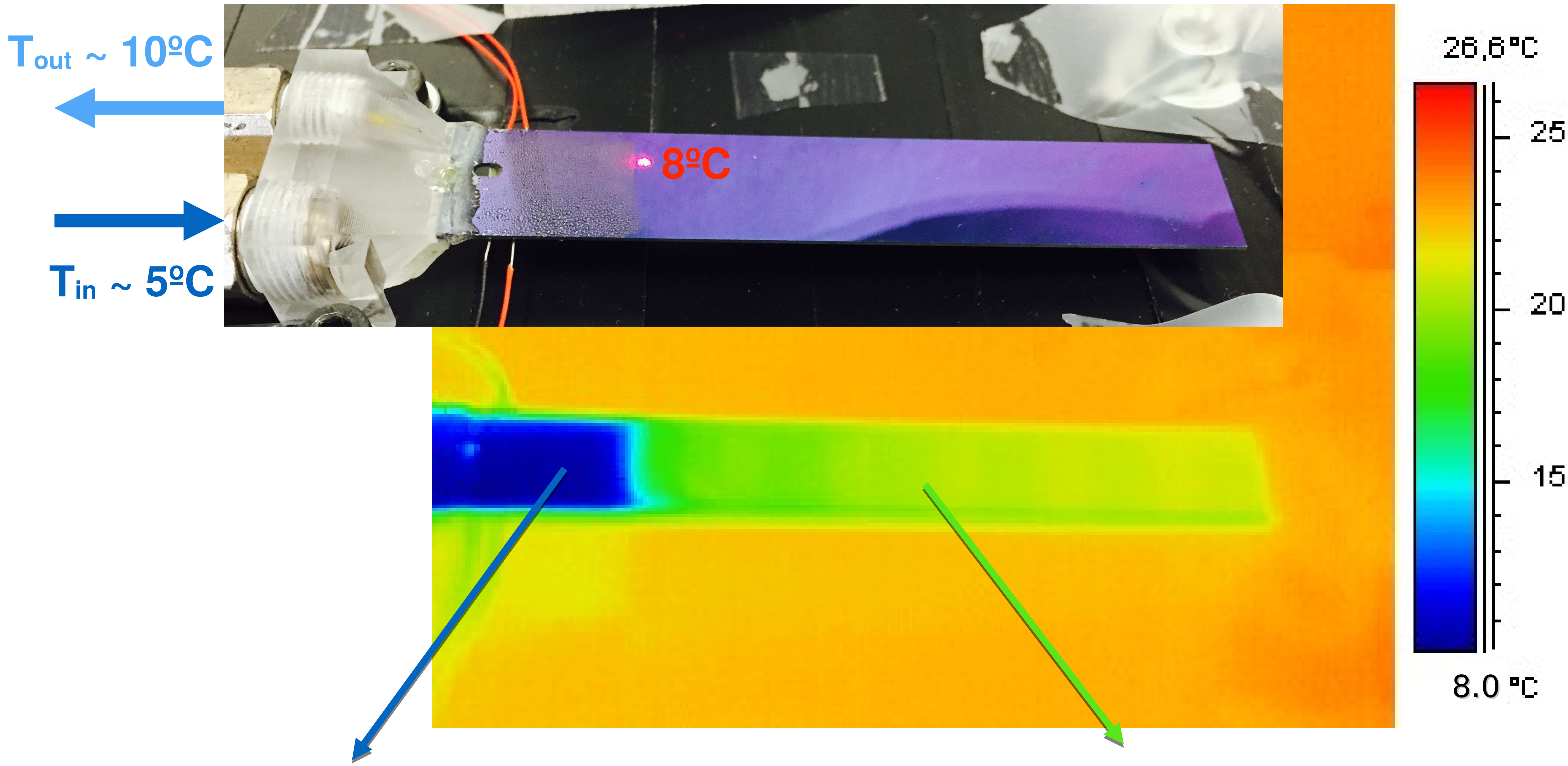
T_{in} ~ 5ºC



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)

