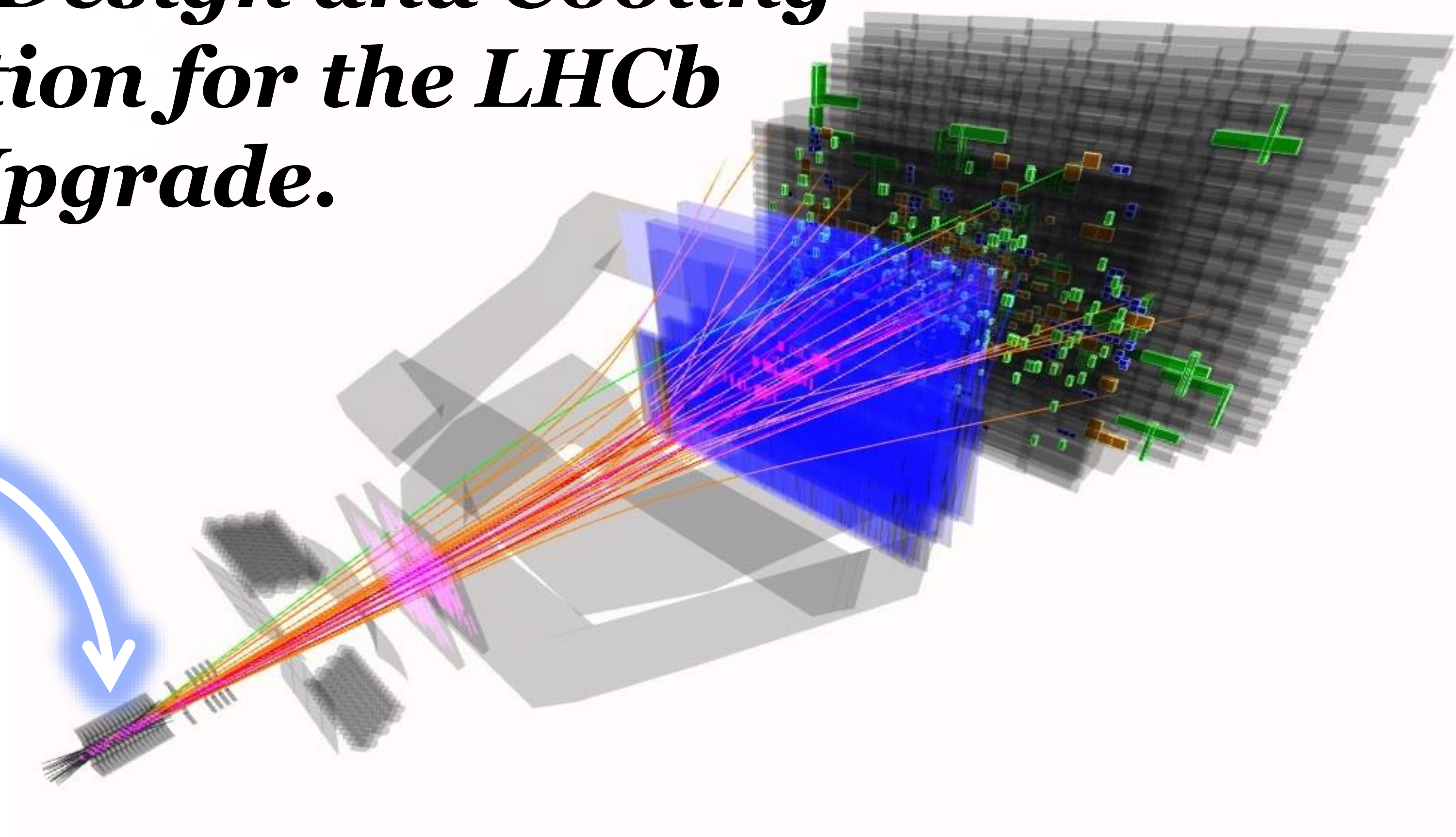
Module Design and Cooling Integration for the LHCb VELO Upgrade.



Wiktor Byczyński on behalf of the VELO group

Forum on Tracking Detector Mechanics
Marseille 2017

EP-DT
Detector Technologies

Outline

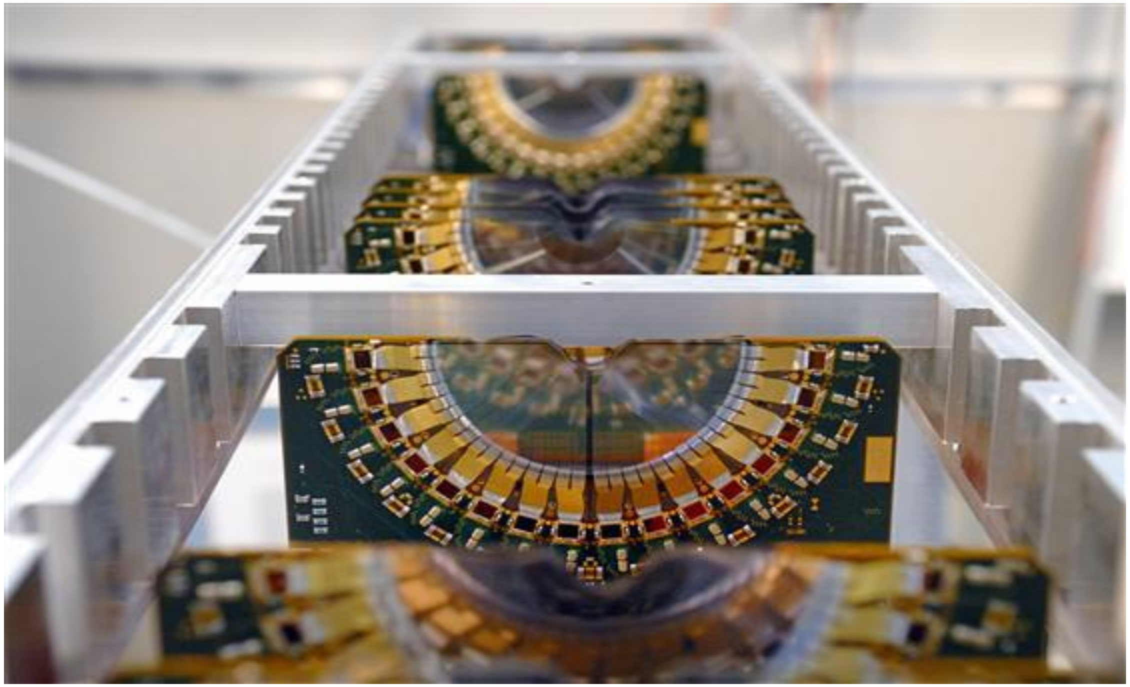
Introduction:

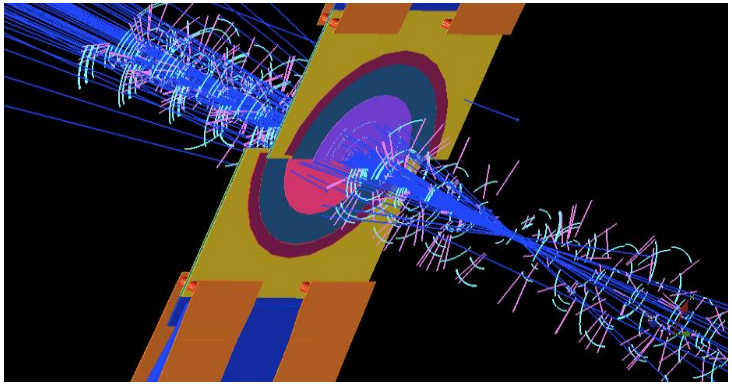
- **Current VELO and Upgrade:**
  - **Module Design**
  - **Cooling substrate:**
    1. **Microchannels:**
       - **Design**
       - **Attachment of the fluidic connector**
       - **Reliability tests of the solder joint**
       - **Fluidic characterization**
       - **Boiling stability**
    2. **Alternative plan: Ceramic substrate**
       - **Design**
       - **Constraint system**
       - **Fluidic characterization**

Conclusion

Current VELO Detector

VELO:
- **Vertex reconstruction and tracking**
- **88 Si-strip sensors surrounding the interaction point**
- **Modules are moved away during the beam injection**
- **Excellent impact parameter resolution (down to 11.6 [μm])**
- **Excellent single hit resolution ~4 [μm]**
- **~16.5[W/module]**

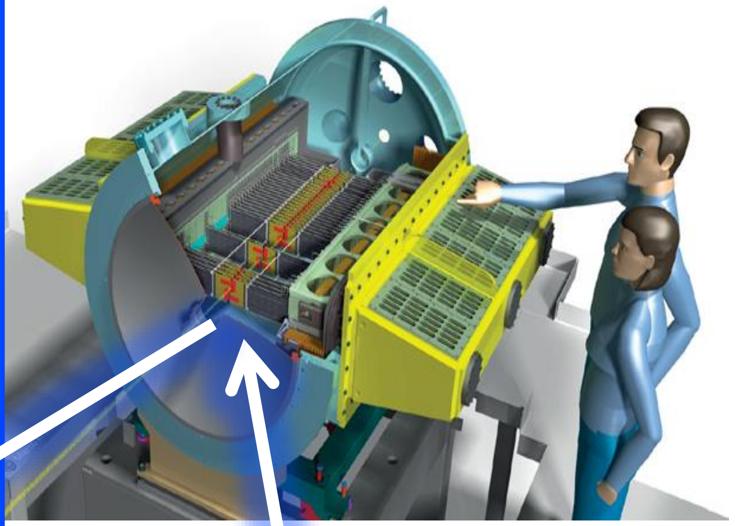


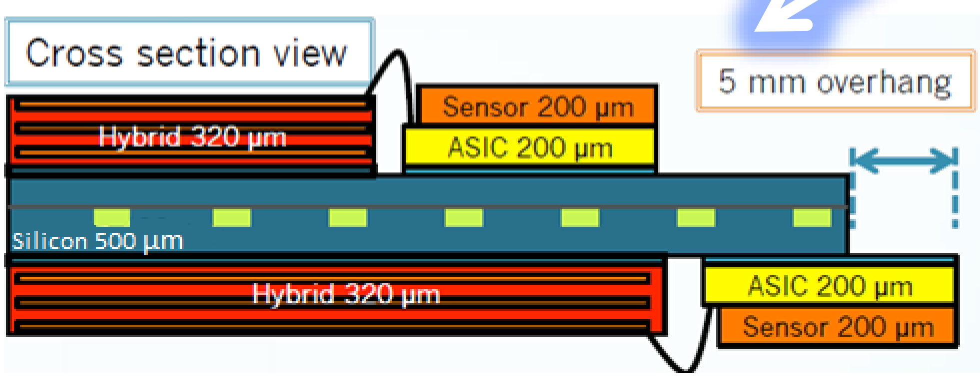


Performance of the LHCb Vertex Locator - arXiv:1405.7808

New VELO Detector

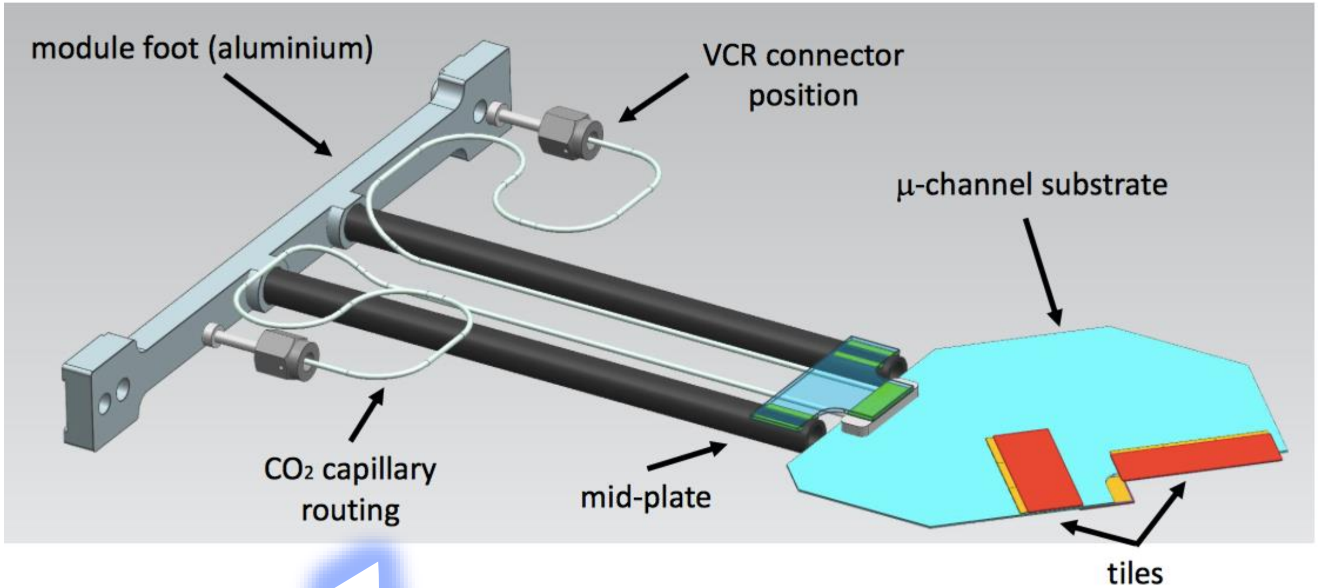
- The closest distance to LHC beam will be 5.1 mm (down from 8.2 mm).
- Very high ($8 \times 10^{15} n_{eq}/cm^2$ for 50 fb^{-1}), non-uniform radiation ($\sim r^{-2}$)
- Huge data bandwidth: up to ~15 Gbit/s for central ASICs and 2.9 Tbit/s in total.
- Sensor temperature < -20°C (CO_2 @ -30°C)
- Total maximum power dissipation/module is ~30 W.
- Minimal material: cooling substrate is retracted 5 mm at the inner region.

