DEPFET thermal tests

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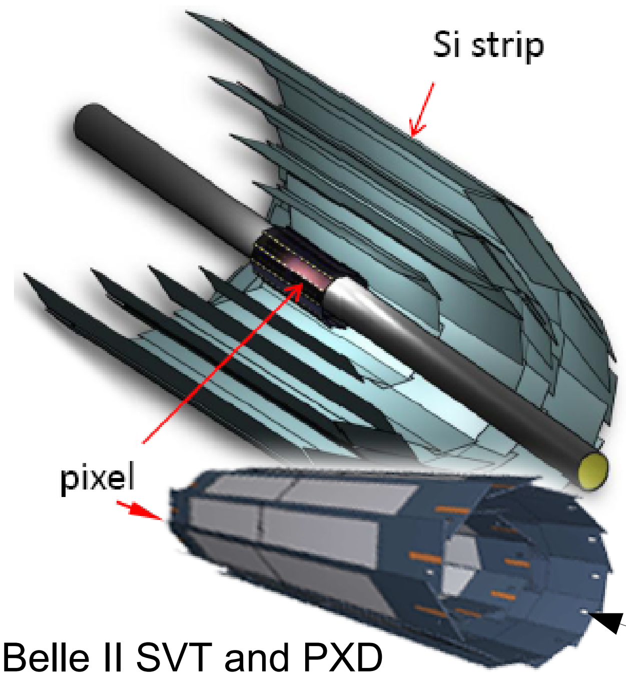
Outline

- Motivation
- Thermal dissipation studies (reminder)
- Conclusions and prospects

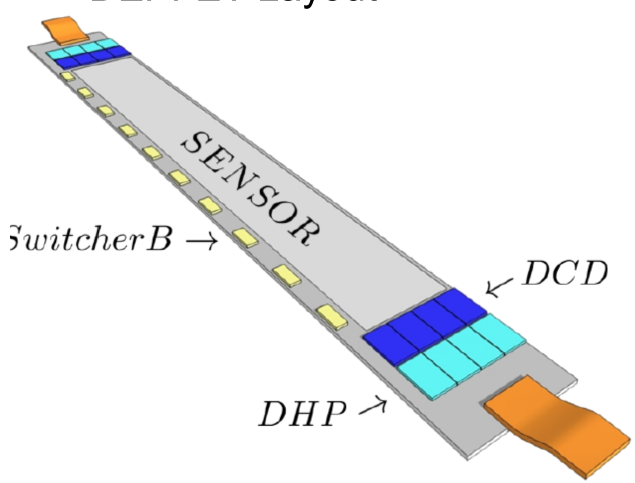
Motivation

- New tracker detectors require ultra-thin sensors to reduce multiple scattering:
  - DEpleted P-channel Field Effect Transistor (DEPFET)
  - Chosen technology for Belle II PXD
  - Candidate for ILD (among FPCCD, CMOS)

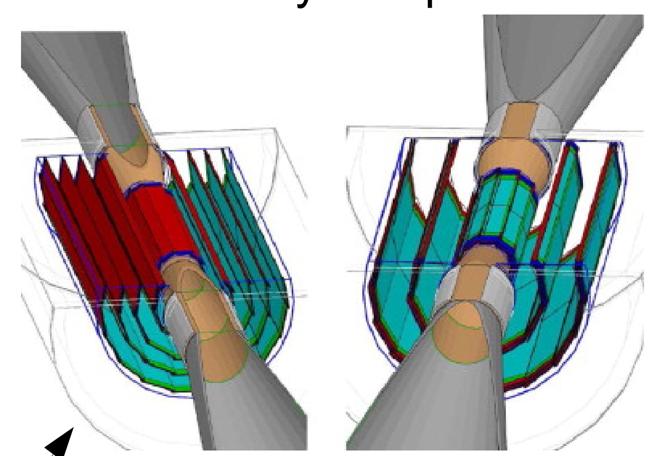


Belle II SVT and PXD

DEPFET Layout



ILD tracker layout options



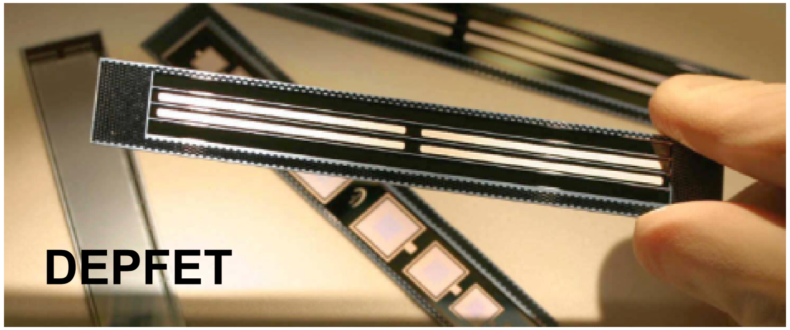
Single sided
5 Layers

Double sided 2mm thick
3 Layers

50 µm-thick sensors in ILD
75 µm-thick sensors in Belle II

Motivation

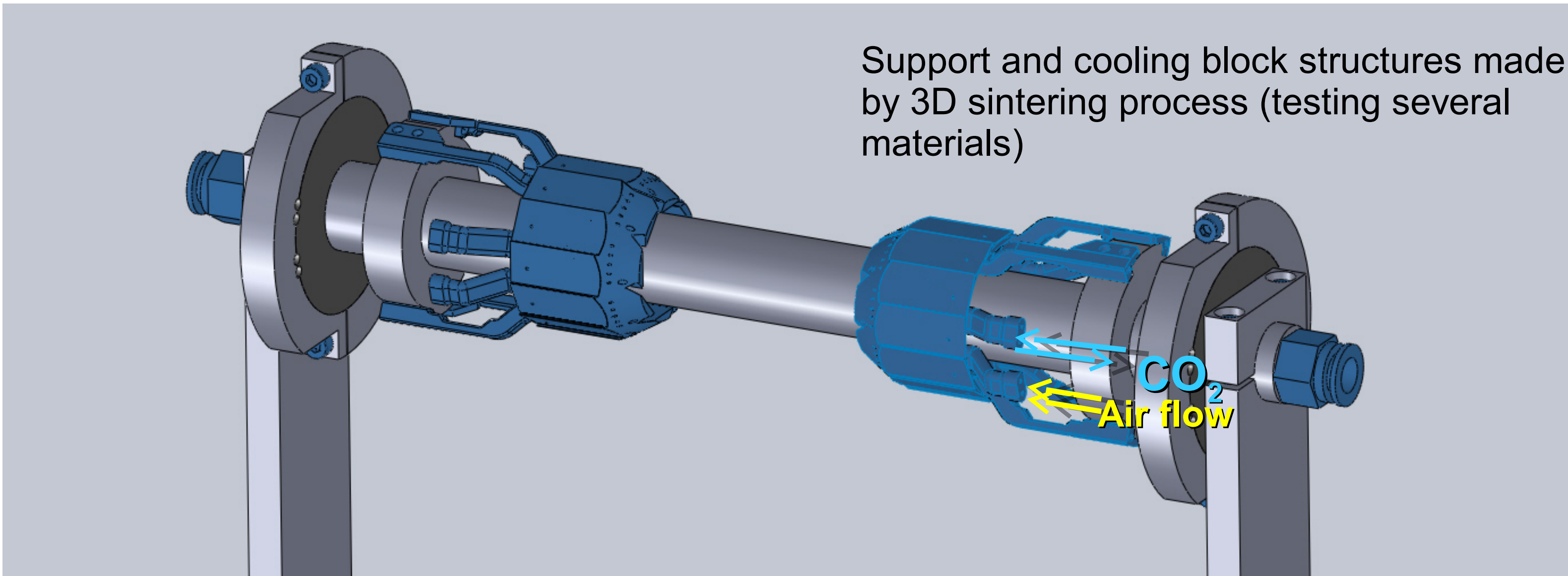
- DEPFET (Belle II)
  - 360 W entire detector
  - Convective cooling in the thin sensor area
  - CO_2 active cooling out of the acceptance
- DEPFET (ILD)
  - ~1200 W total
  - ~6 W with power pulsing (1:200 duty cycle)
  - No active cooling due to angular acceptance requirements

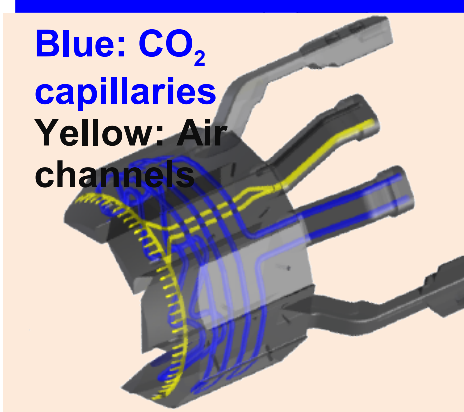


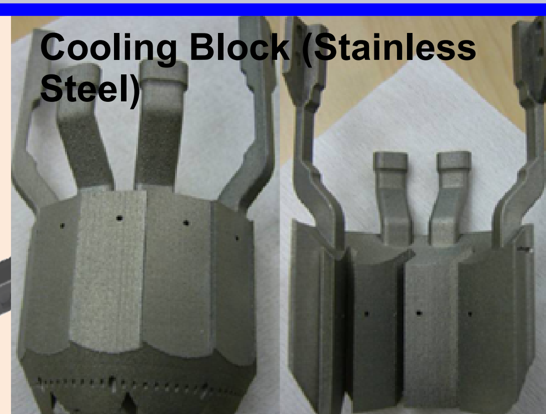
Convective cooling studies
for Belle II

- Determination of cooling parameters:
  - Minimize temperature in the ladder...
  - ...while mantaining a small ΔT
  - Mass flow rate? Pressure?