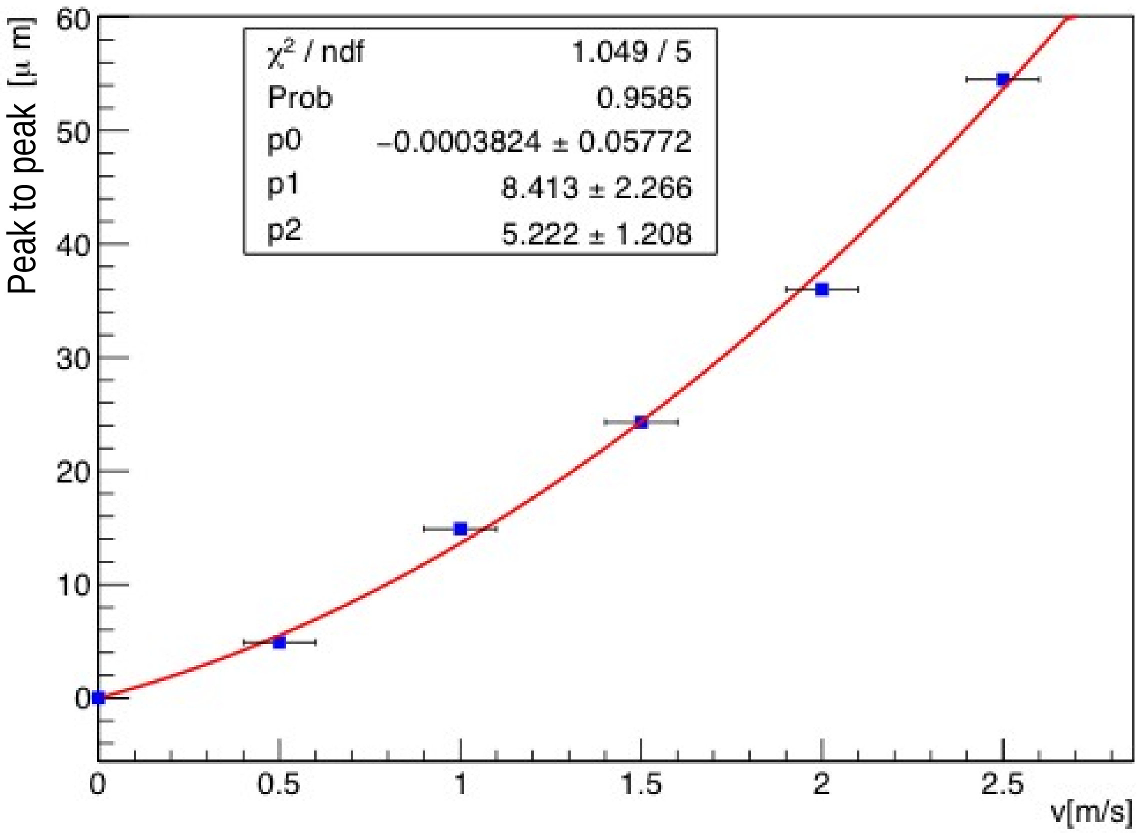
Thermal measurements: cold water