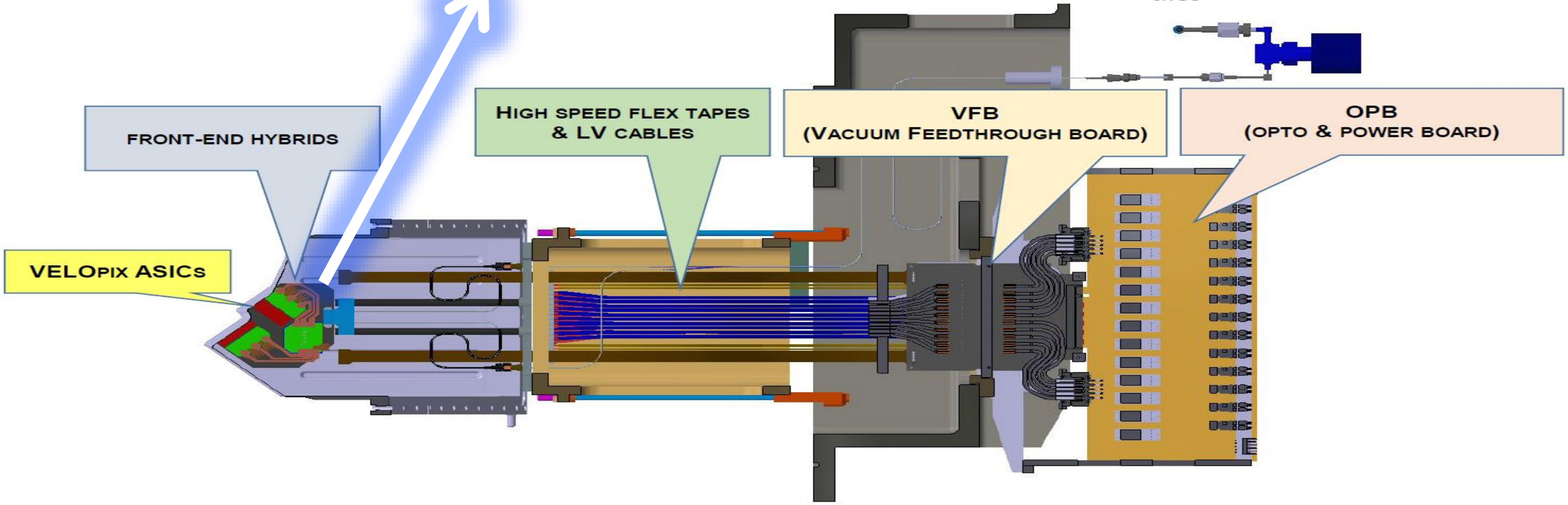




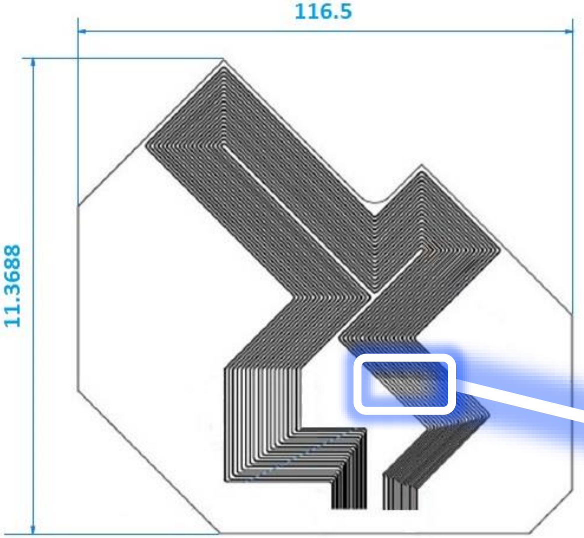
52 Modules (26 per side)

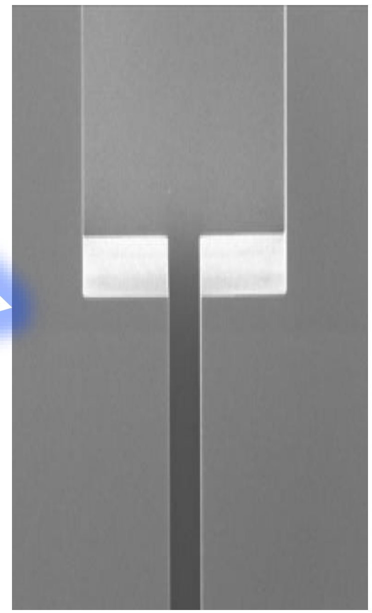
Module design



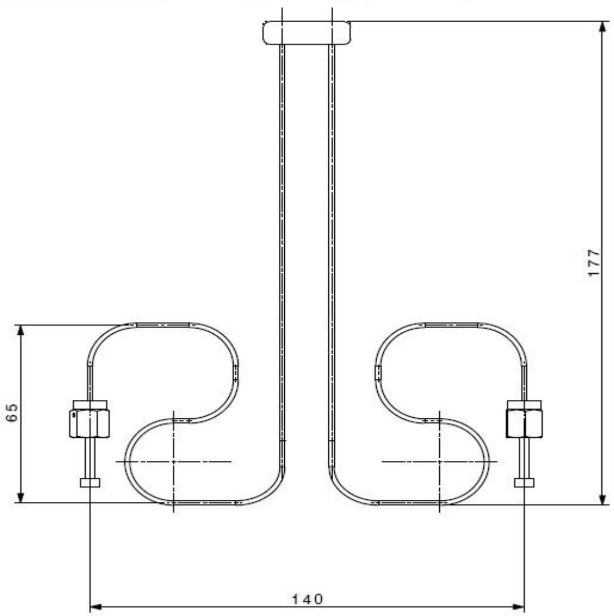


Silicon microchannel substrate design



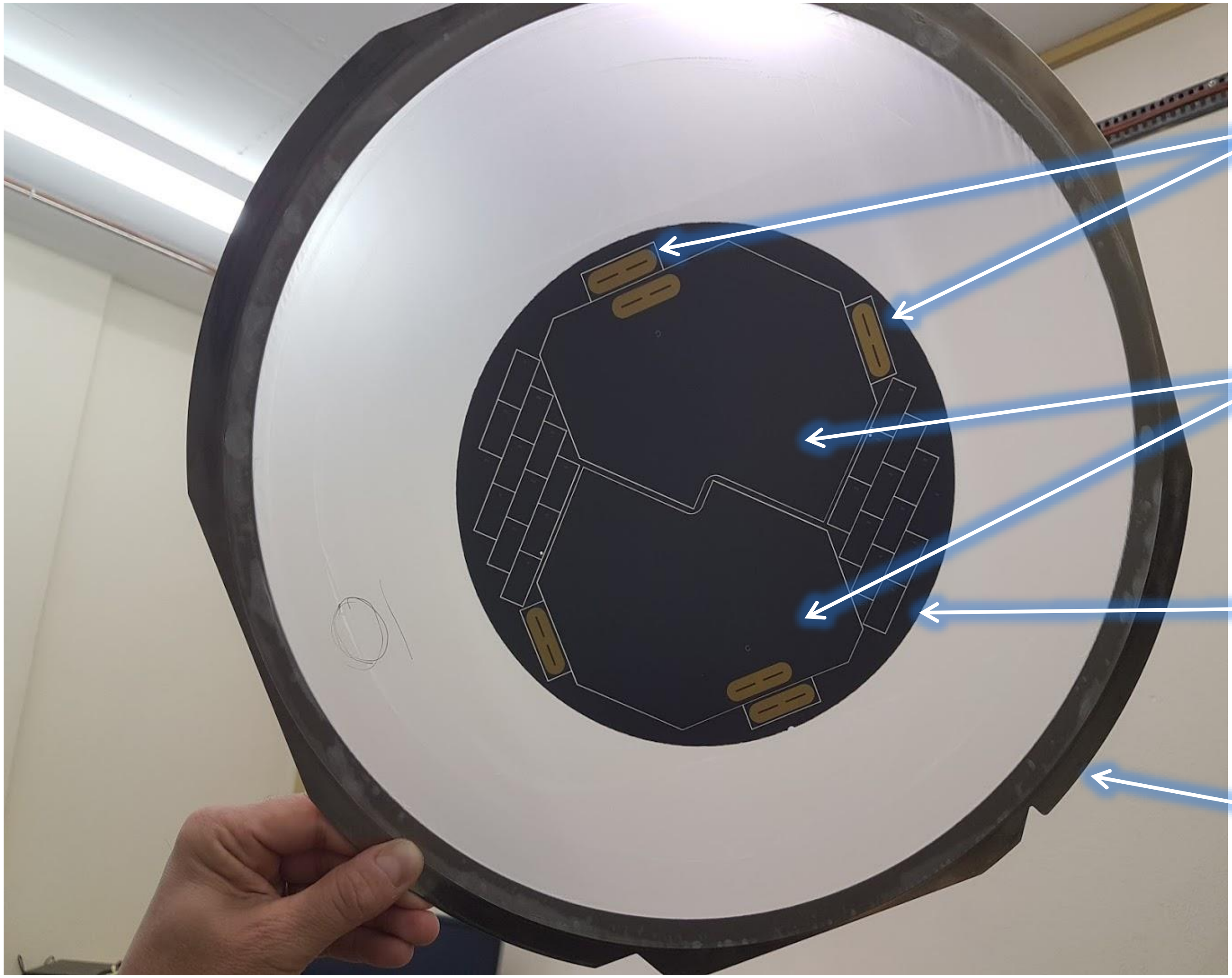


Channel	Restriction length [mm]	Main channel length [mm]
1	40.00	230.86
2	40.00	234.28
3	40.00	237.70
4	40.00	241.11
5	40.00	244.53
6	40.00	247.95
7	40.00	251.36
8	40.00	254.78
9	40.00	258.20
10	40.00	261.61
11	40.00	265.03
12	40.00	268.45
13	40.00	271.87
14	40.00	275.28
15	40.00	278.70
16	40.00	282.12
17	40.00	285.53
18	40.00	288.95
19	40.00	292.37



- **Silicon thickness - 500 [μm]**
- **Main Channel 120 [μm] x 200 [μm]**
- **Restriction 60 [μm] x 60 [μm]**

Silicon microchannel substrates



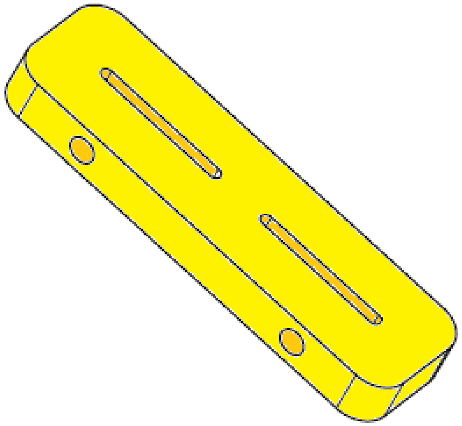
Metallization samples

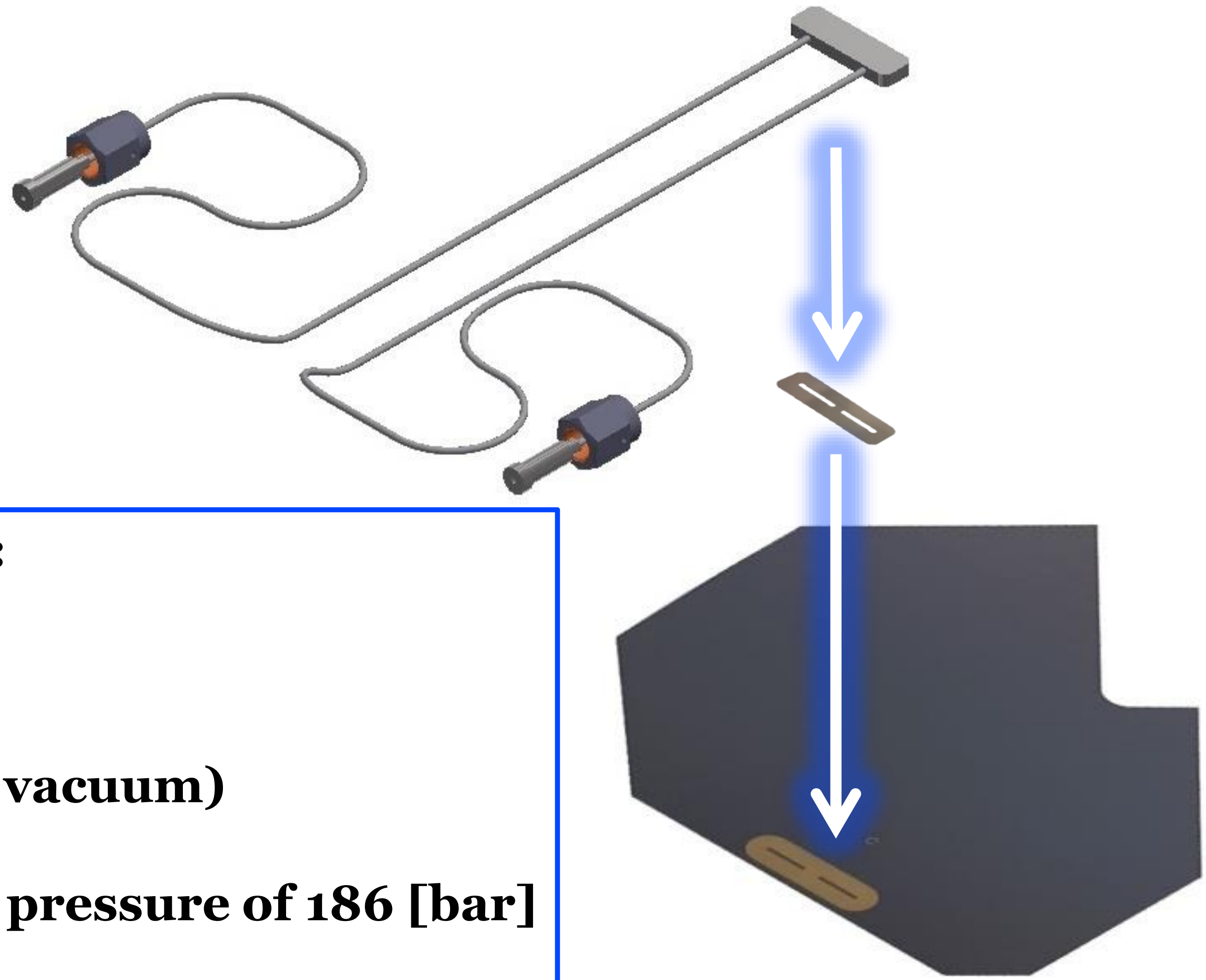
Silicon microchannel substrates

Silicon Wafer 8”

Transport ring

Soldering Fluidic Connector

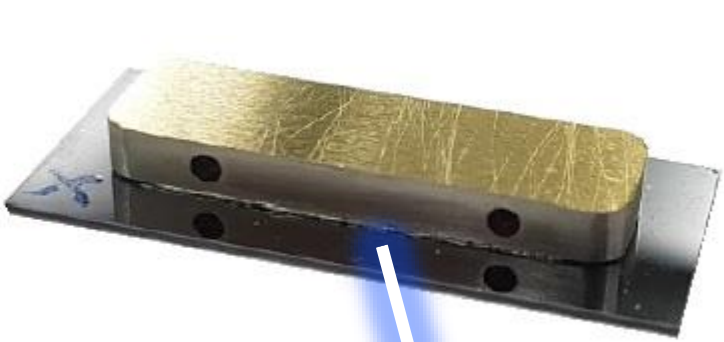


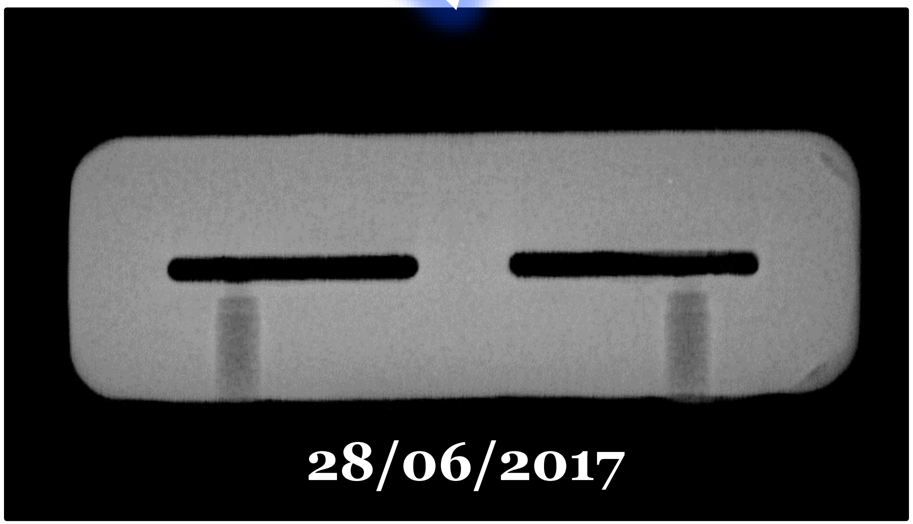


Joint Requirements:

- **Reliable**
- **Leak tight (under vacuum)**
- **Able to withstand pressure of 186 [bar]**

Soldering Fluidic Connector Results





X-ray result of the solder joint in small sample

Full size – dummy substrate

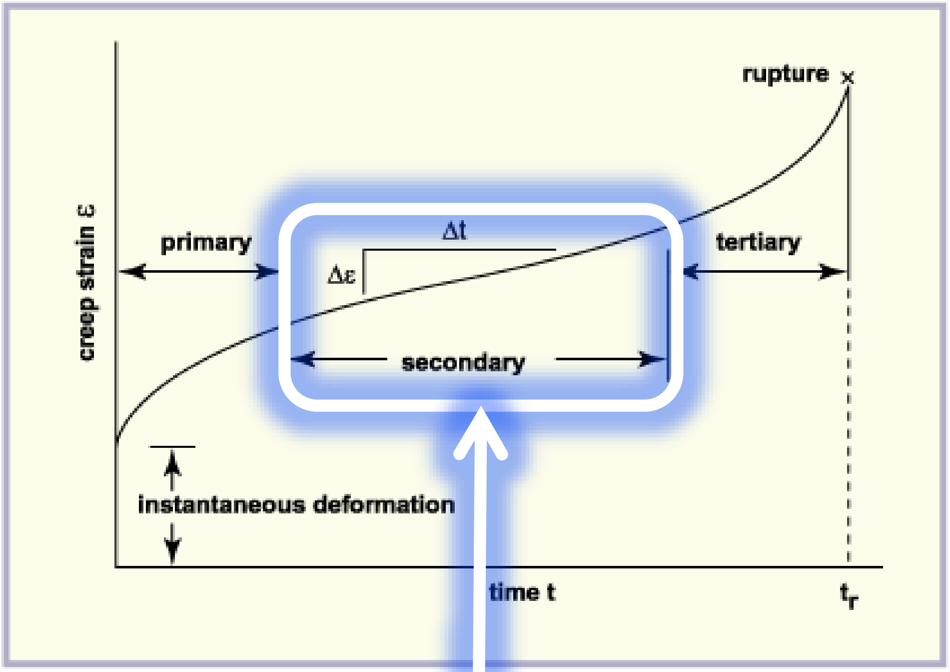
Creep effect in the solder joint

"Plastic deformation of a material at very low mechanical stress levels".

- Present in many materials.
- Stress can be caused by its own weight (e.g. glaciers or glass windows).
- Can lead to failure after long time.
- Typically can be neglected only if:

  Temperature < T-critical

  T-critical = 50% of absolute melting Temperature.
- For SnPb: T-critical = - 46 [°C].
- VELO should be at - 30 [°C], so expect very small creep effects.



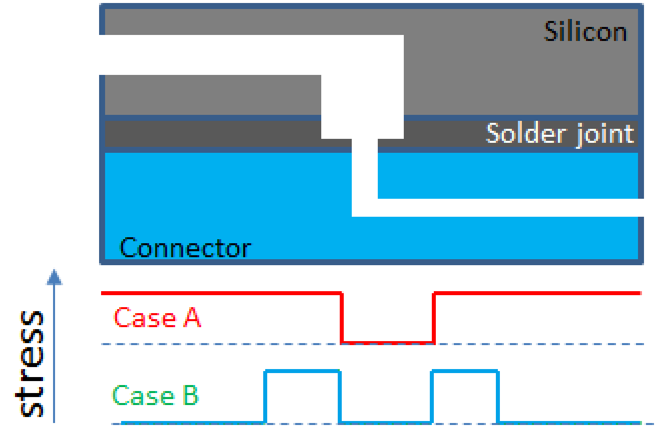
Models exist for linear (secondary) region :
e.g. ***"A new creep constitutive model for eutectic solder alloy."*** Shi, Wang, Zhou, Pang, Yang , 2002. Transactions of the ASME page 84, Vol124, June 2002.

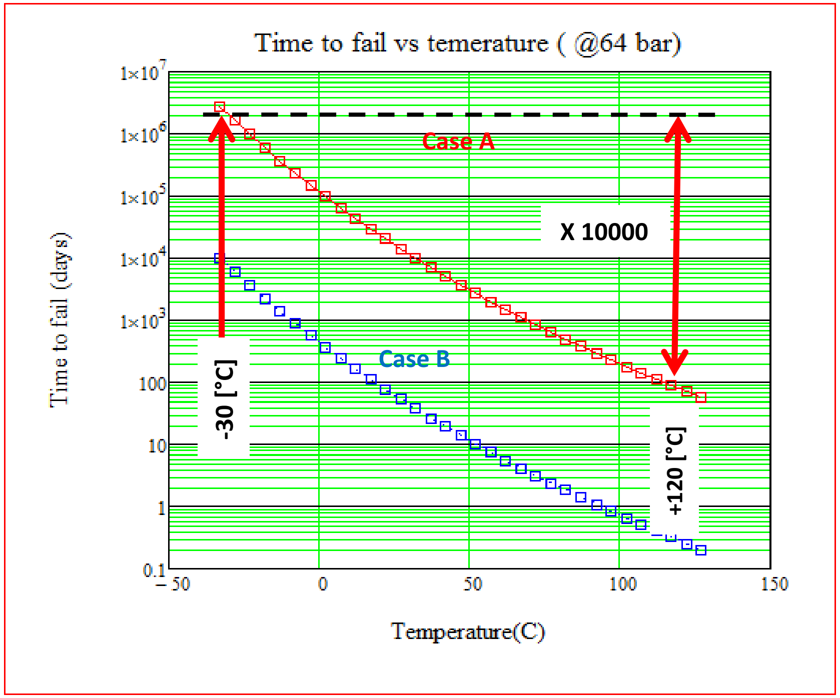
CO_2 pressure at -30 [°C] ~20 [bar]

Creep effect in the solder joint - simulation

- **Strain rate (=strain/sec) is function of Temperature (T) and stress (τ).**
- **Stress distribution is not well known: assume 2 extreme cases:**
  - **Case A: total force is spread uniformly over soldered surface.**
  - **Case B: total force is highly concentrated near the slits.**

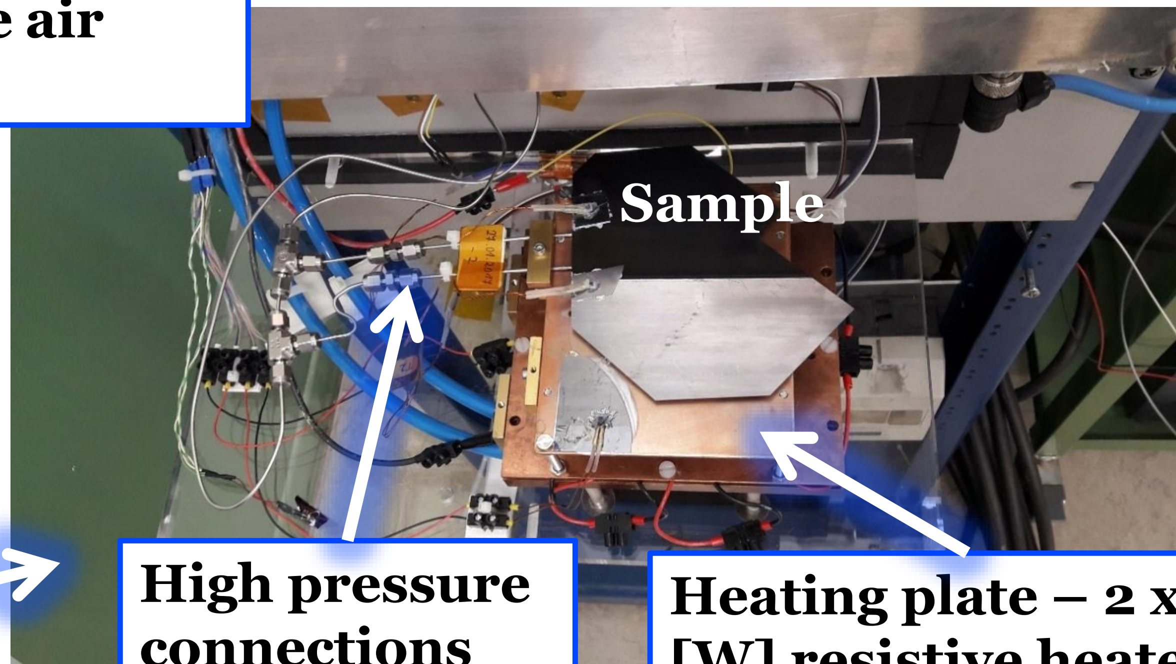
"A new creep constitutive model for eutectic solder alloy." Shi, Wang, Zhou, Pang, Yang , 2002. Transactions of the ASME page 84, Vol124, June 2002.





Creep effect test stand

High pressure air bottle



High pressure connections

Heating plate – 2 x 50 [W] resistive heaters

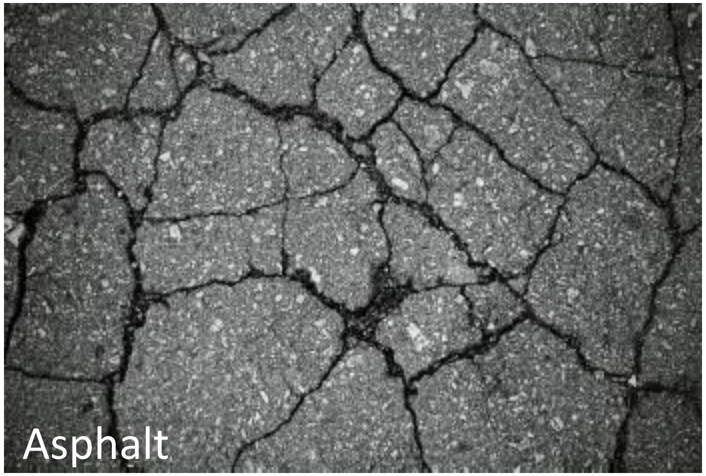
2017:

- 8 samples tested
- Withstand from 50 to 140 [h] (1 hour =~ 1 year)

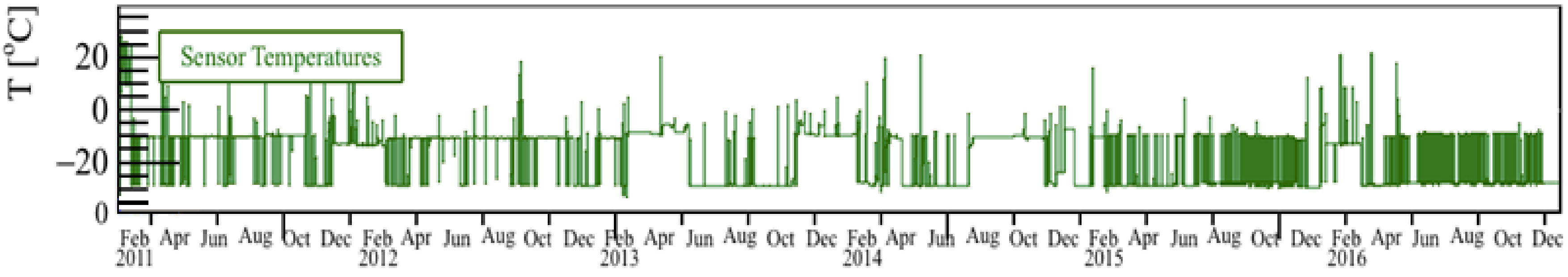
Fatigue effect in the solder joint

"Fatigue is the weakening of a material caused by repeatedly applied loads."

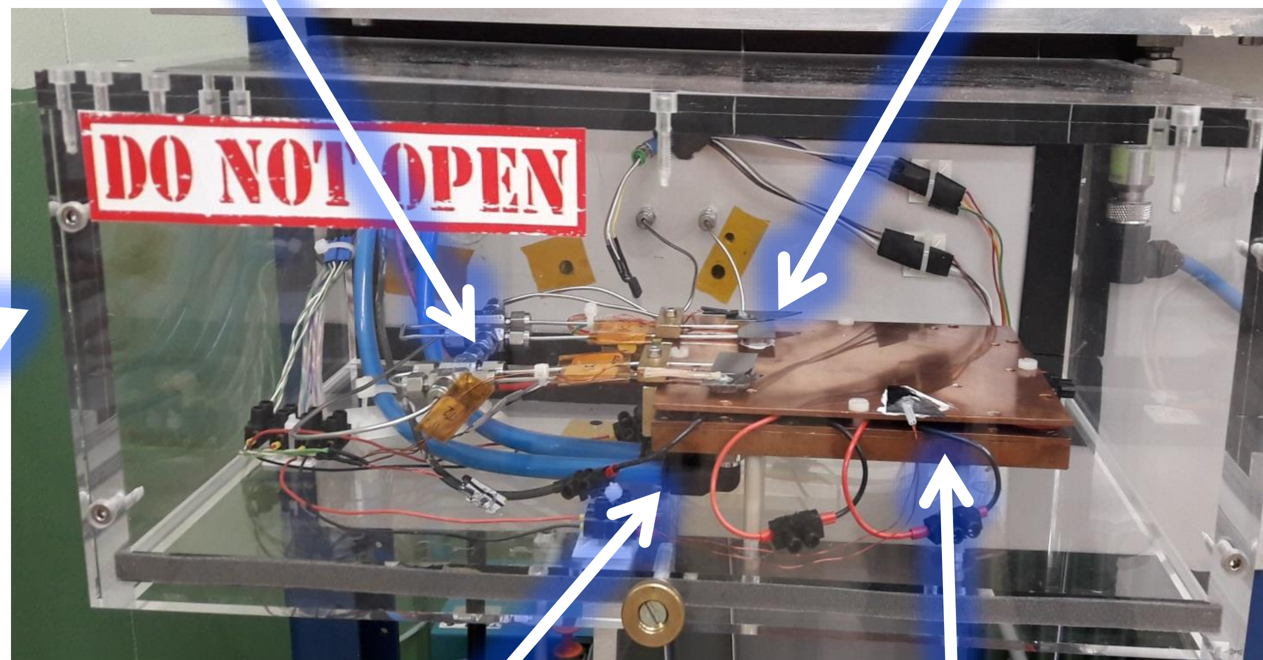
Effect occurs when a material is subjected to repeated loading and unloading.