Belle II PXD (2 layers) Setup

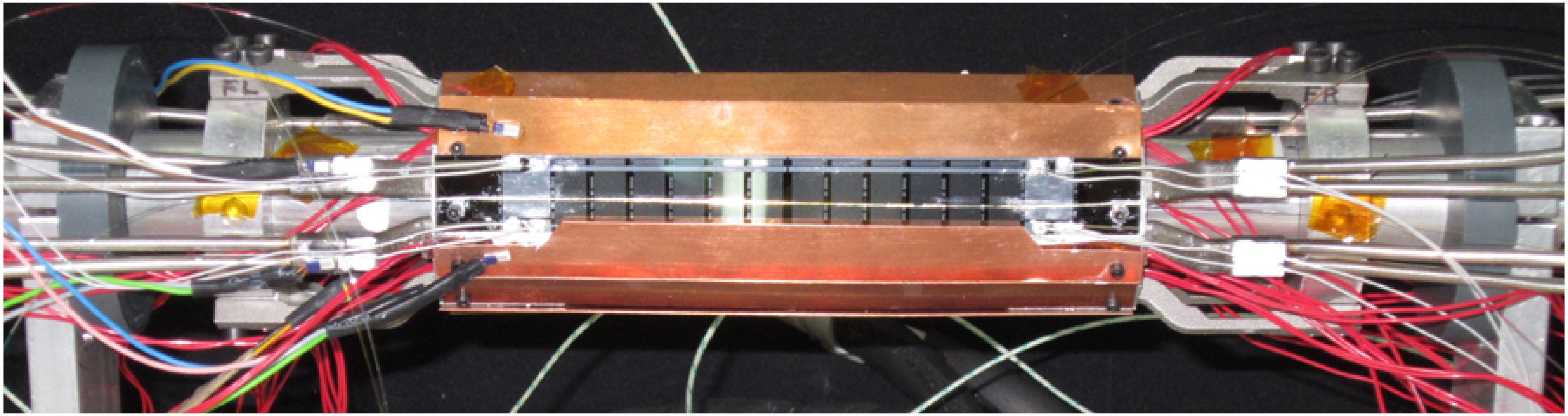






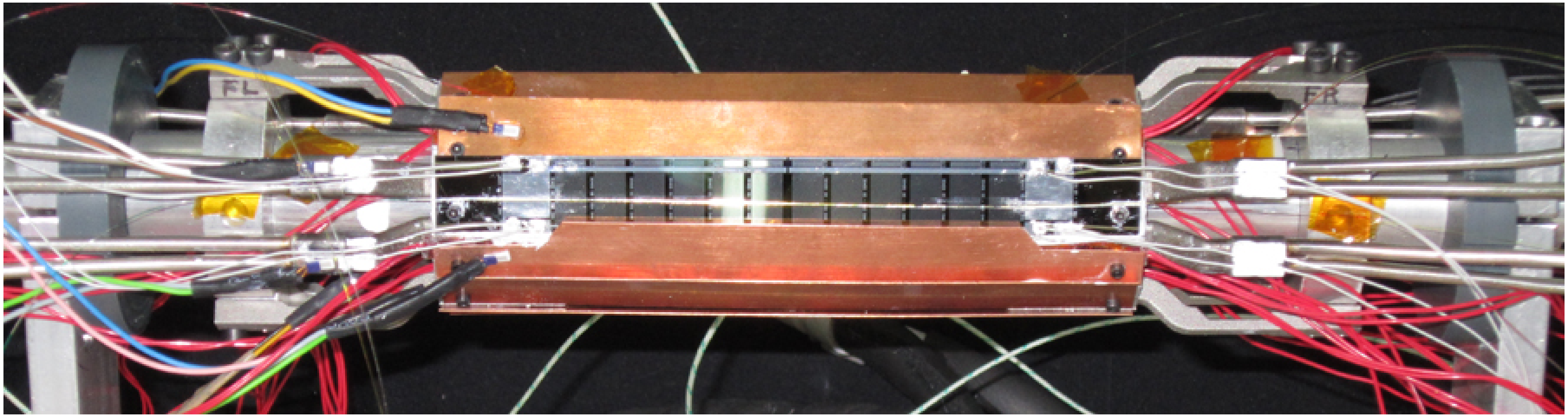
Experimental setup

- Fully enclosed volume with Cu dummies and Si resistive sample in outer layer, using stainless steel cooling blocks (CB).



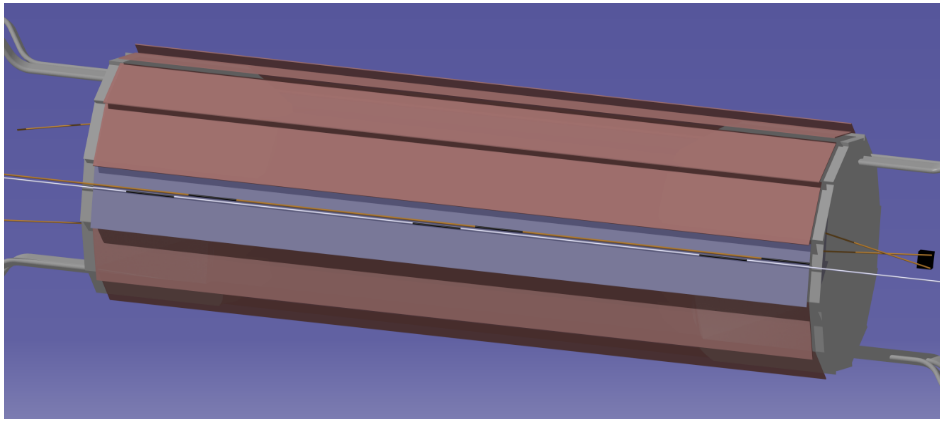
- 24 resistive heaters (6.35 mm x 12.70 mm) simulating FEE dissipation (8W per heater, 192W total) in CBs
- N_2 gas cooled down to ~0ºC through Cu coil in LN_2 Dewar atmosphere
- Two phase CO_2 cooling (T~-35ºC)
- BP cooled down to 15ºC (Liquid coolant)

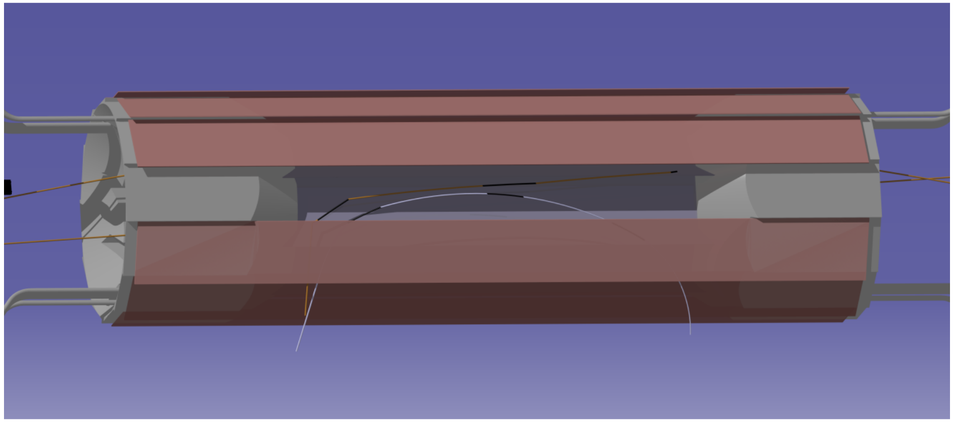
Experimental setup



- 6 Pt100 probes
  - CO_2 and Air inlets
  - 2 Cu ladders adjacent to the resistive ladder
  - Cooling Block
  - Beam pipe
- Thermal imaging camera (±3ºC accuracy from emissivity corrections)
- Tipp-ex marks as emissivity reference for cross-checking