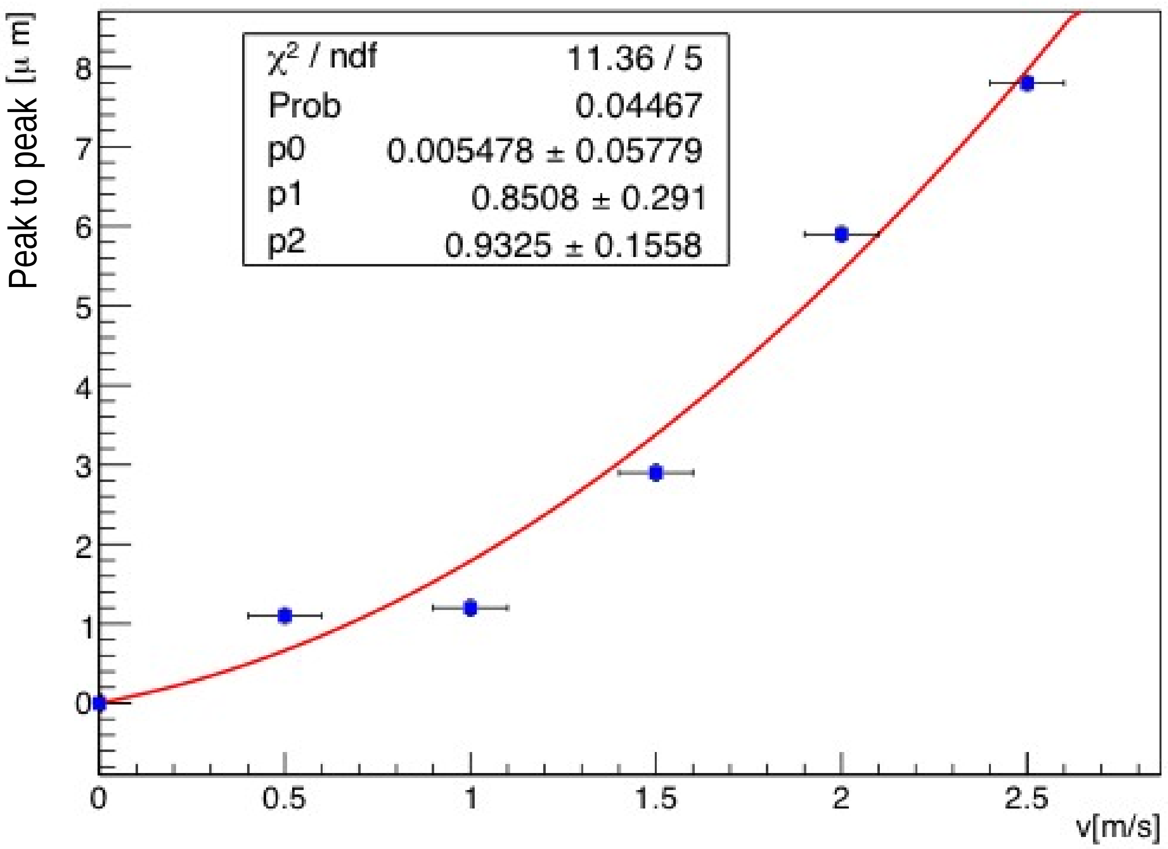
MCC region is cooled 18ºC below T_{Room}