Current Velo – Few hundred Temperature and Pressure Cycles (300 roughly)



Fatigue test stand



High pressure connections

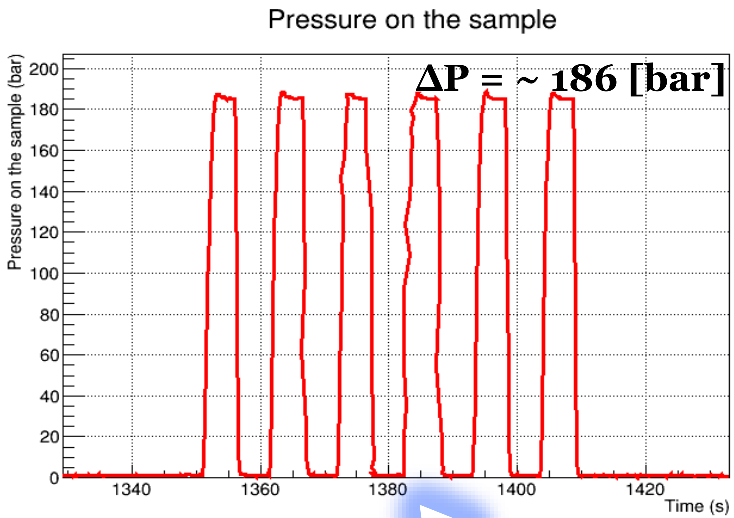
Samples

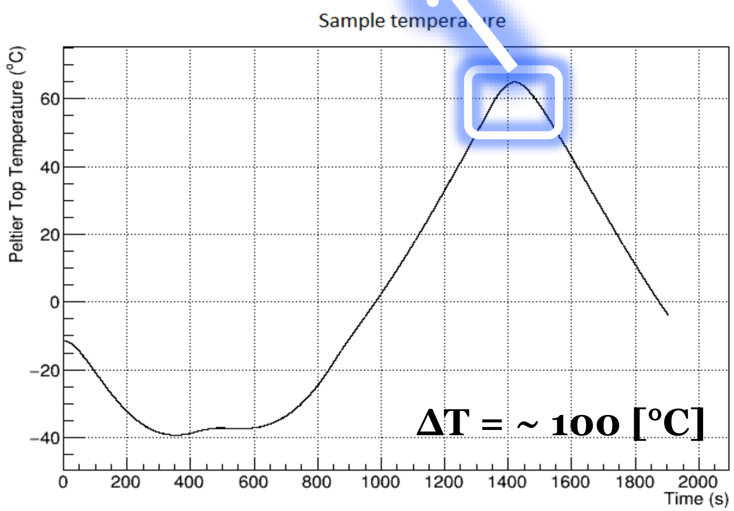
Bottom heat exchanger – glycol flow

Heating/Cooling plate – 6 x 40 [W] Peltiers

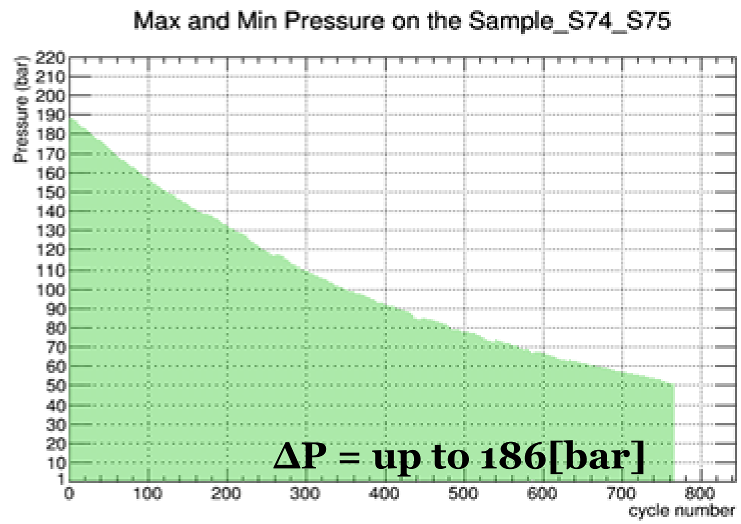
Fatigue test results example

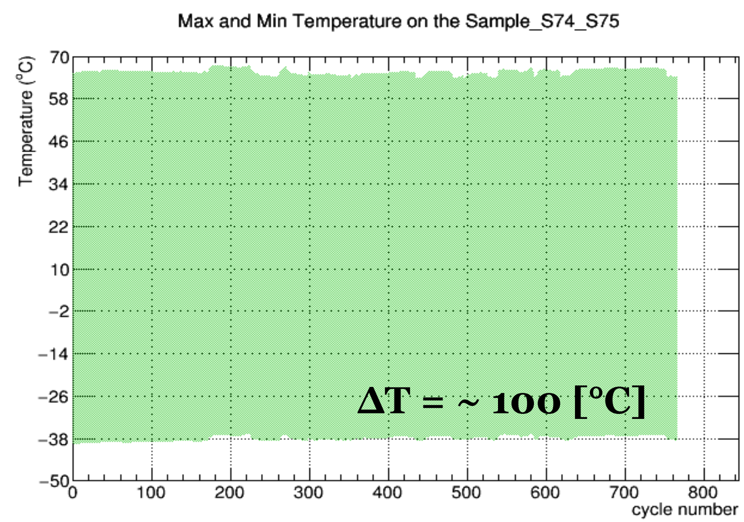
Single cycle



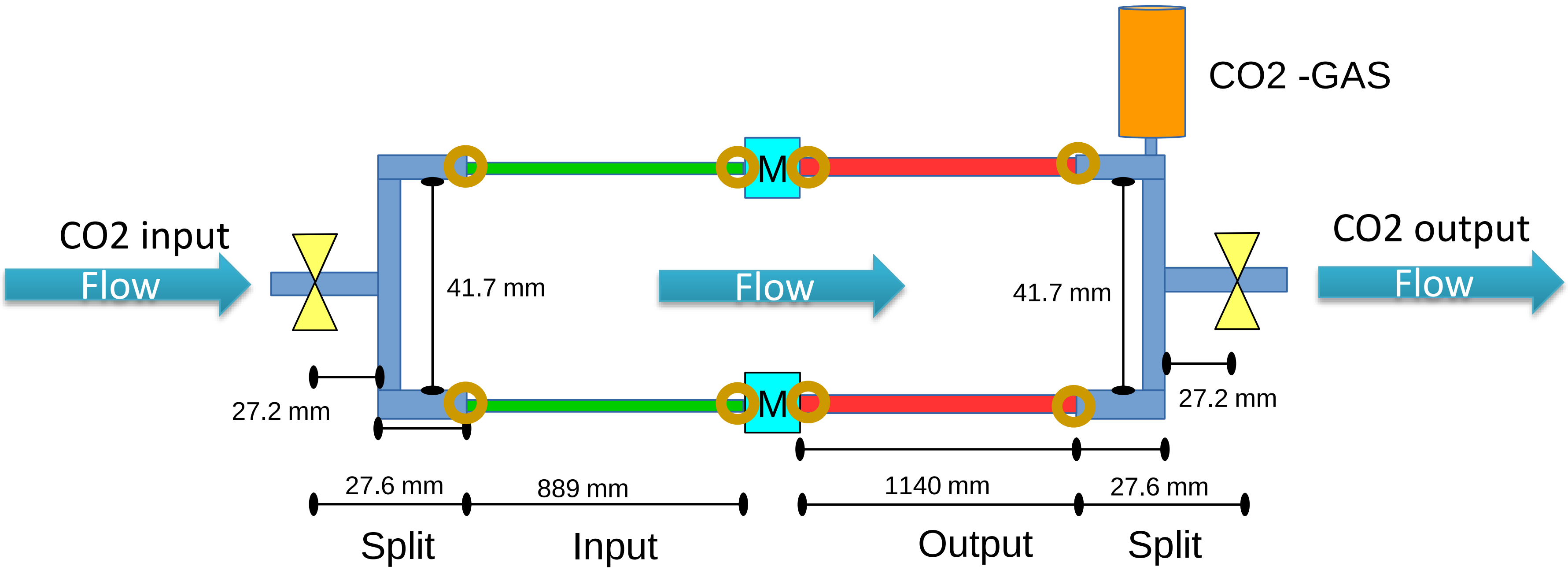


Full test



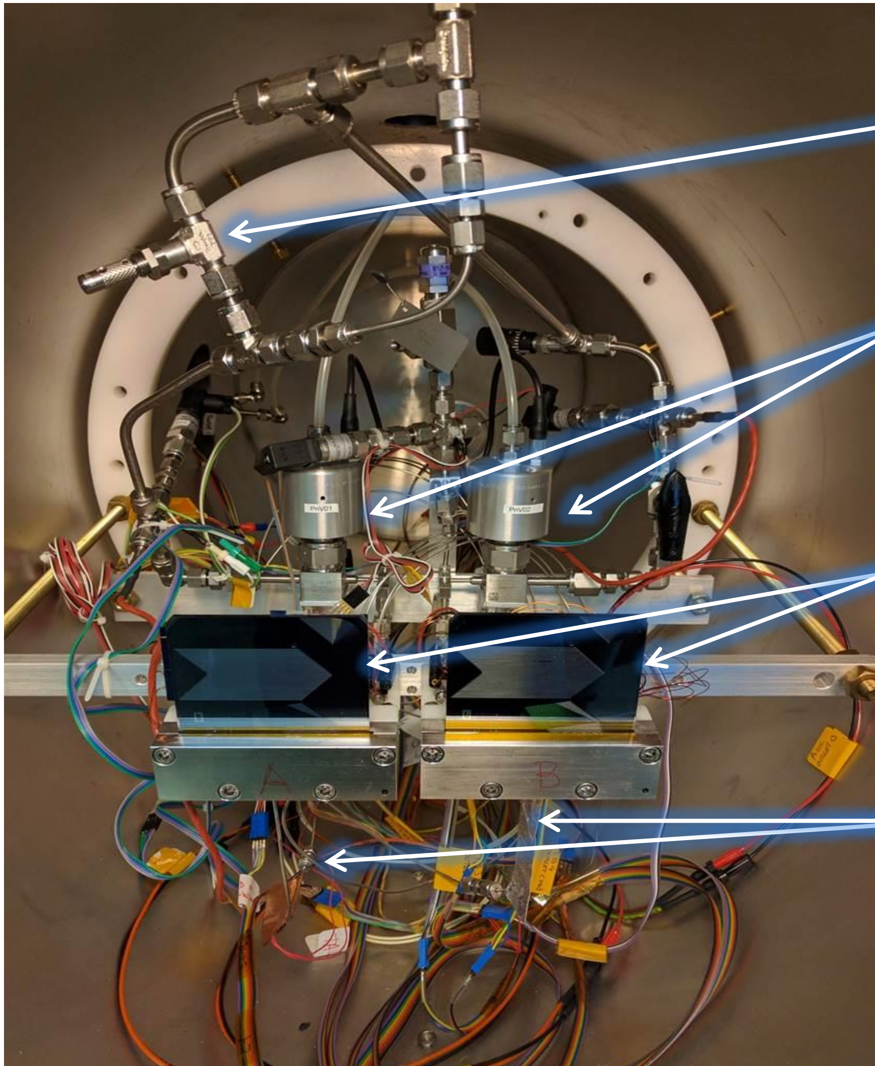


Two microchannels in parallel



- 1/8" (ID 1.397 mm)
- 1/16" (ID 0.5715 mm)
- 1/16" (ID 0.8763 mm)
- 3/8" (ID 6.223 mm)
- VCR connector 1/8" (~5mm)
- 1/2" (ID 9.398 mm)
- Safety volume between the valves
- M Module - 2x320 mm 1/16 " to the connector in the module (Microchannels – Input + output)
- Safety valves (pneumatic)

Fluidic characterization test stand



Vacuum chamber view

Bypass (metering valve)

Safety Valves (pneumatic)

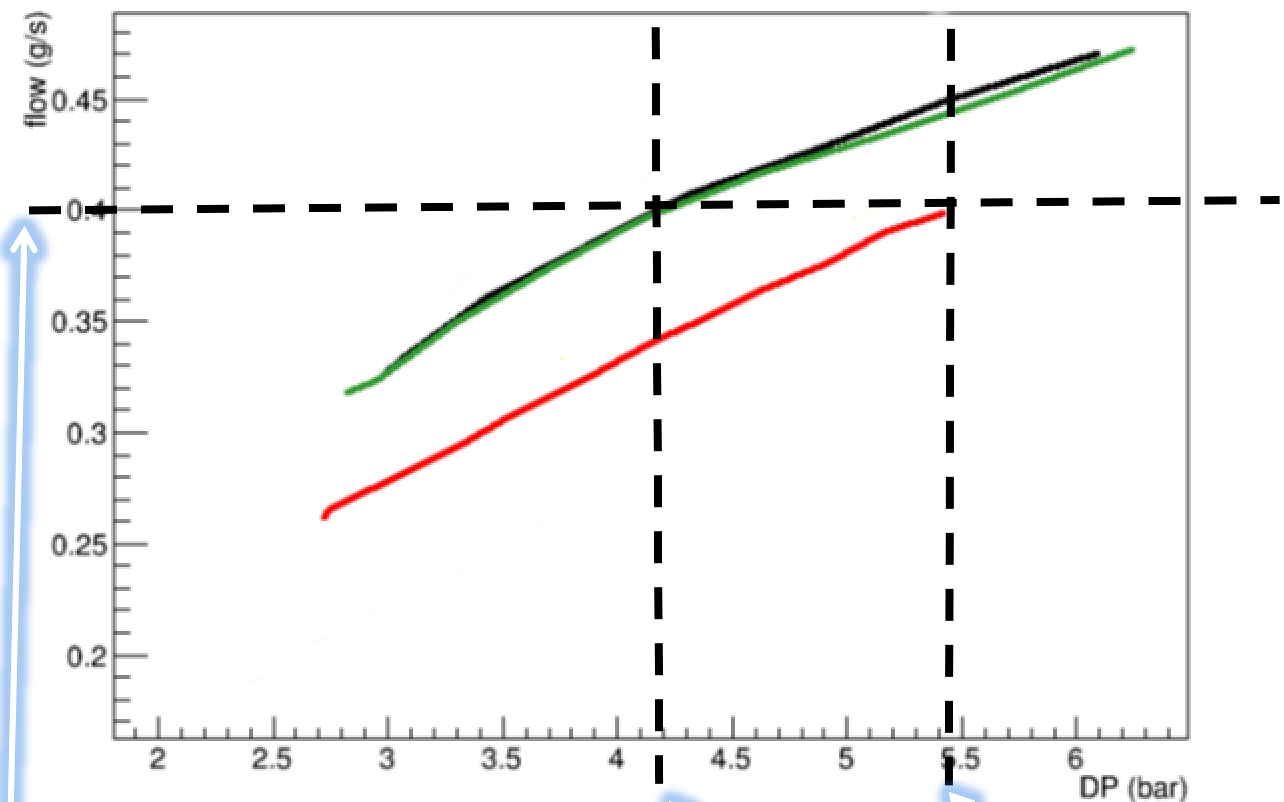
Microchannel substrates silicon/pyrex

Preheaters

Isolated concentric tube

Silicon substrate fluidic characterization

CO2 Temperature -25 [°C]



Applied Power:
0W, (2016)
5W, (2016)
30W, (2016)

Max ΔP = ~5.45 [bar]

0.4 [g/s] - nominal flow

Min ΔP = ~4.2 [bar]

Flow stability test

There should be no interplay between the two modules in the same cooling loop.