Experimental setup

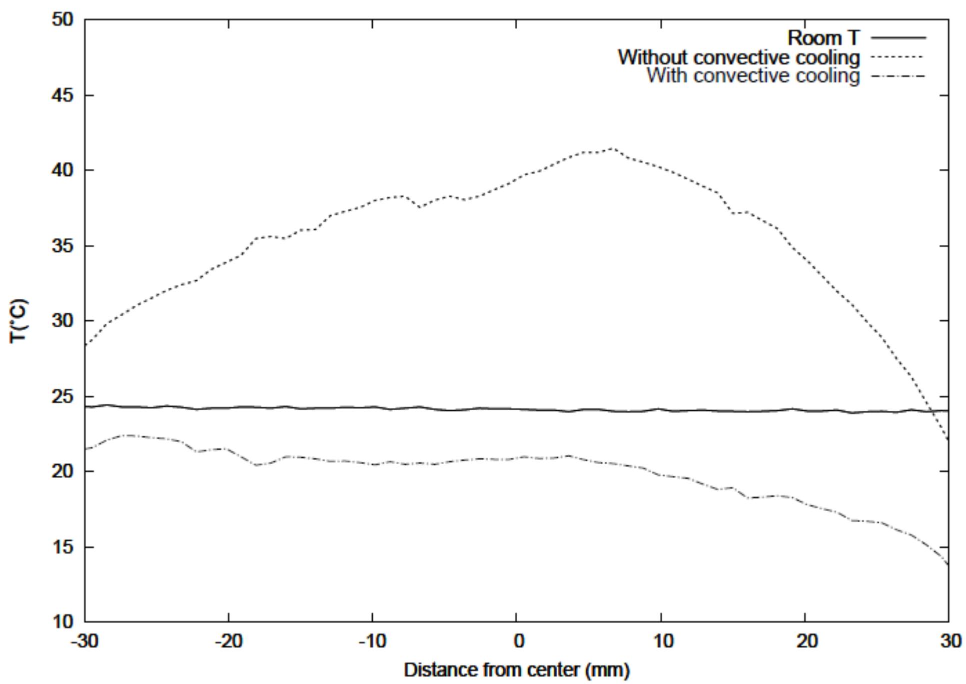




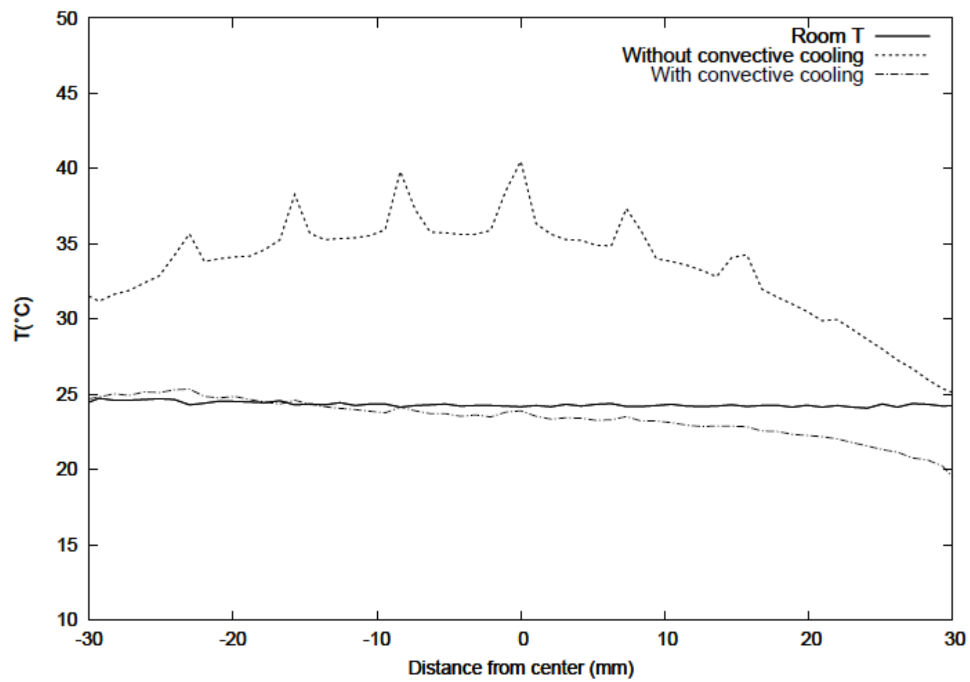
- IFCA FBG sensors (Acrylate and polyamide pairs)
  - Between BP and inner layer
  - Between inner and outer layer
  - Over outer layer
    - On Cu ladders
    - On the Si ladder