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

Amplitude vs v_{air}



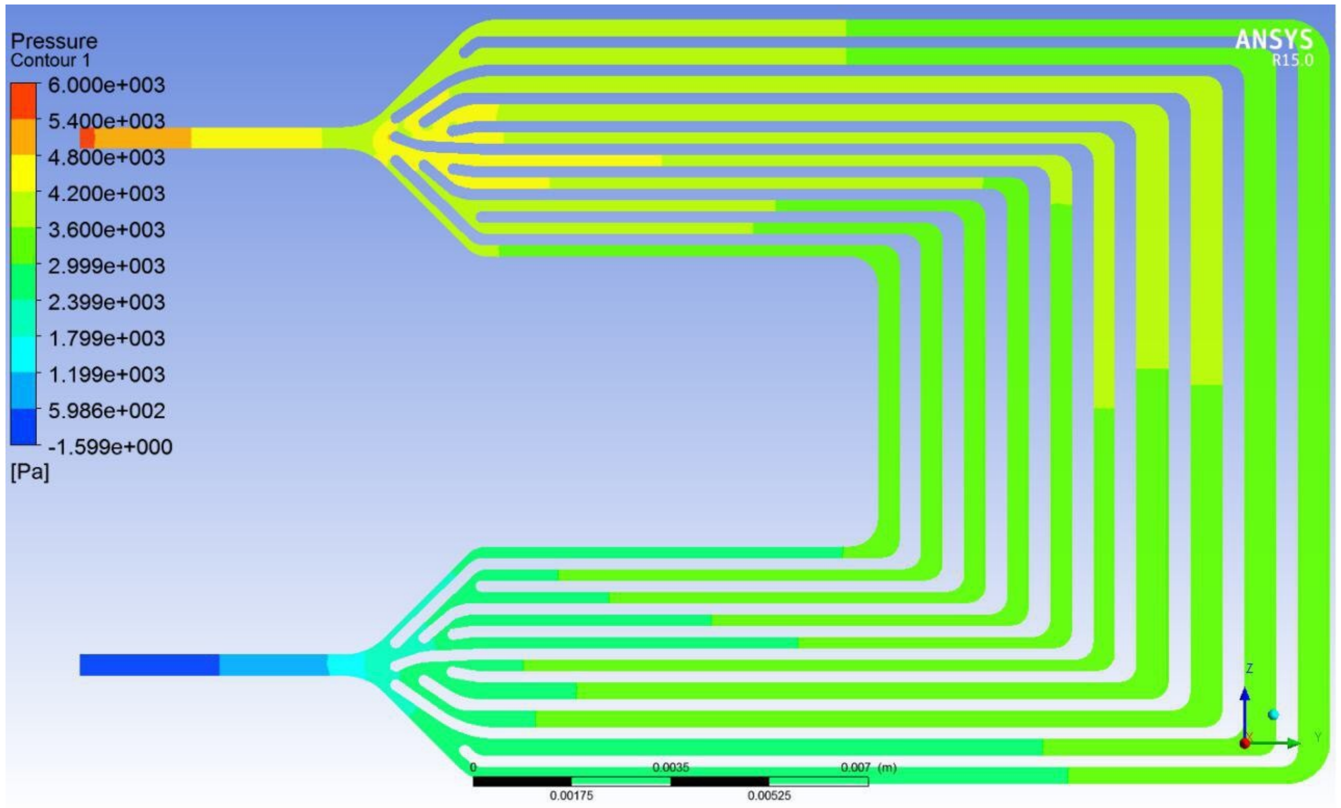
Clamped-Free



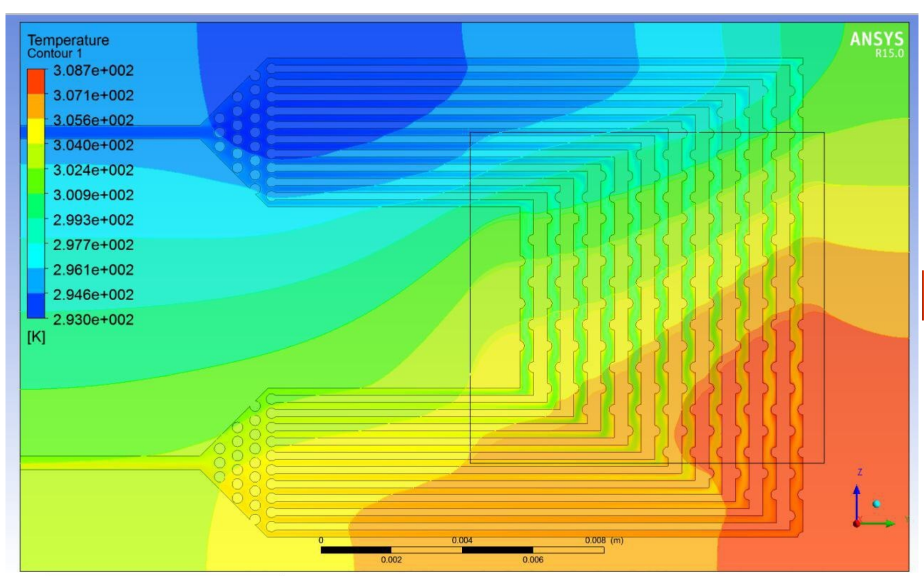
Clamped-Clamped

- *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**