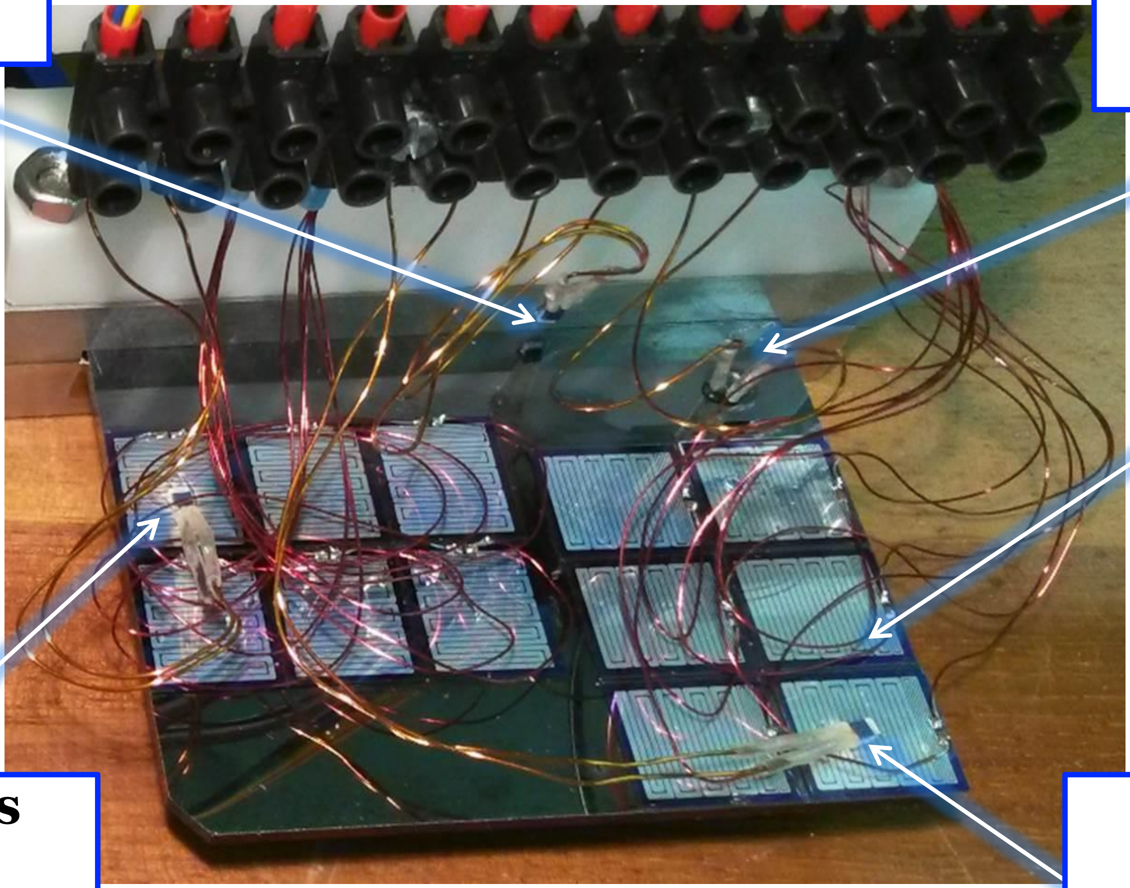
Test procedure:

- Power one microchannel (A or B) with 30[W]
- Make cyclic changes of power on the other microchannel between 0-30[W]

Since the cooling plant will be flow driven, the flow is adjusted manually to 2*0.4 [g/s] (0.4[g/s] is the nominal flow per microchannel)

If the system is stable, the module with constant power should not be affect by the power variation on the second one.

Silicon substrate – temperature probes



Connector temperature (Con)

Microchannel Outlet temperature (MCoutput)

12 ASIC heat mockups

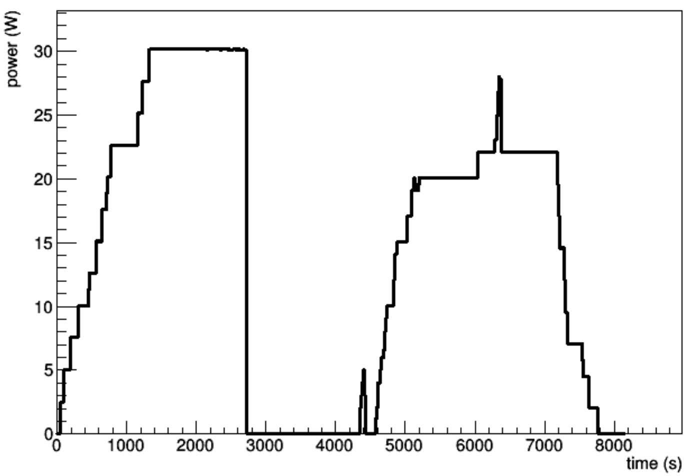
Inlet Asics Heaters temperature (MCinput)

Outlet Asics Heaters temperature (OAH)

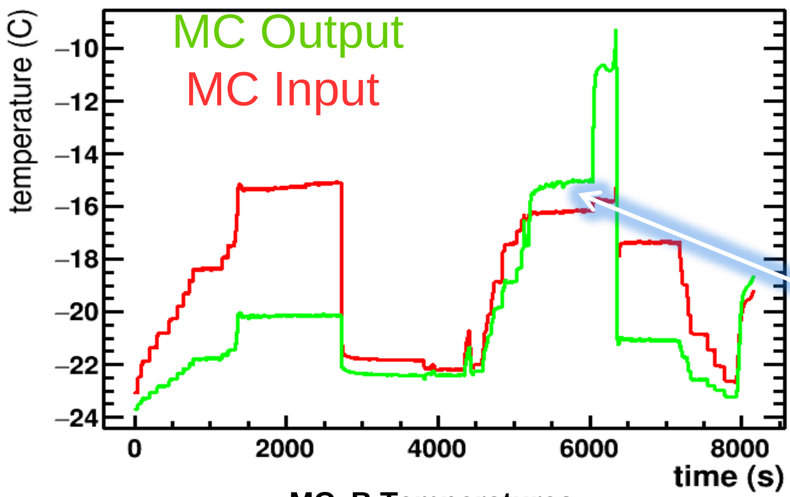
Flow stability in paraller operation

Total Flow ~ 0.8 [g/s]

Total power A

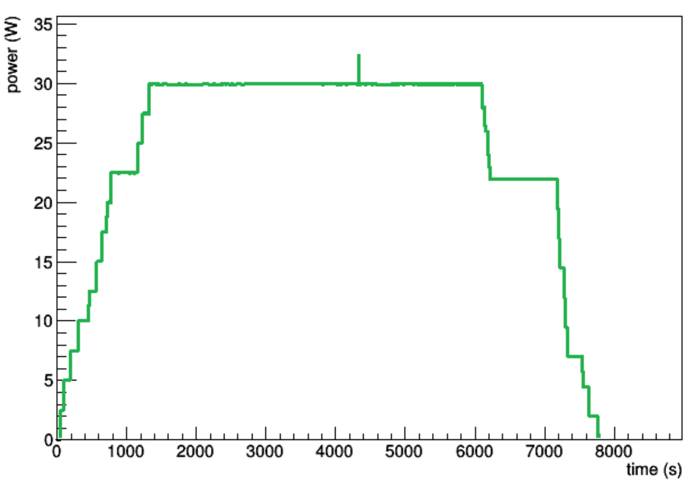


MC A Temperatures

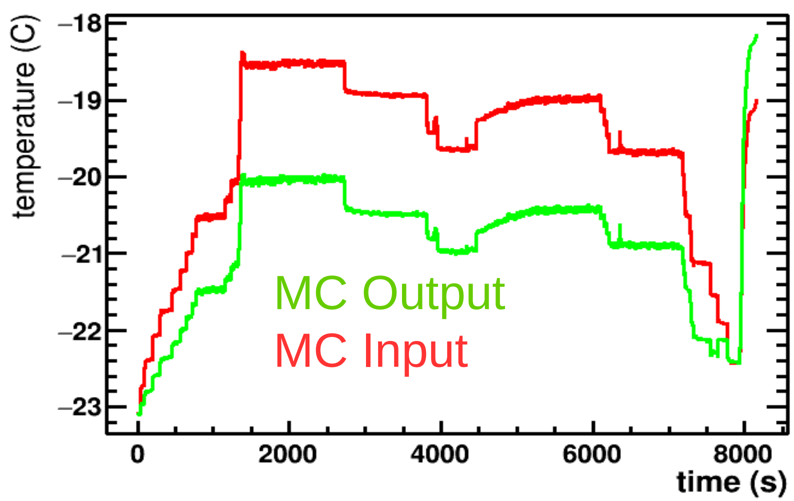


MCOutput warmer than MCInput!