Results

Sensor surface

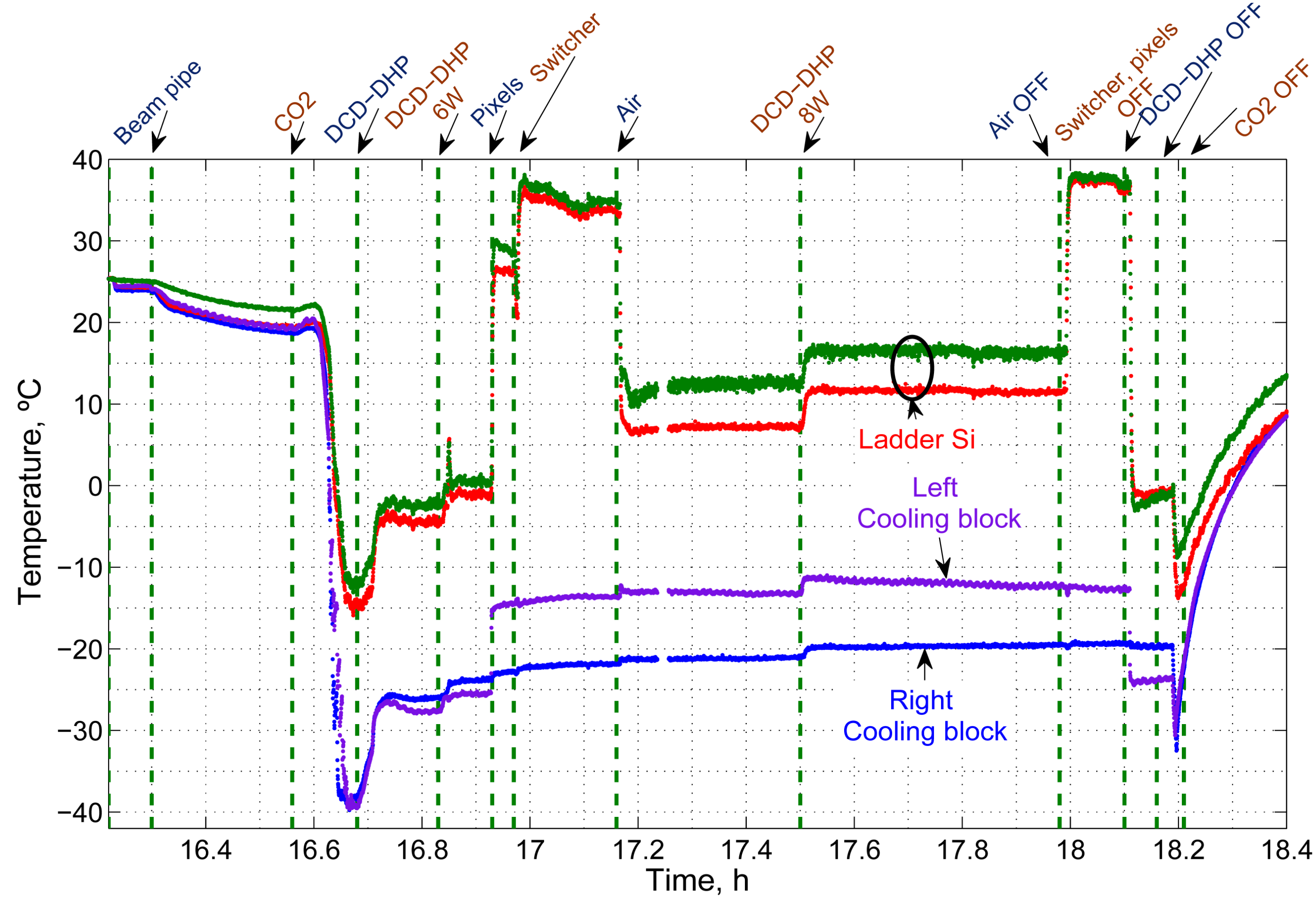


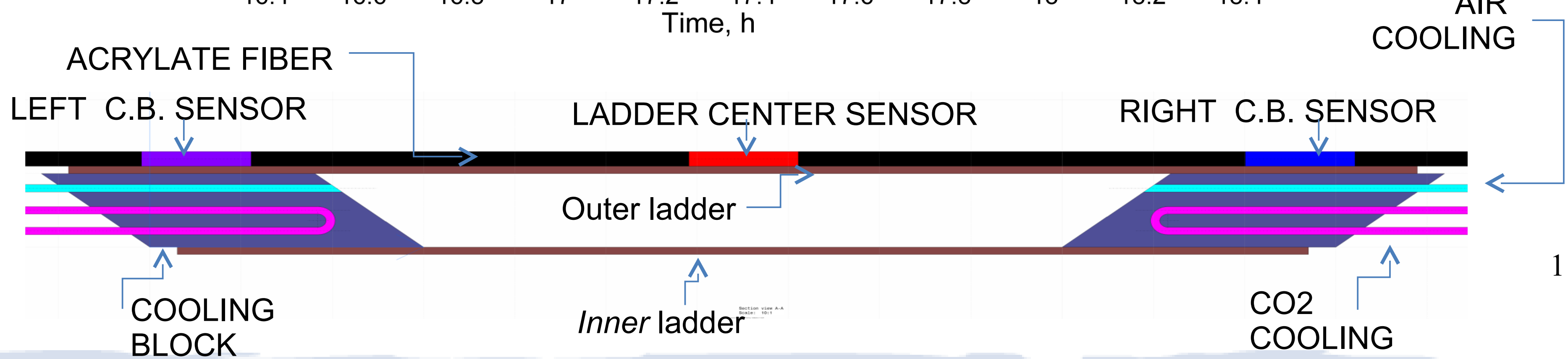
Switcher surface



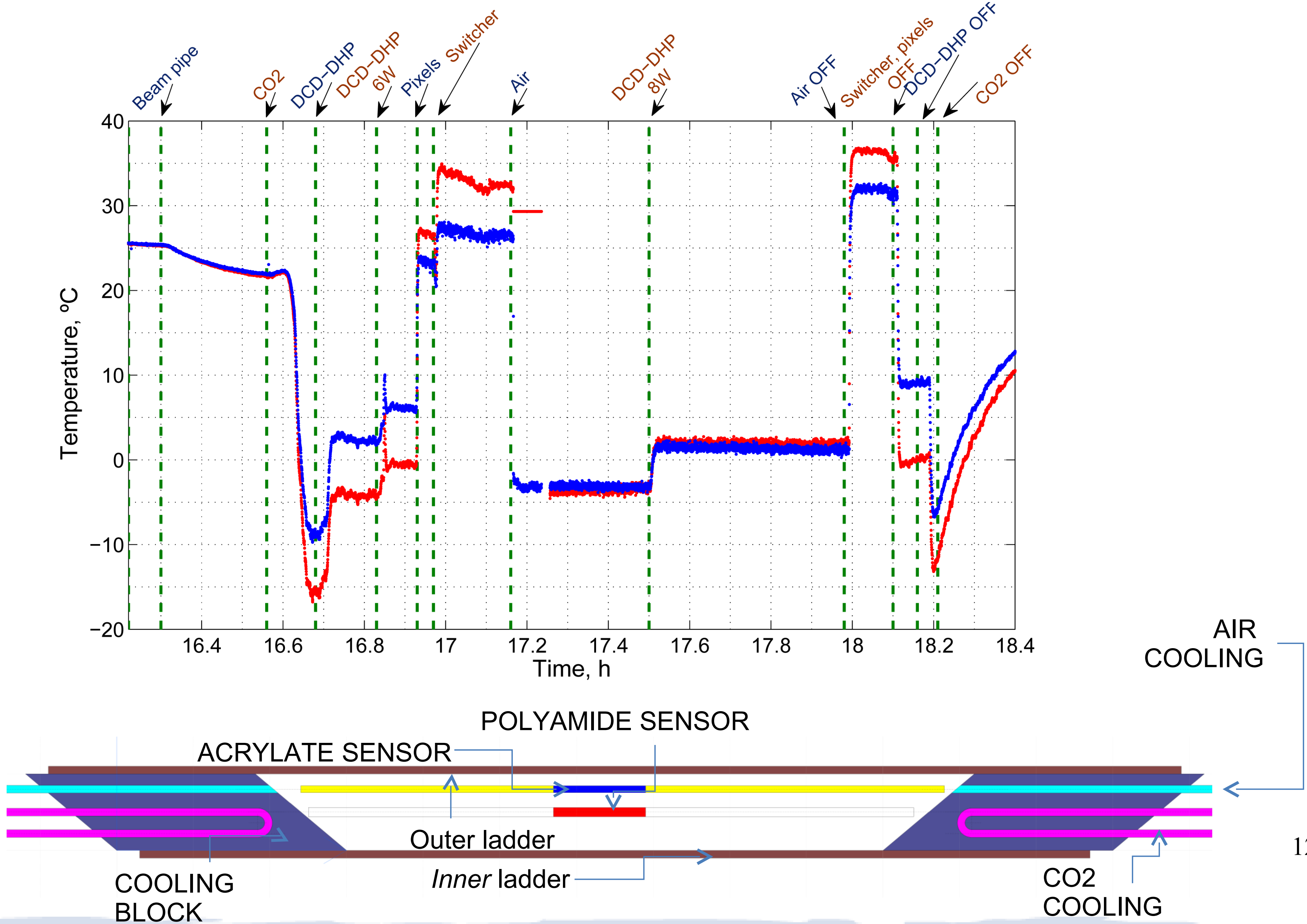
Without convective cooling	T_{MAX}~40ºC	ΔT~15ºC
With convective cooling	T_{MAX}~25ºC	ΔT~5ºC

External ladder monitoring





Intermediate volume monitoring



Vibration and deformation

Cooling attainable with a flow rate of 15 L/min, pressure 3 bar and v=2 m/s. This is below fundamental mode vibration conditions.

Minimum pressure for vibrations (4 bar):

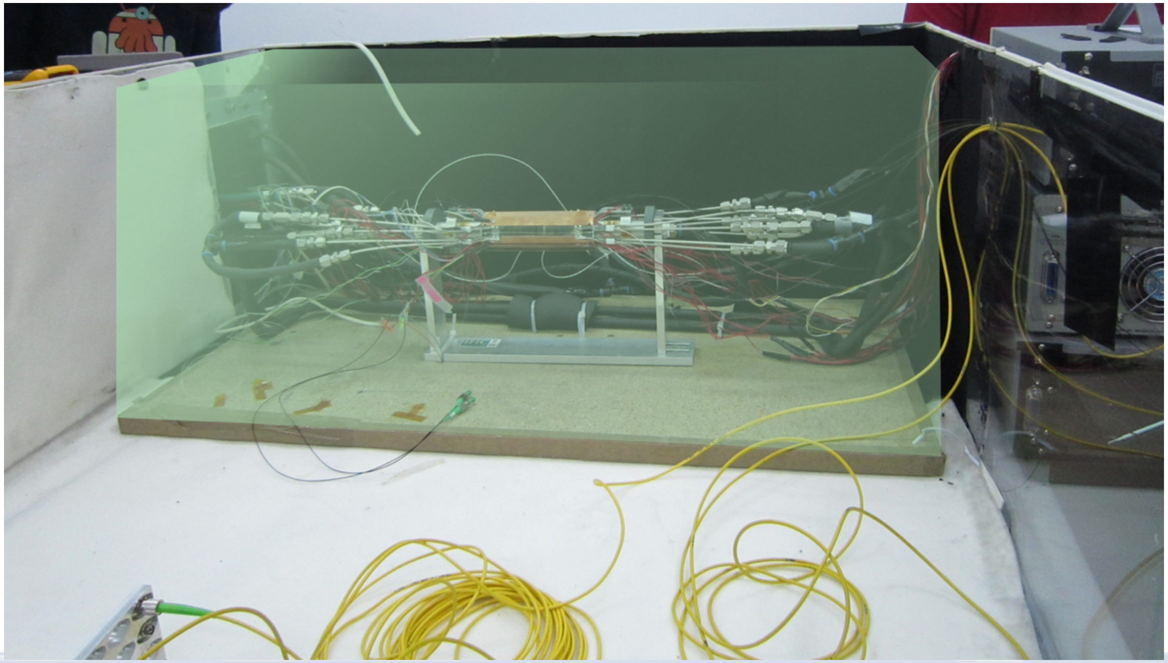
- Single ~400Hz Vibration (fundamental mode), amplitude 0.7μm rms
- Maximum deformation (center) 1.8±0.8 μm

Relevance for ILD

- Convective cooling works for ultra-thin sensors
- Tested for DEPFET (Belle II)
  - CO_2 and Air cooling (in an enclosed volume) manage to reduce the temperature profile to around 20ºC, and achieve a more homogeneous temperature profile (ΔT~5ºC).
- Expected power consumption @ILD is lower (duty cycle)
  - Convective cooling seems like a viable option but...
  - … no active CO_2 cooling (No massive structures as the support due to full angular coverage).
  - Can an only-convective option bear the load?

Prospects

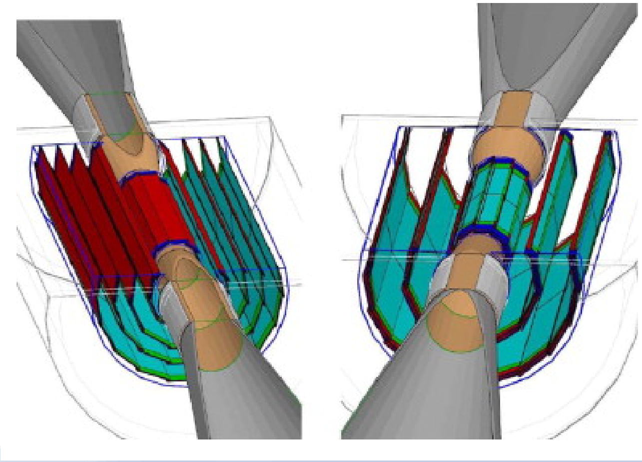
- Future tests in a colder and dryer N_2 atmosphere:
  - Observed dependency with ambient T, can we use to lower sensor temperature?
  - Testing of the FBG fibers.
  - A setup is being prepared, scheduled measurements for early 2013.
    - Smaller methacrylate box (easier control of the atmosphere but no thermal imaging...)
    - Measurements with FBG and Pt100 sensors
  - Looking forward to publish a paper with the results obtained



Prospects

- Adaptation to ILD:
  - Some key structural departures from Belle II's design:
    - Forward Tracker Disks
    - No massive support structures mean no active cooling available
    - Single sided or Double sided Ladders?
  - An appropriate mockup should be built with these conditions in mind to allow testing of the convective cooling solution.
  - Power pulsing effects on temperature and deformation can be observed with FBG sensors due to their fast response. A power pulsing setup is being developed at IFIC

VTX-SL
5 layers



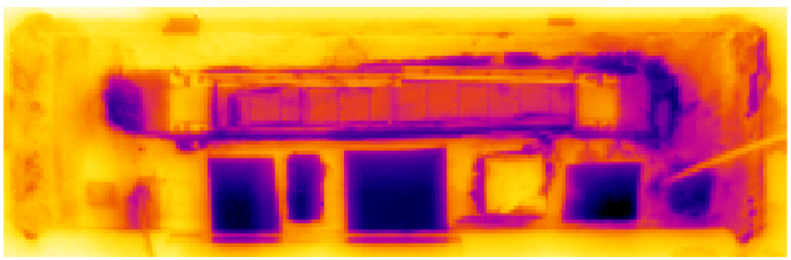
VTX-DL
3 layers

Thank you very much!