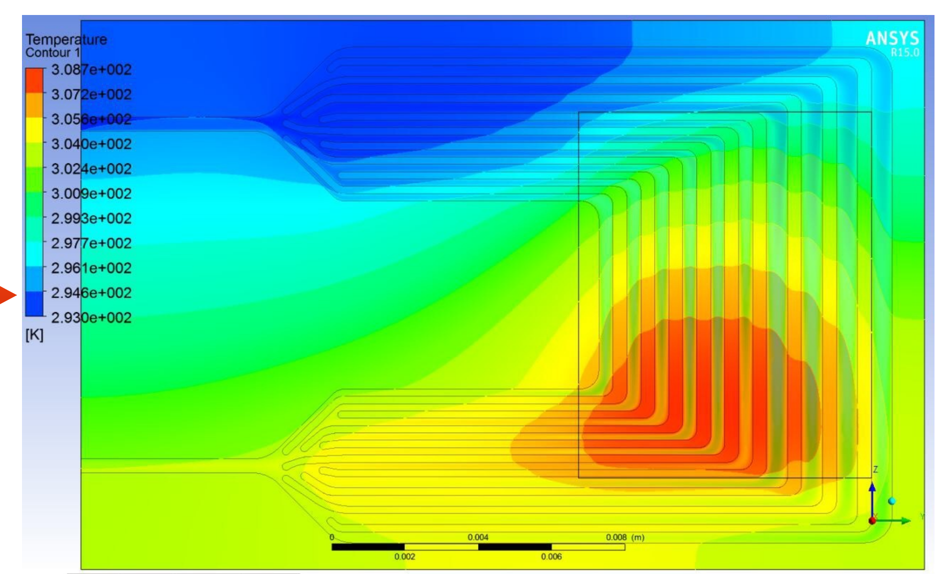
Optimized MCC geometry



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



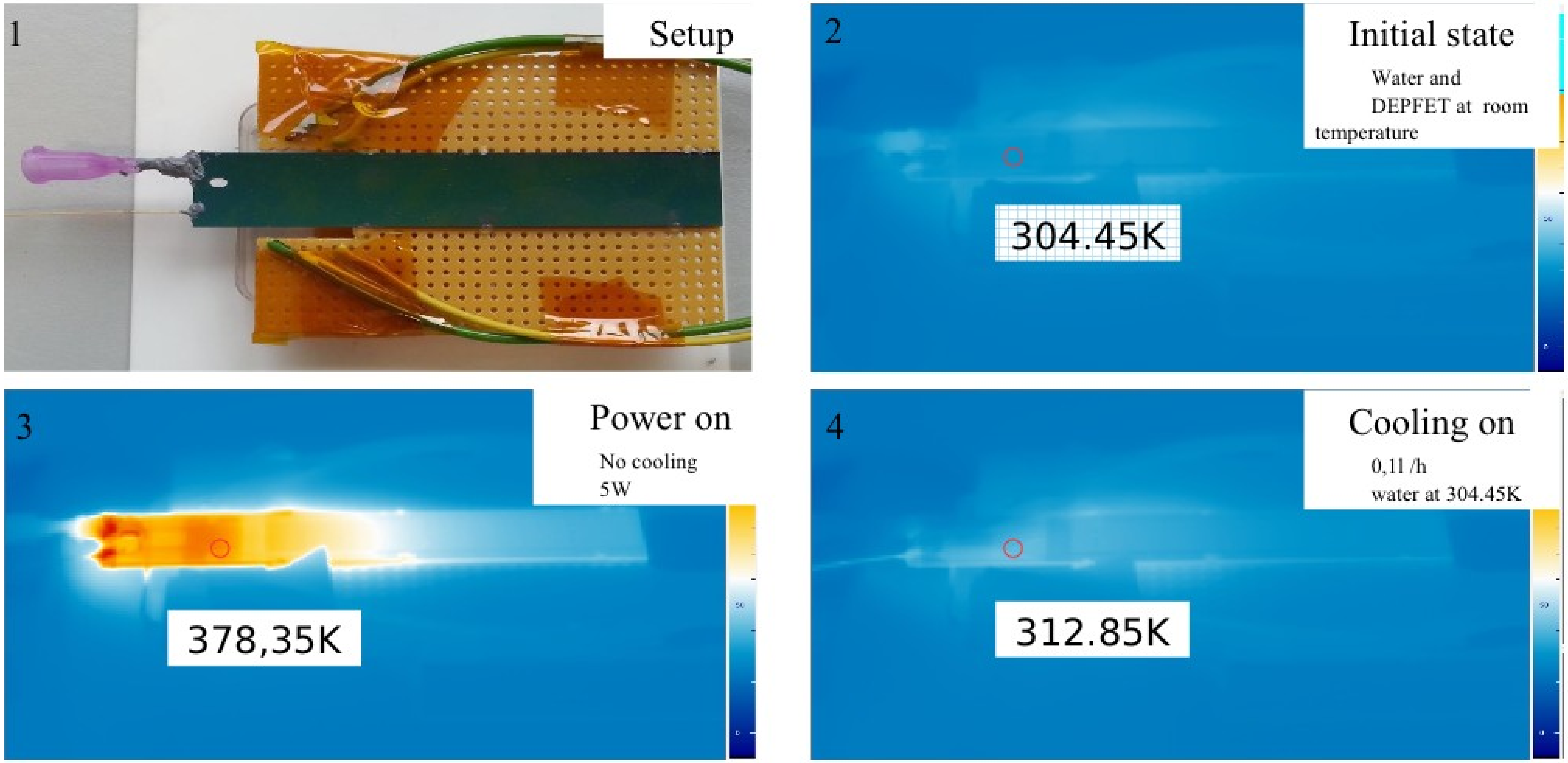
Recent geometry



Optimized geometry

Micro-channel Cooling