Total power B



MC B Temperatures



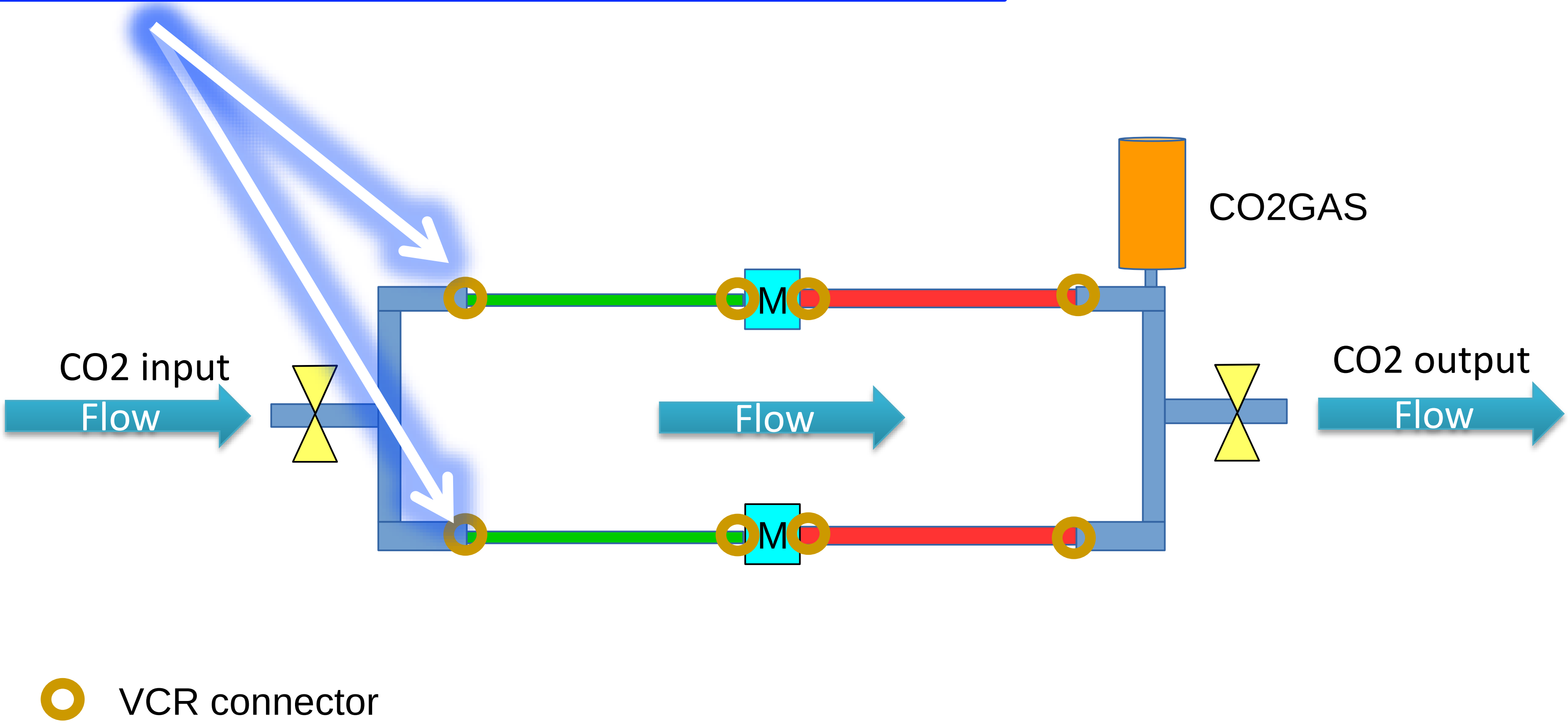
Flow instabilities

Possible solutions

- **Gasket restrictors**
- **Preheaters**

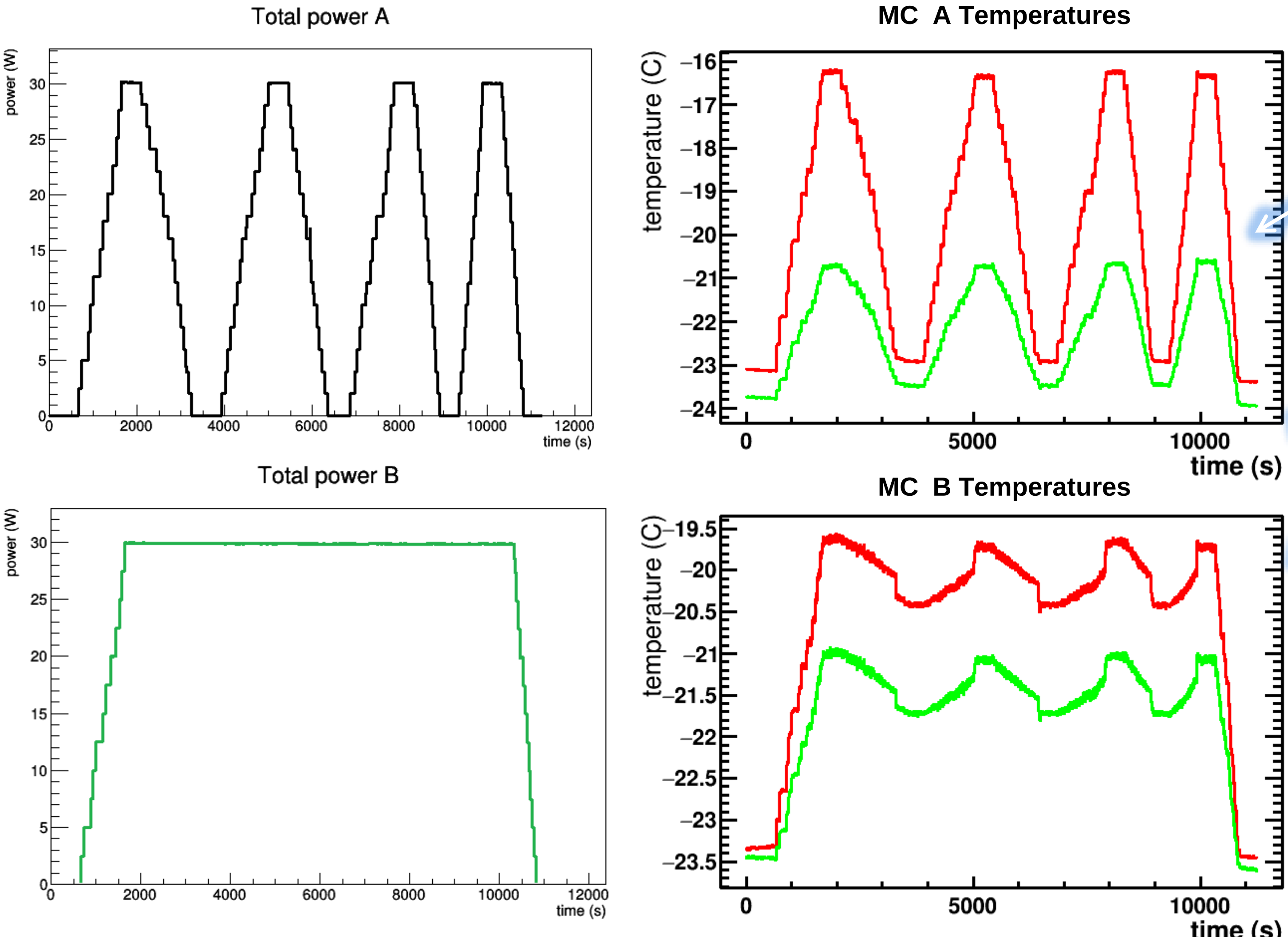
Gasket Restrictors position

VCR gaskets with orifices to create additional pressure drop



Gasket Restrictor 0.150 [mm]

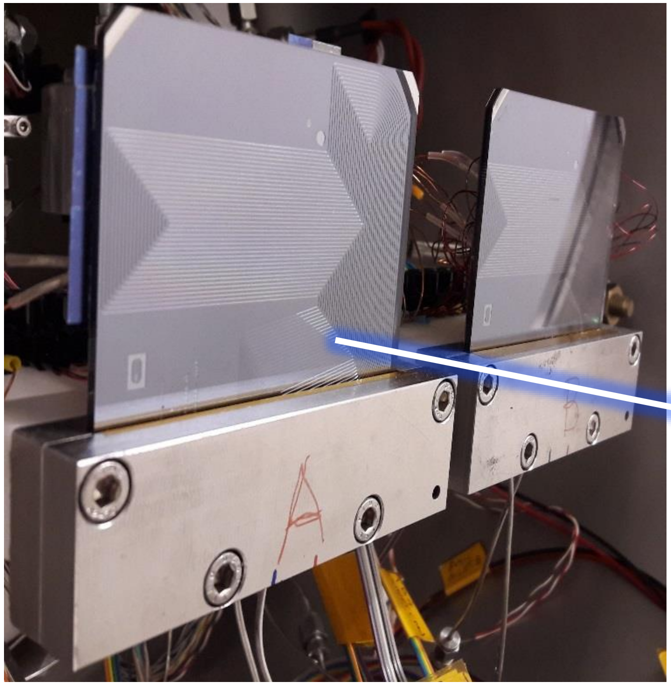
Total Flow ~ 0.64 [g/s]

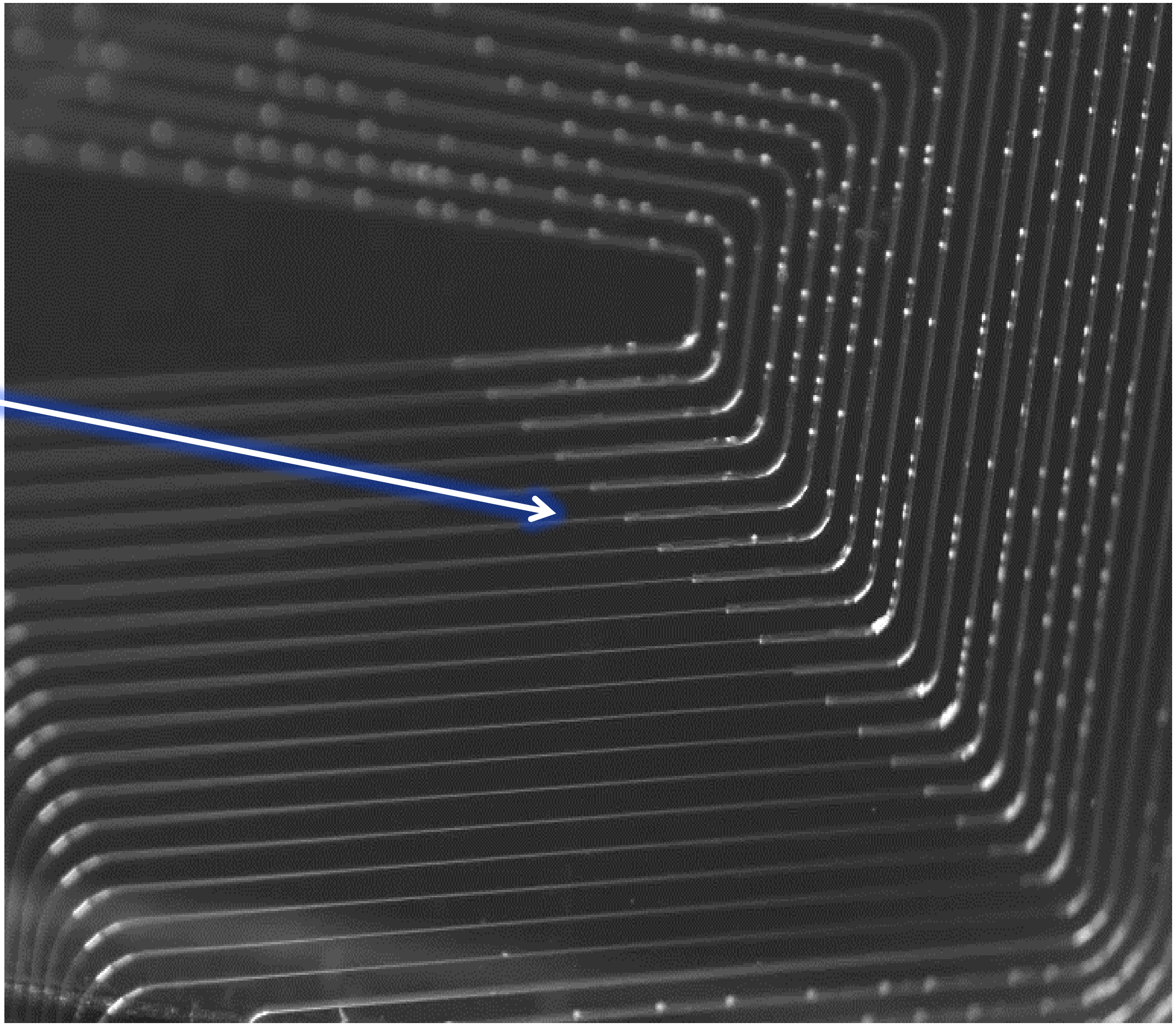


MCOutput colder than MCInput

Stable operation during power cycling

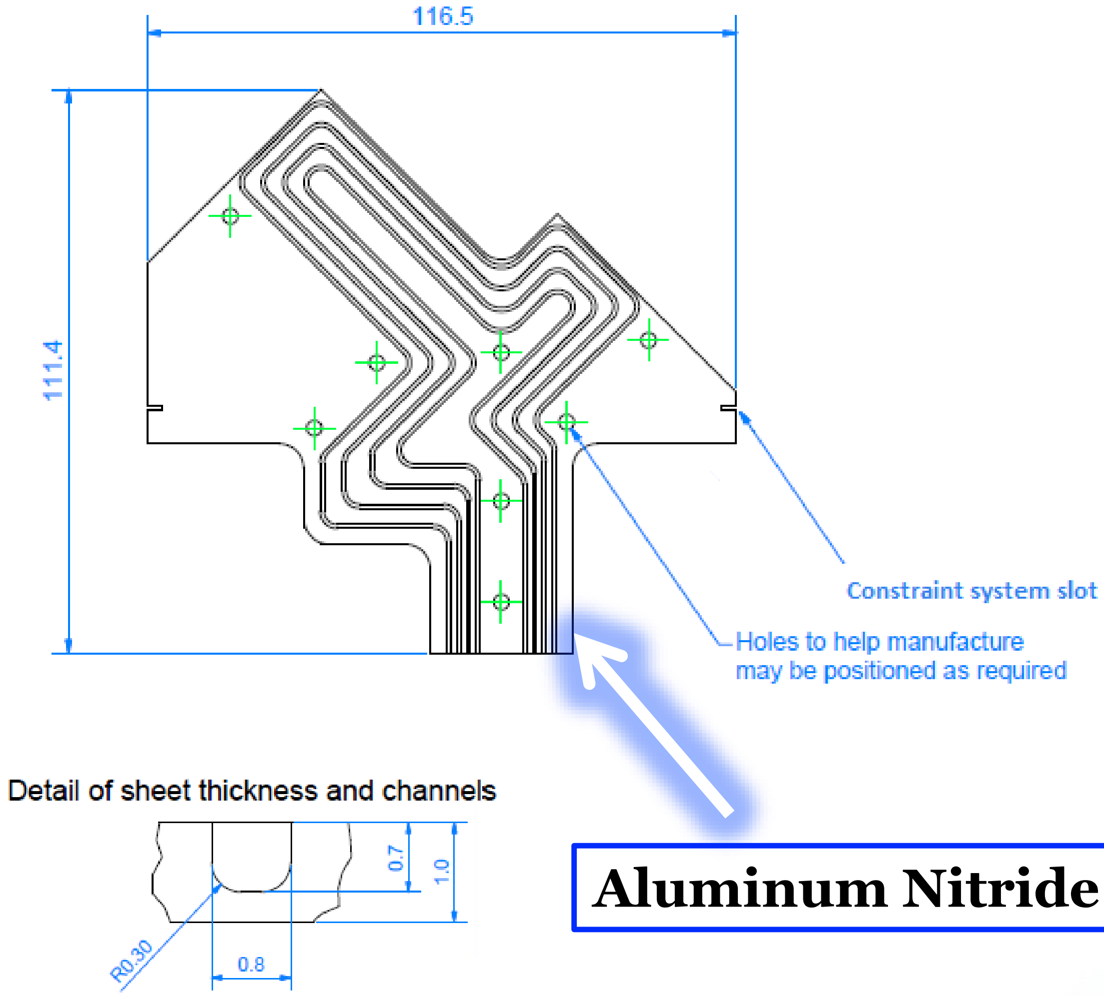
Flow through silicon microchannel substrate





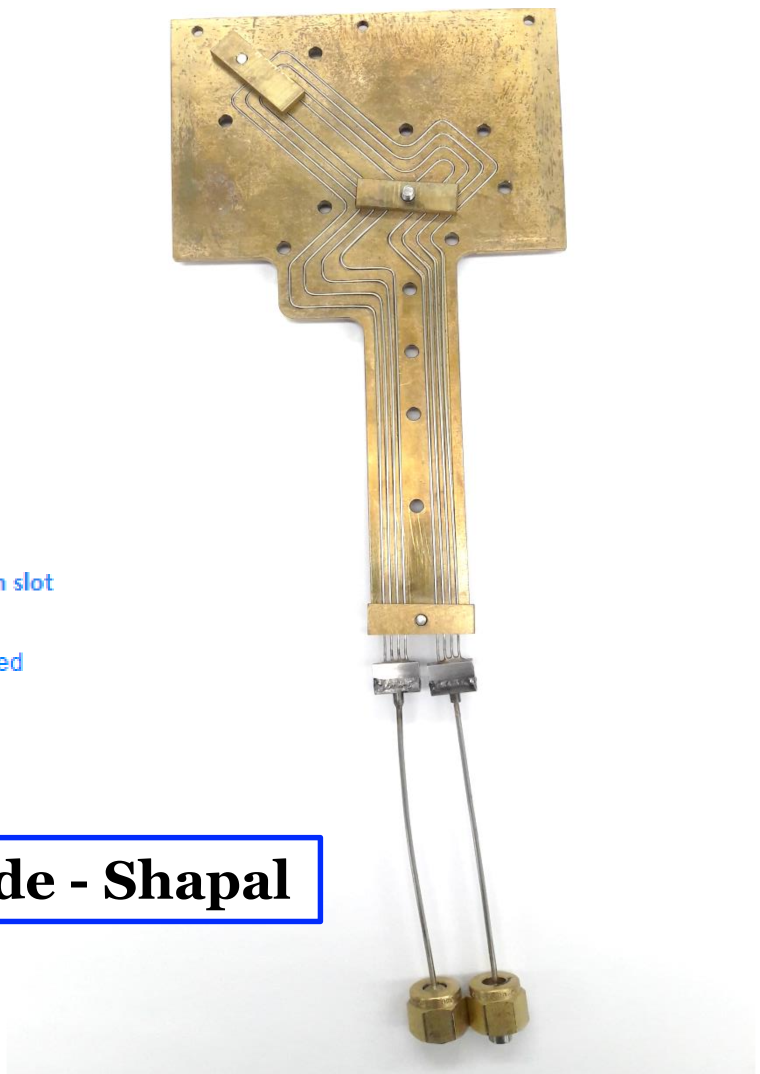
Single CO2 bubble speed – up to 1 [m/s]