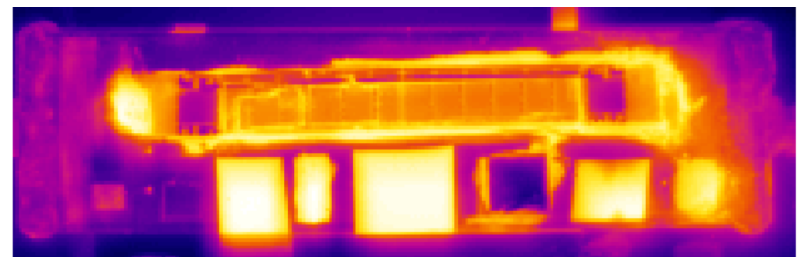
Backup slides

Emissivity calibration

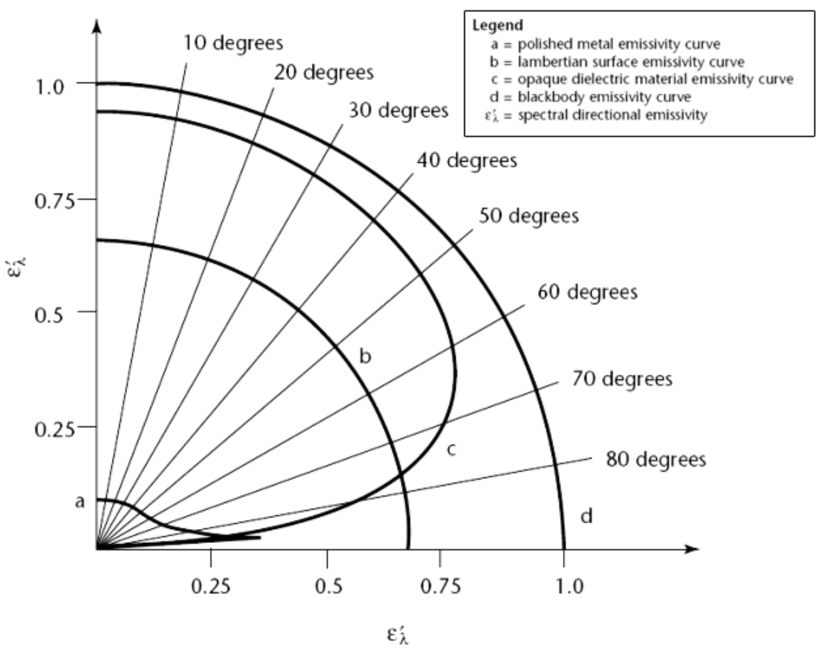
Variable temperature box with different surface samples, measured normal incidence emissivities at different temperatures and found no significant behavior with temperature. Emissivity corrections are done by adjusting ε until temperature is consistent with PT100/thermocouple measurements



-20ºC



95ºC



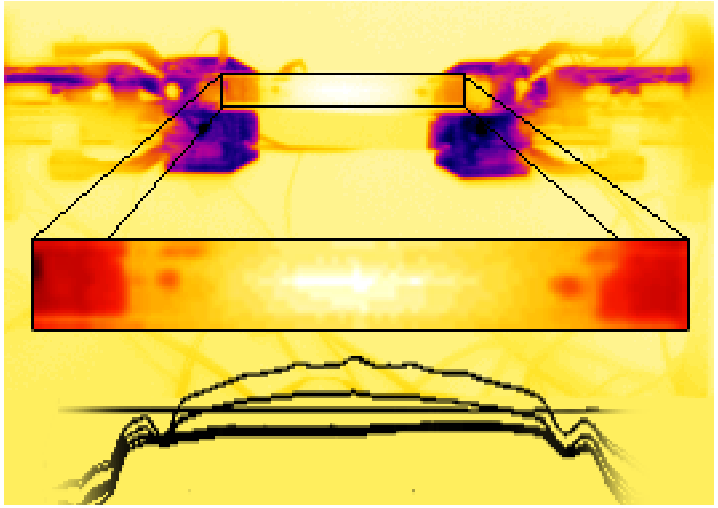
Material	Normal Emissivity
Sensor surface	0,67±0,03
DCD-DHP	0,34±0,04
Tipp-ex	0,97±0,09
Al	0,26±0,12
Cu	0,22±0,12
Thermal paste	0,88±0,09
Kapton Tape	0,99±0,10

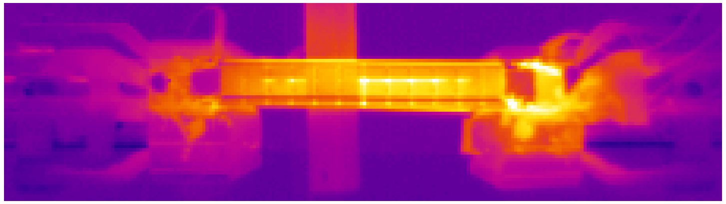
Transparency of the Si sensor

Peculiar shape of the T profile revealed infrared transparency of the ultrathin sensor layer.

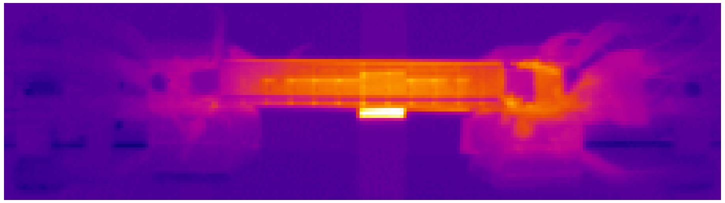
Measurements at the switchers (thicker) avoid this effect, we can still trust sensor surface values away from the CB regions.

Fig. *a* shows opaque slide behind sensor, while *b* shows reflective slide, observe the pattern along the sensor surface change accordingly in each case.