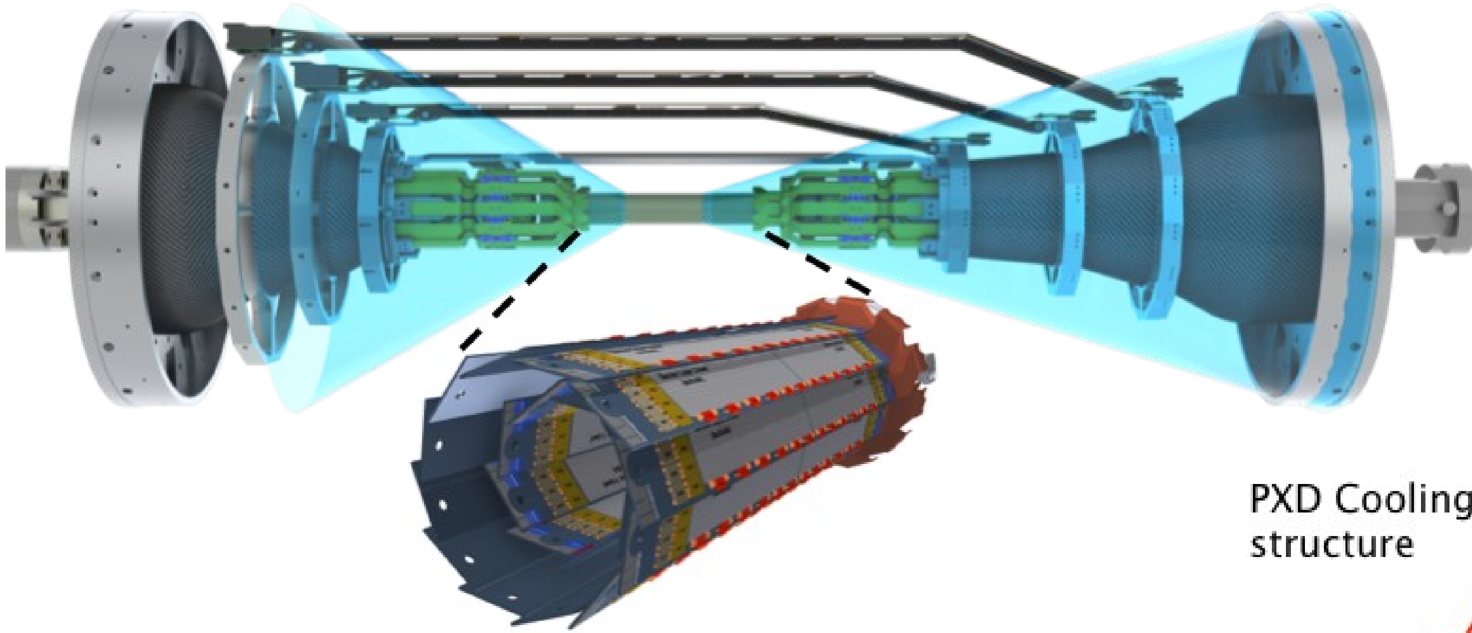
Tests made: 5W and water cooling



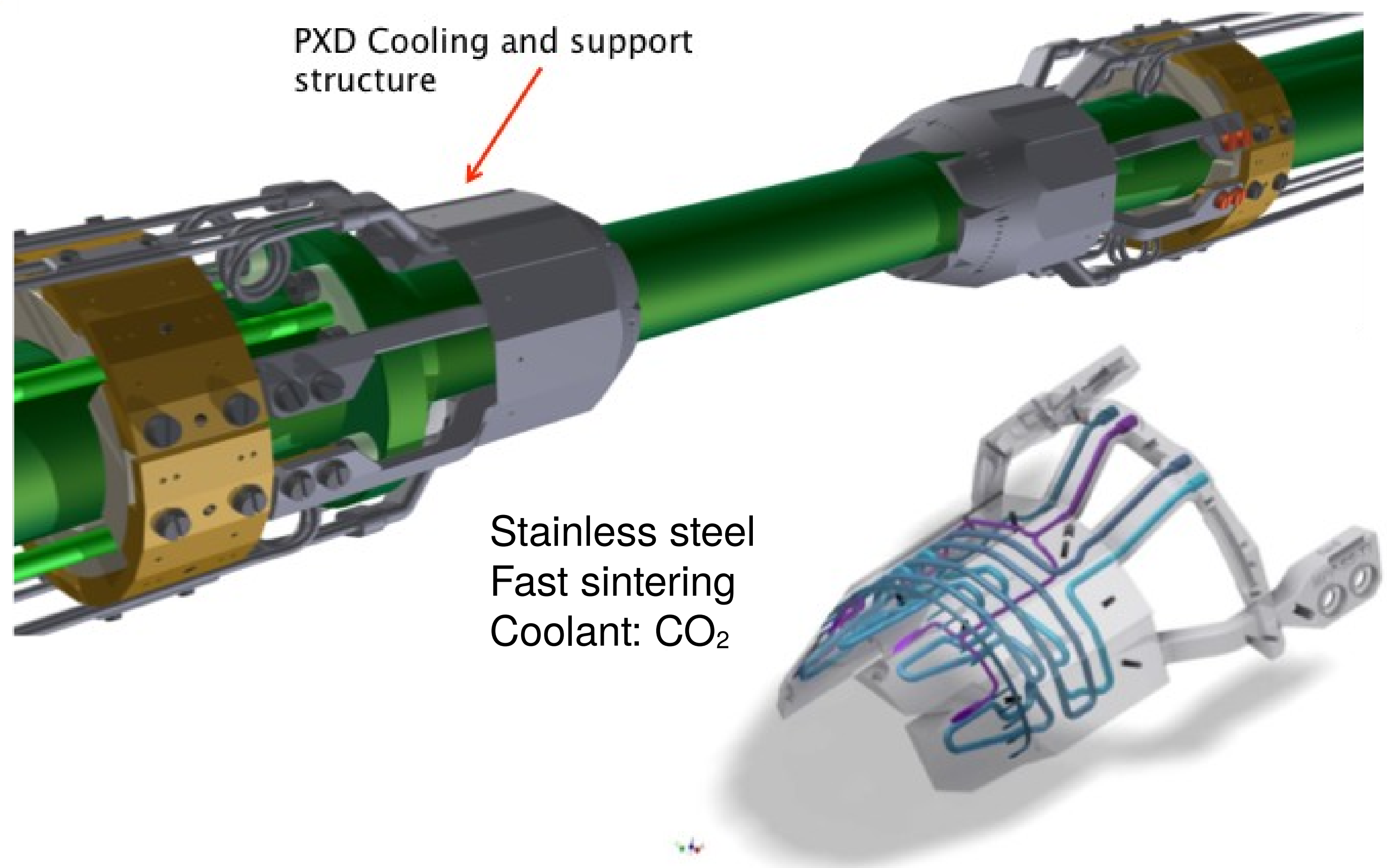
As shown first measurements, MCC with a flow of 0.1 l/h offers promising results

LCWS 2014 Belgrade: https://agenda.linearcollider.org/event/6389/session/4/contribution/172/material/slides/0.pdf

Cooling strategies



Belle II



Massive structures outside the acceptance to cool down the readout chips

Stainless steel
Fast sintering
Coolant: CO_2