Ceramic substrate design



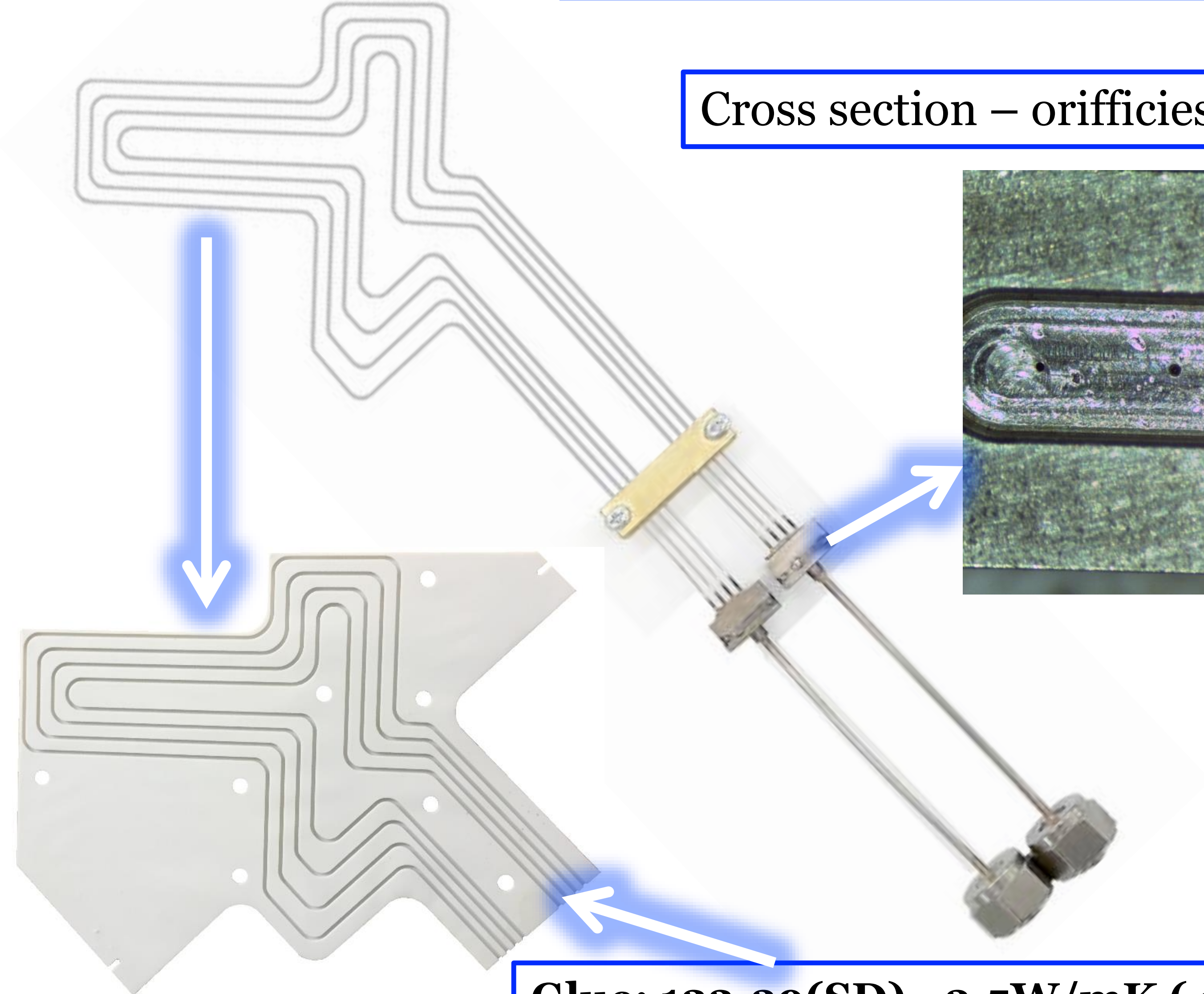
Aluminum Nitride - Shapal

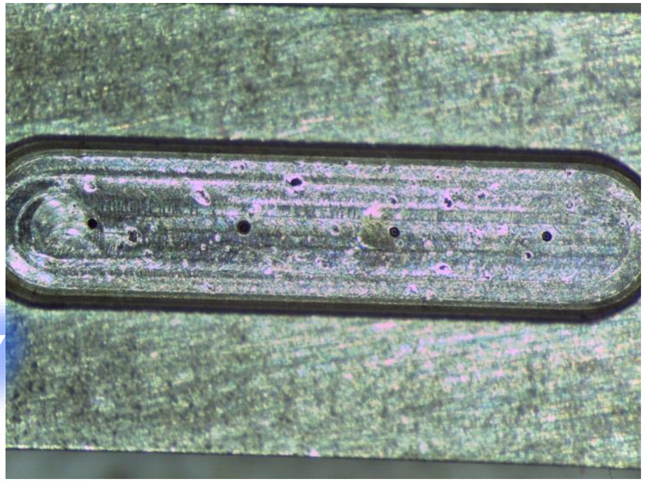
Bending jig



Ceramic substrate fabrication

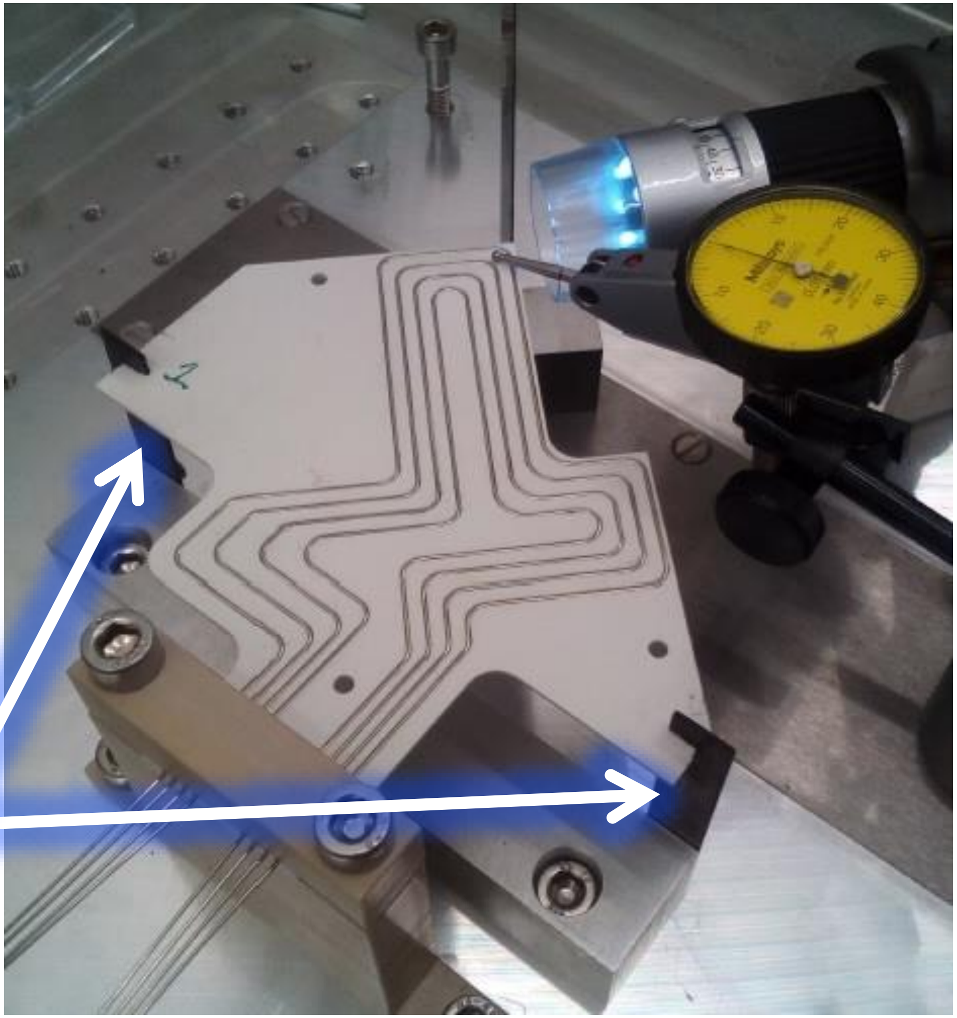
Cross section – oriffices 125 +/-5 [μm]





Glue: 122-39(SD) - 3.5W/mK (applied by robot)

Ceramic substrate constraint system

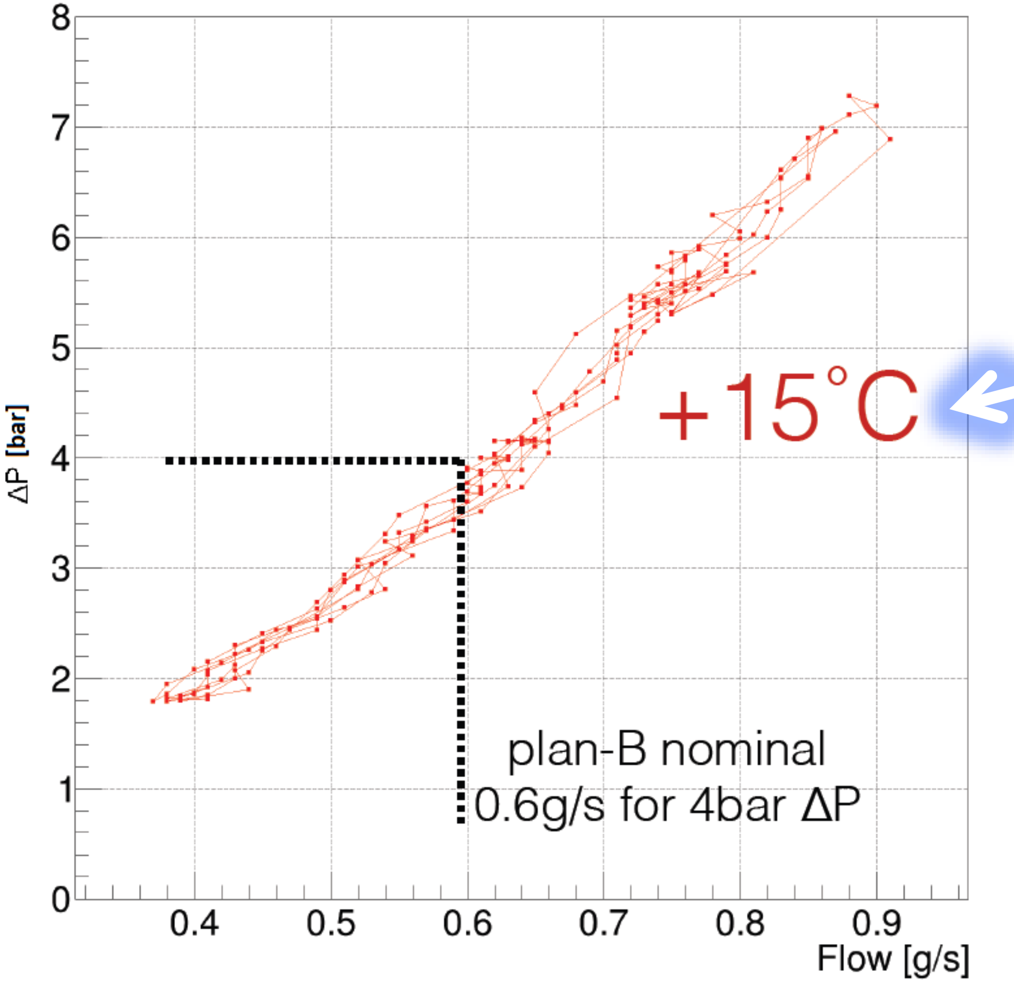


Carbon fibre constraint system

Deflections < 100 [μm] - due to temperature variation

Ceramic Substrate fluidic characterization

Capillaries 0.41 [mm] ID



CO_2 temperature

Conclusion

Microchannels:

- Better Physics performance due to less material
- No CTE mismatch between sensors and substrate
- High thermal conductivity (silicon)
- No fatigue or accumulated stress effects have been observed by doing cyclic stress tests
- The orifices approach is a quite promising technique to solve the boiling instabilities.
- Soldering technique is quite advanced. The first microchannels will be soldered in a few weeks.

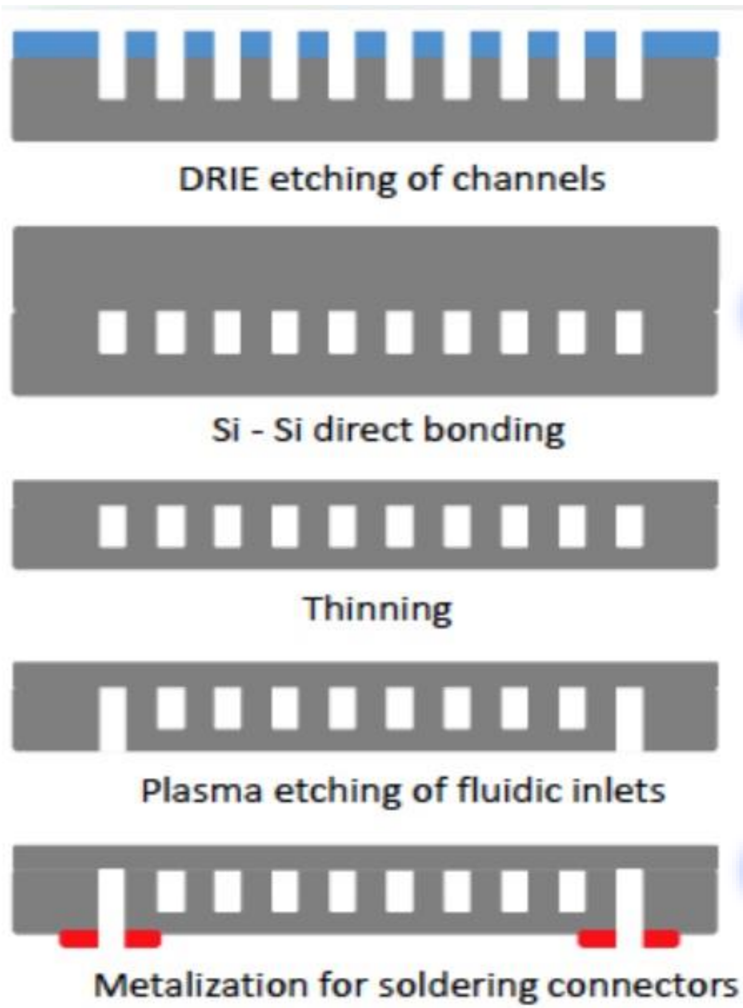
Ceramic substrate:

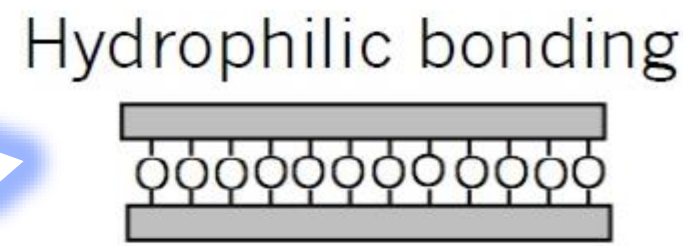
- A more conservative approach is being developed in parallel
- Small deflection due to the thermal variations (< 100 [μm])
- Smaller fluidic resistance
- Reliability tests (pressure and temperature cycling) ongoing.