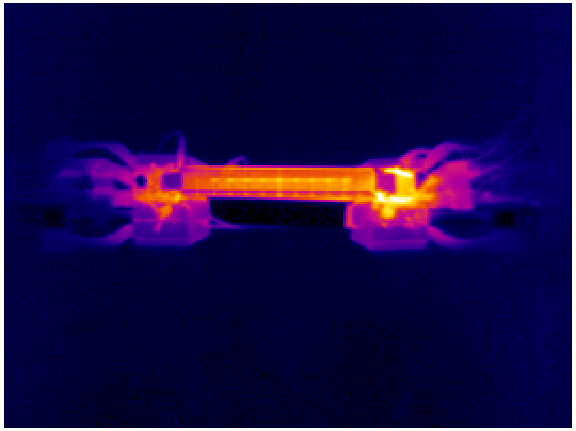


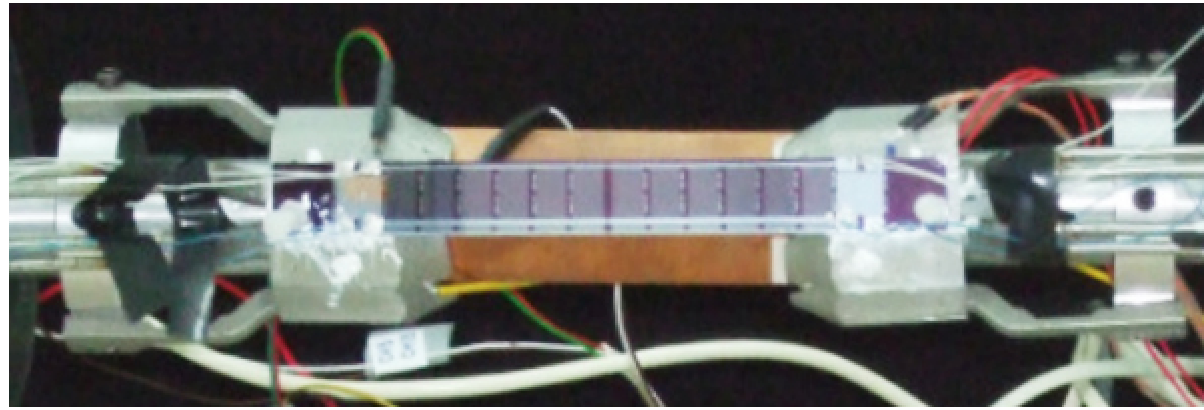
A



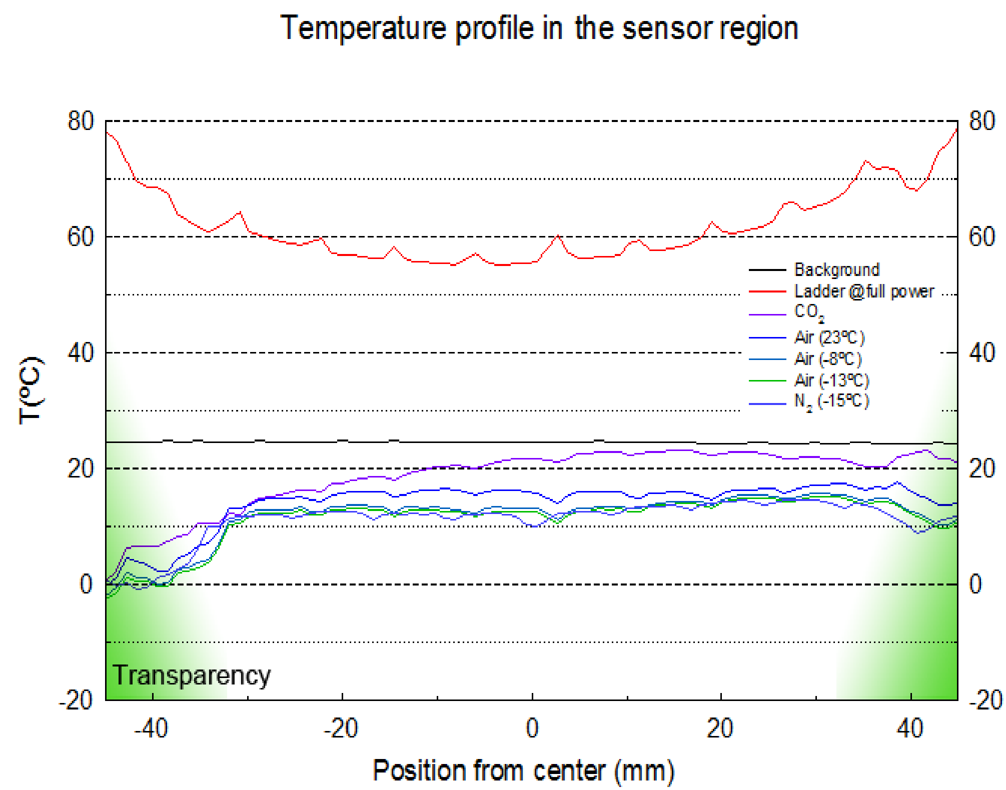
B

Open system results (reminder)



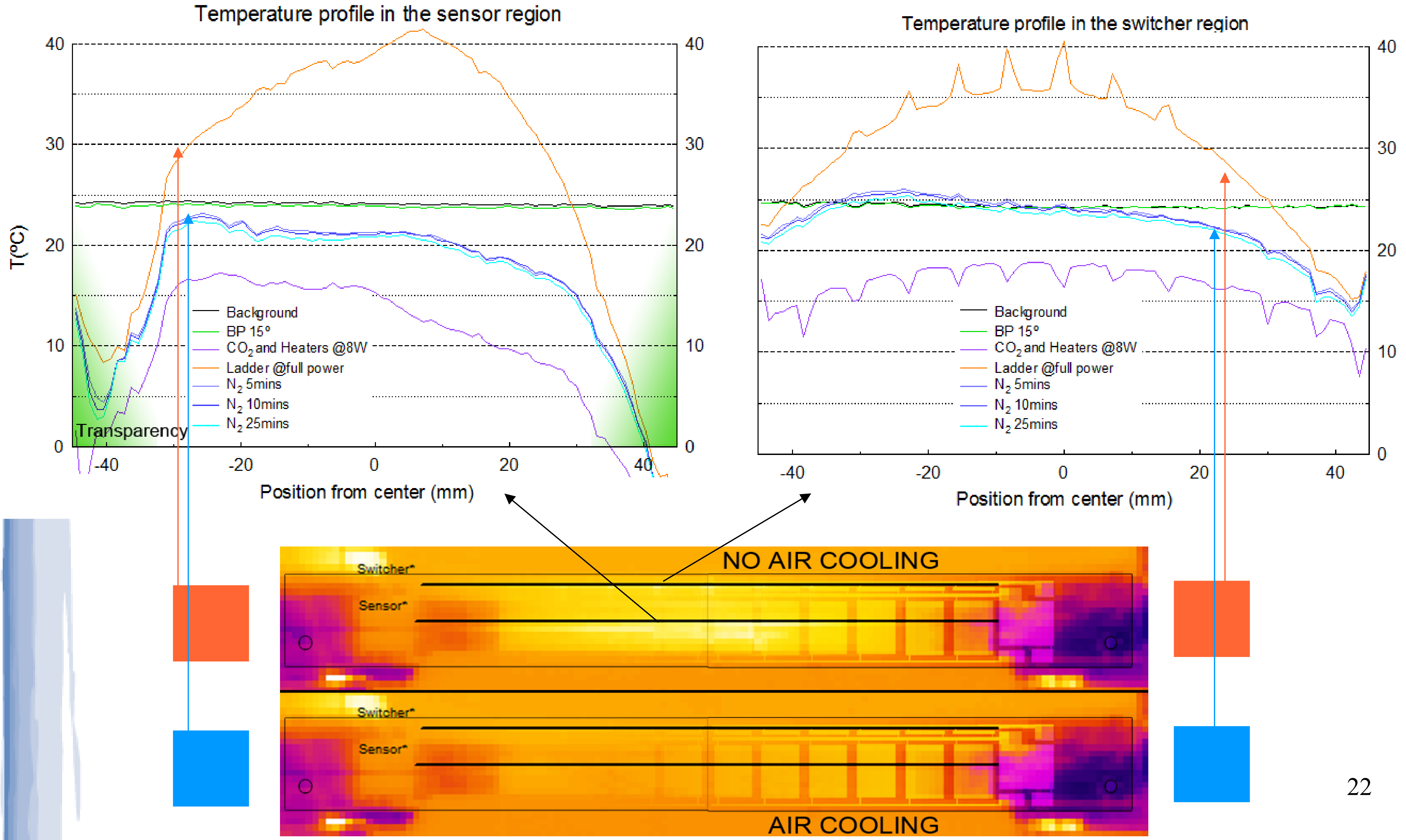


- Conductive+convective cooling decreases sensor T_{MAX} to around or below T_{ROOM}, ~20ºC
- Several measurement cycles showed that we could achieve a $\Delta T<10ºC$ along the surface
- Is a closed system different?

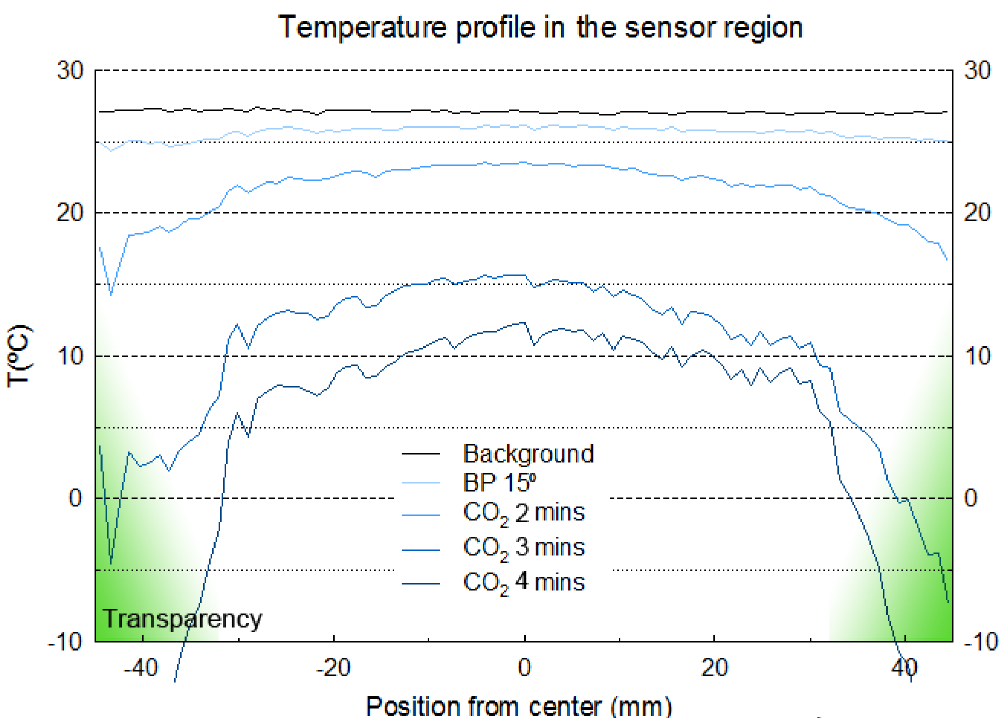


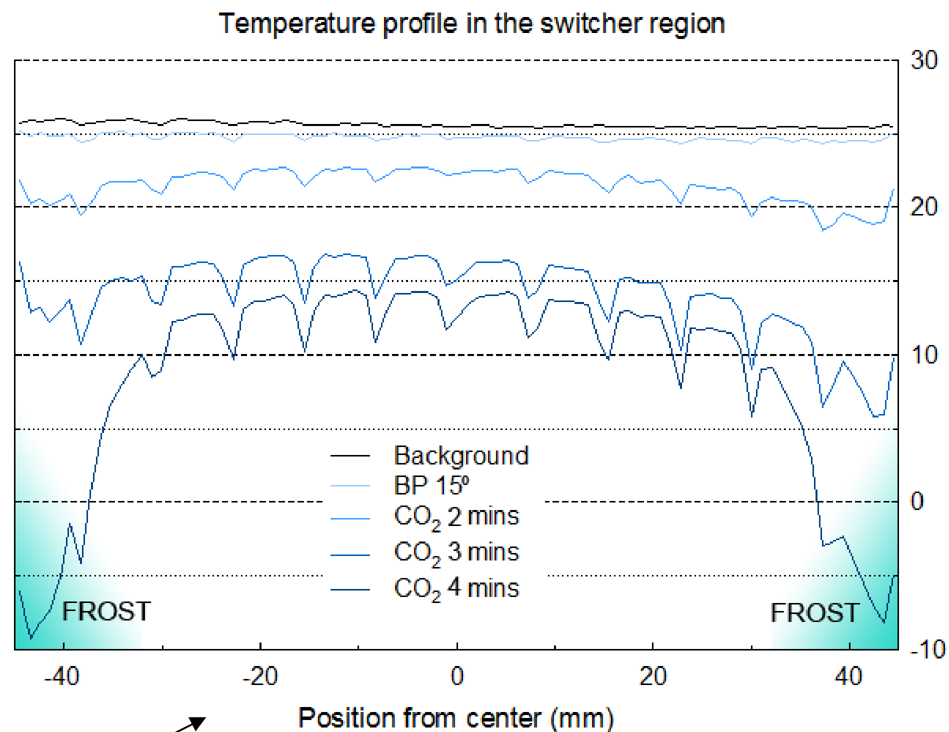
Results

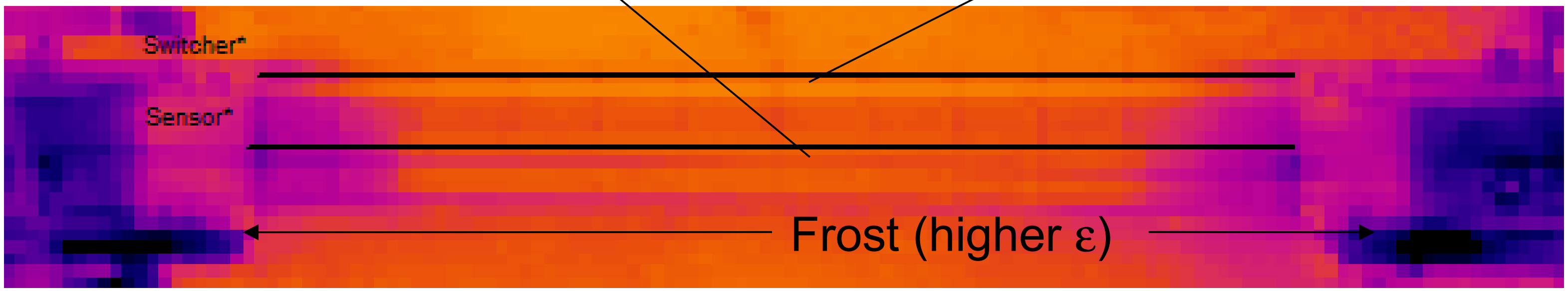
w/o N_2 gas	T_{MAX}~40ºC	ΔT~15ºC
w/ N_2 gas	T_{MAX}~25ºC	ΔT~5ºC



Results

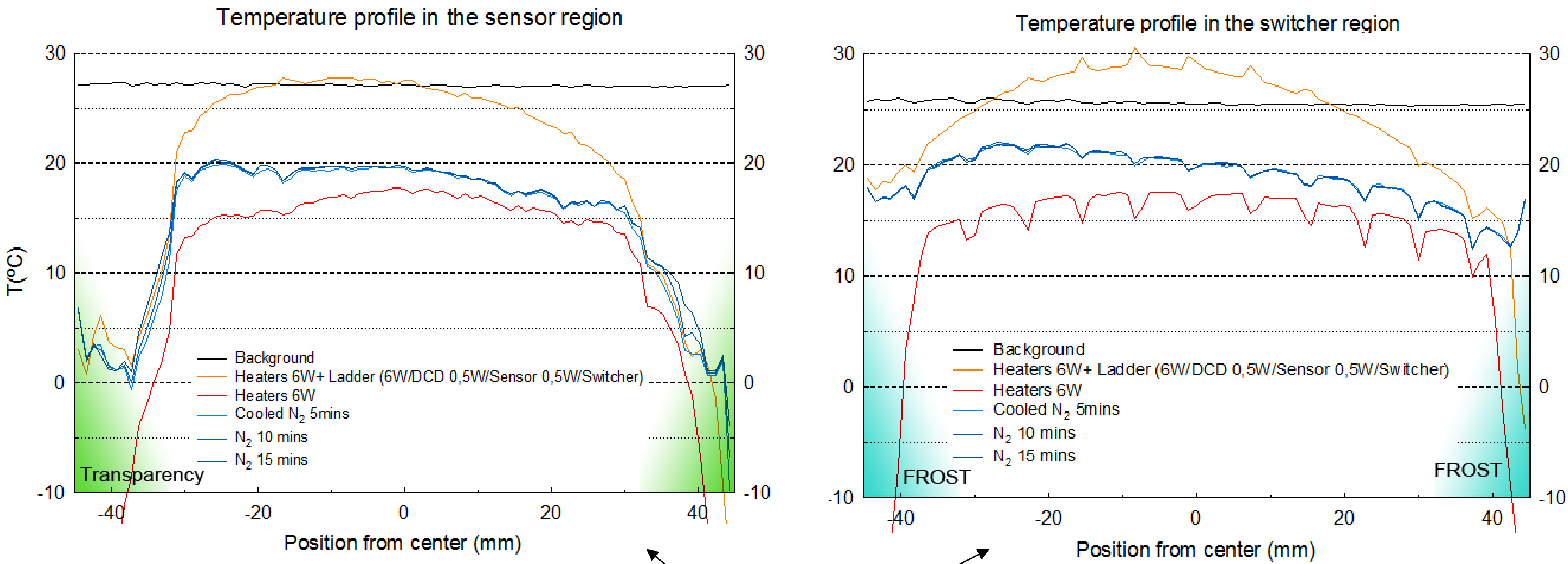


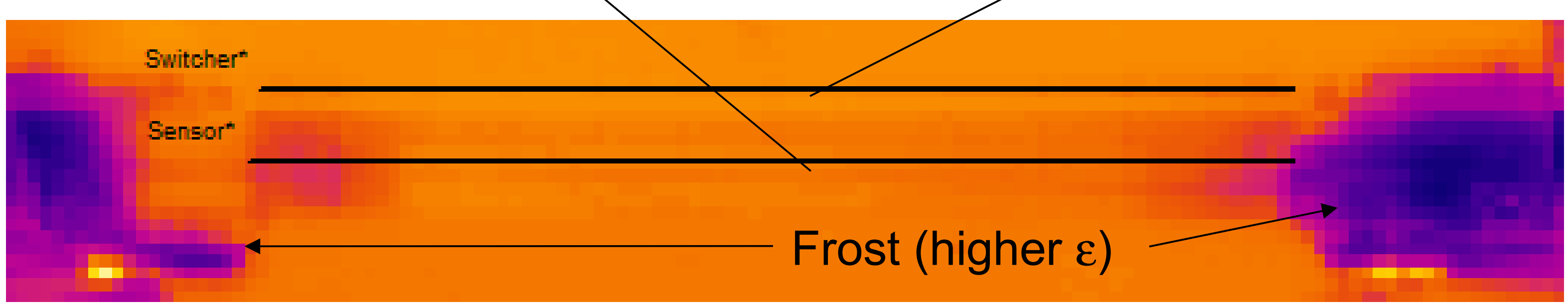




During BP and CB cooling...