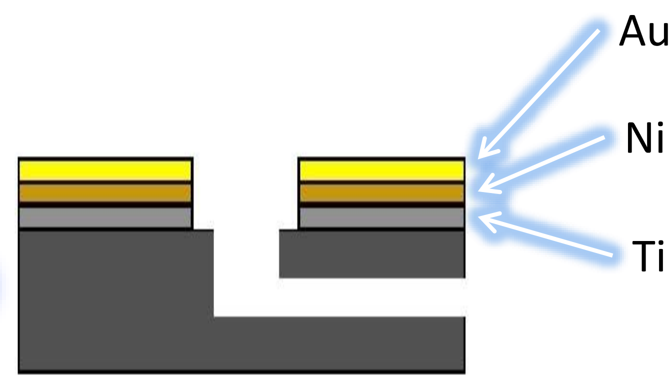
The decision will be taken this summer.

Backup Slides

Microchannels fabrication



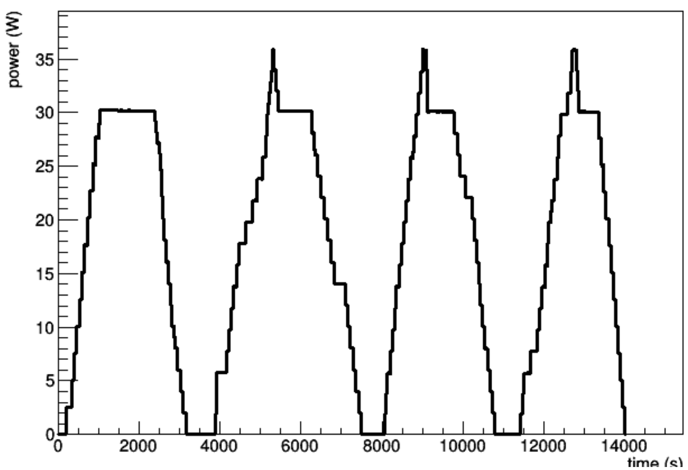




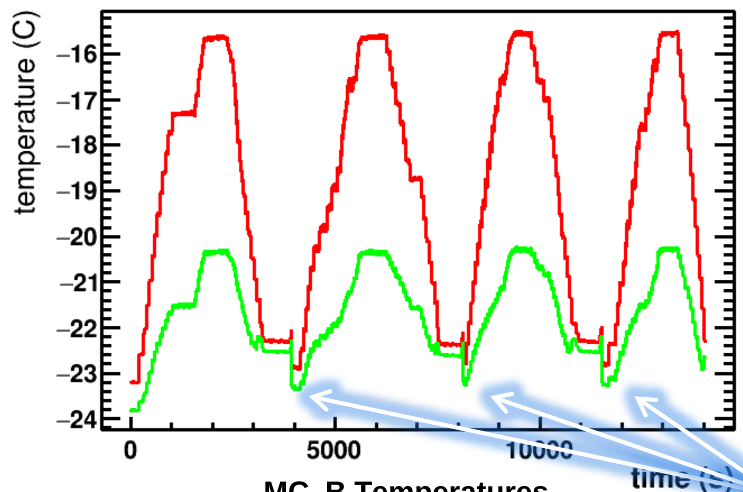
Preheating

Total Flow ~ 0.8 [g/s]

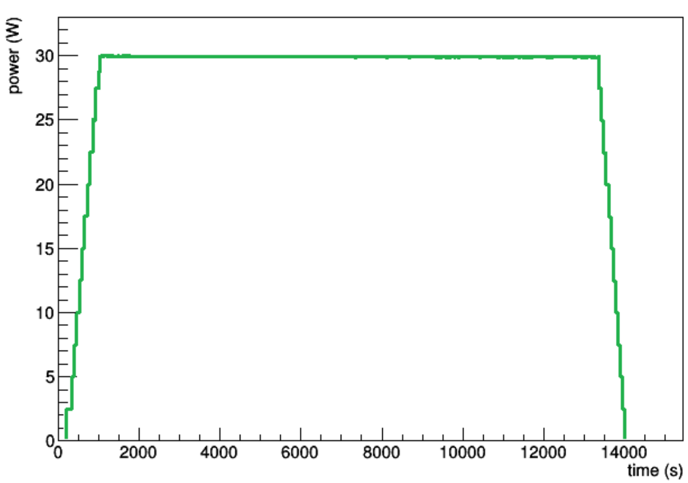
Total power A



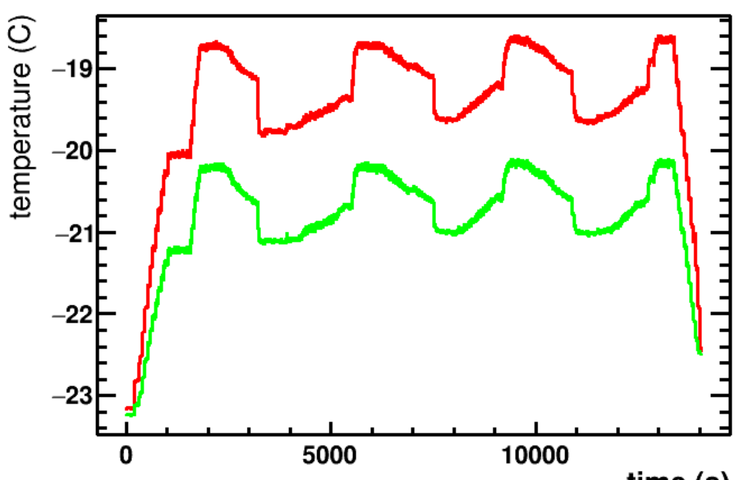
MC A Temperatures



Total power B



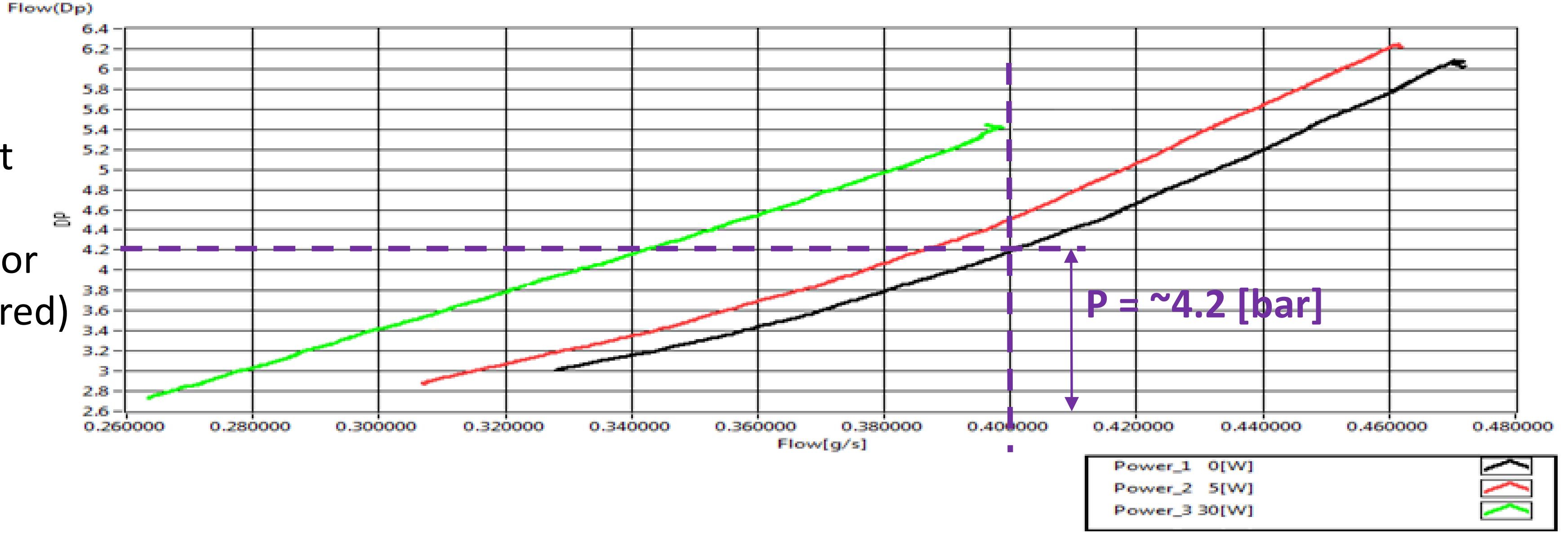
MC B Temperatures



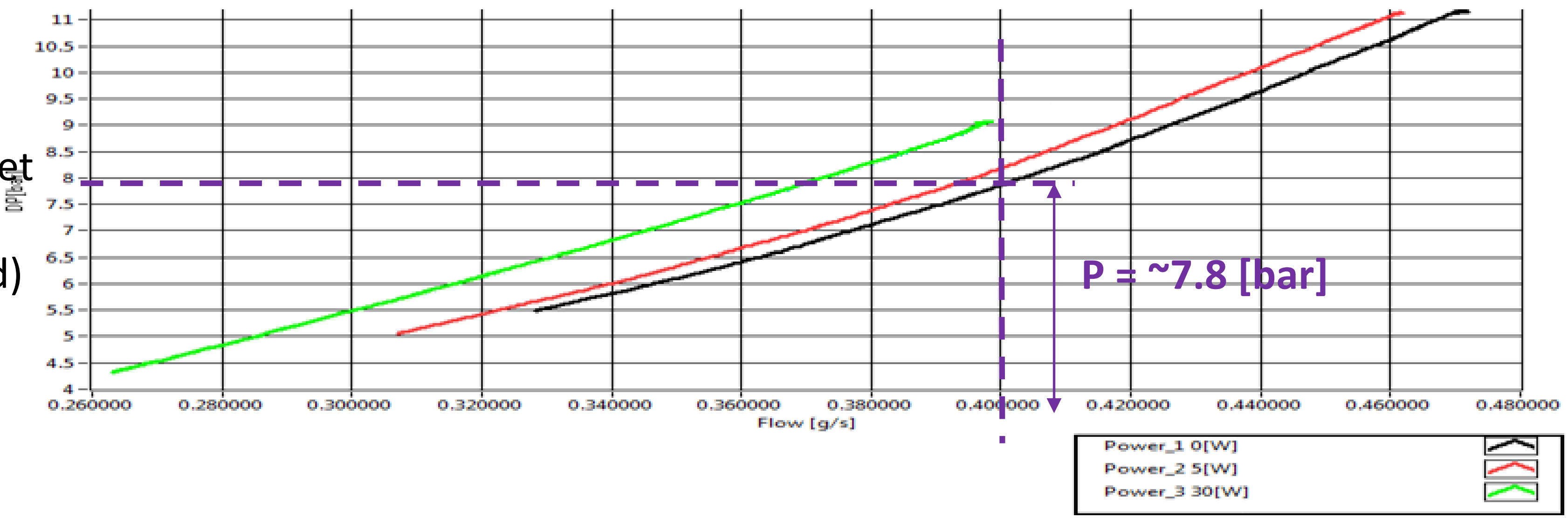
Preheating applied at 0 [W] Load

Gasket Restrictor 0.150 [mm], CO_2 -25[°C]

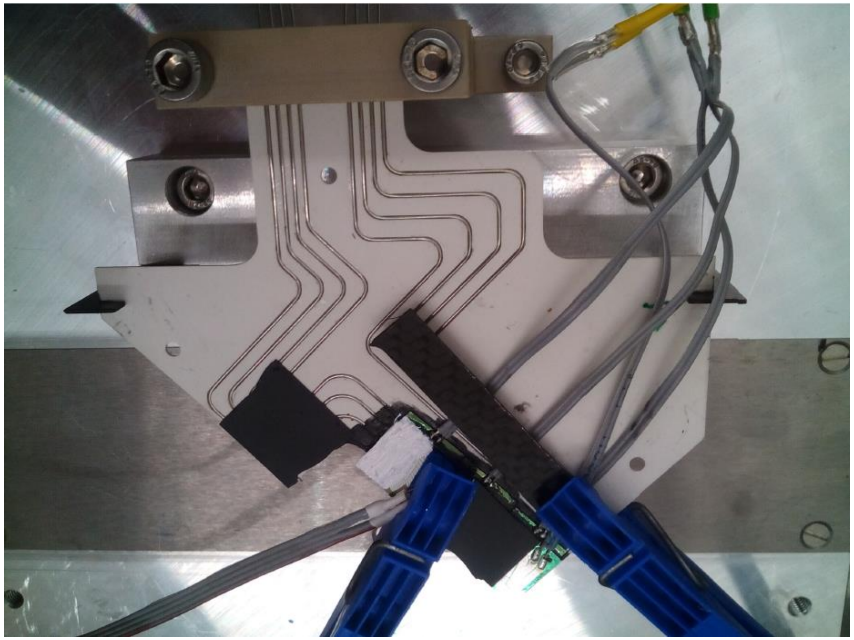
Without Gasket Restrictor (measured)

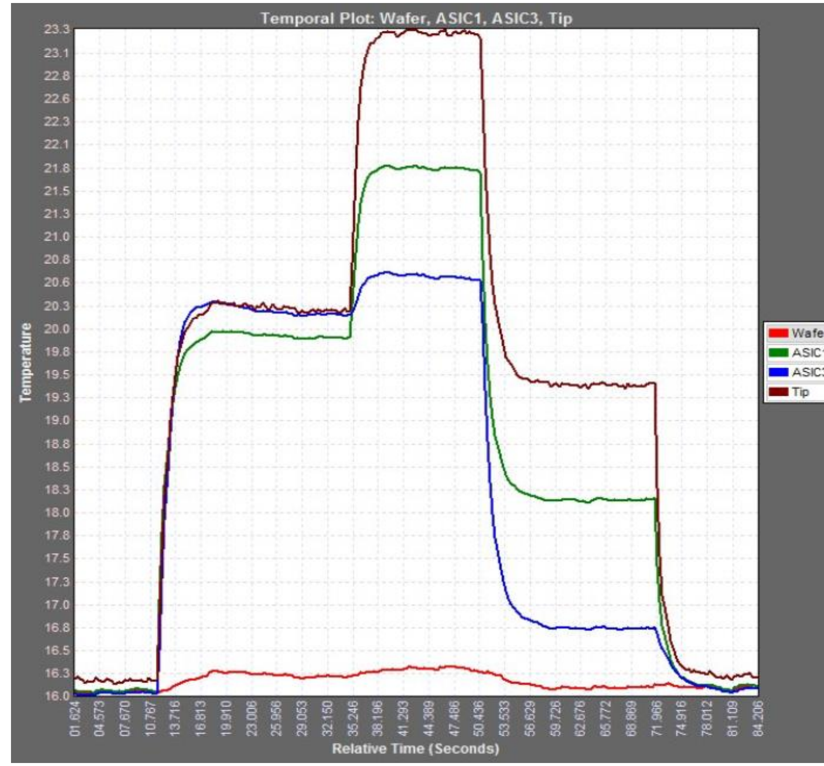


With Gasket Restrictor (calculated)



Cooling performance





CO_2 temperature set to +15[°C]
Heaters mockups simulate the power dissipation due to the 2W/ASICs + 1W/sensor
The measured DT is around [7°C]