Results

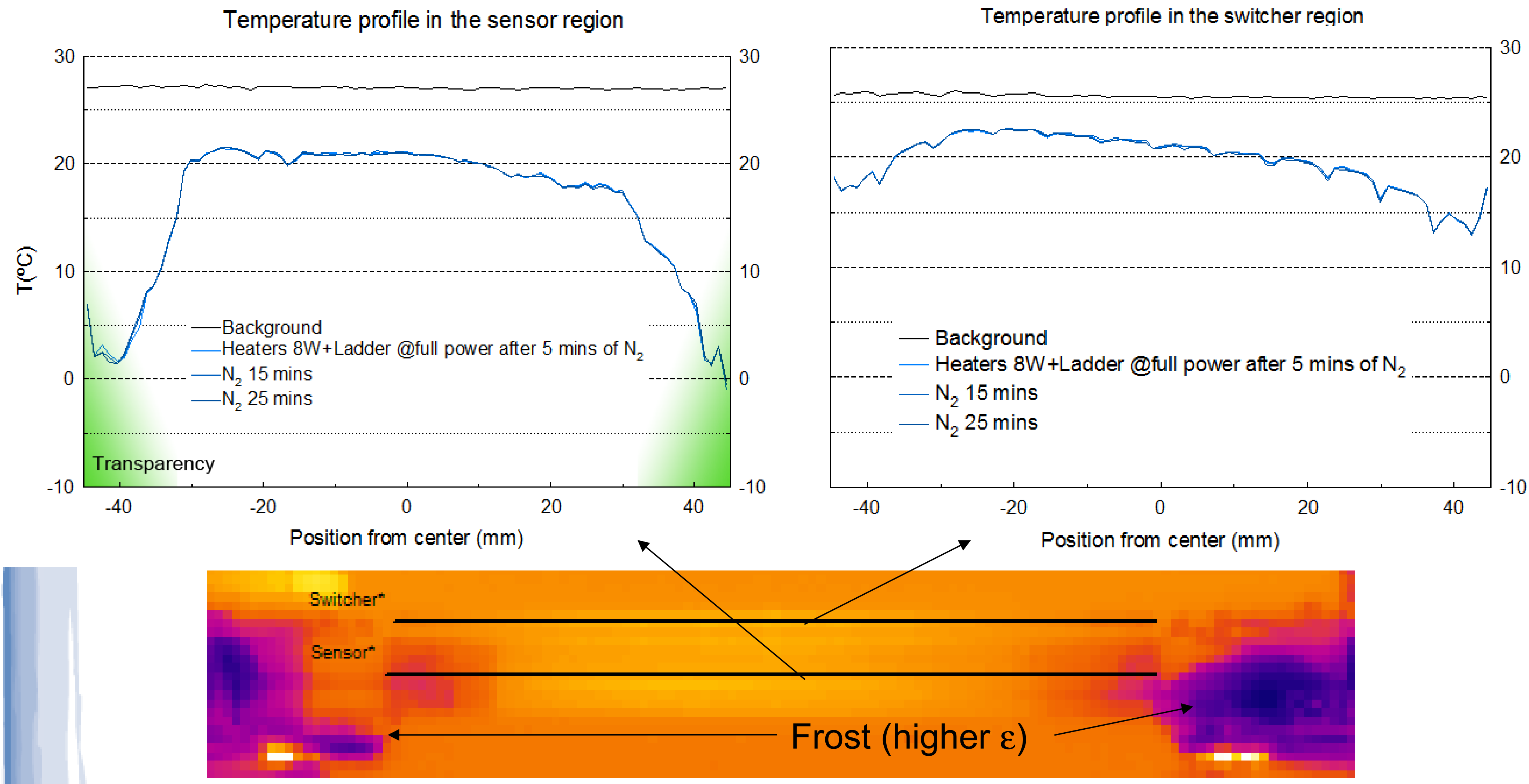




Low power tests (6W in the heaters, 6W in the DCD/DHP module)

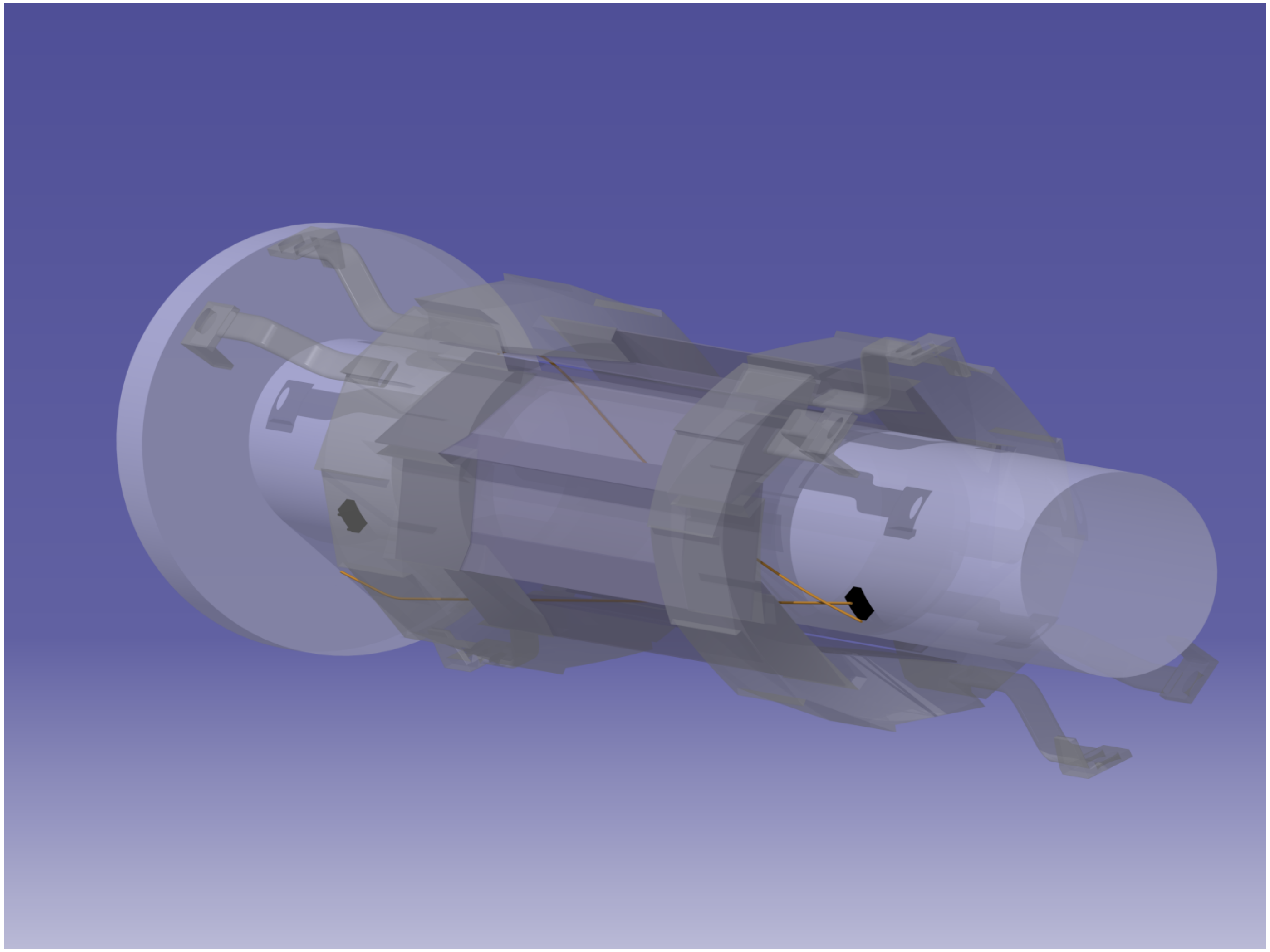
Right DCD/DHP stopped working, measurements only have the left module dissipating heat

Results

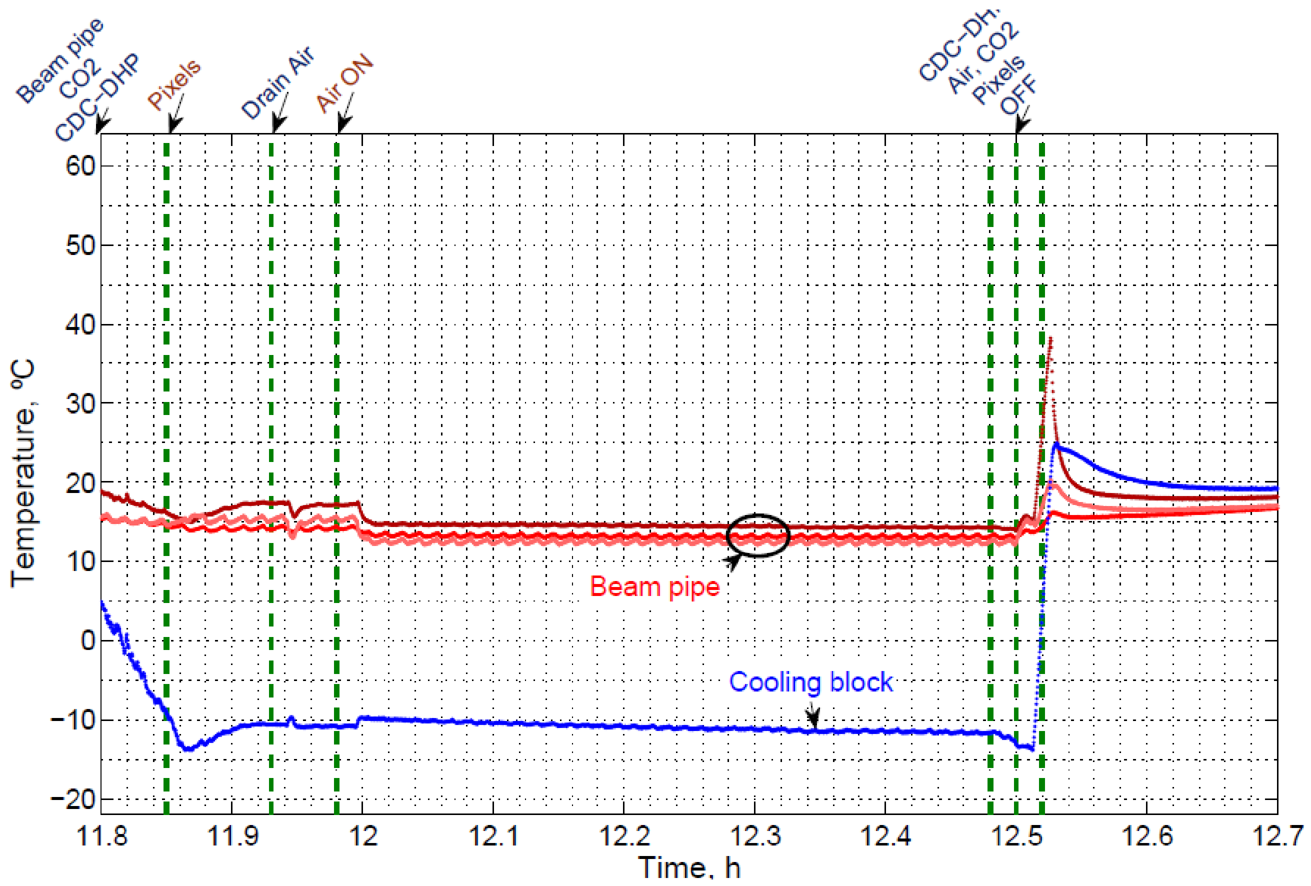


Full power tests (8W in the heaters, 8W in the DCD/DHP module)
(Reminder: no right DCD/DHP dissipating heat**)**

Beam pipe fibers positioning

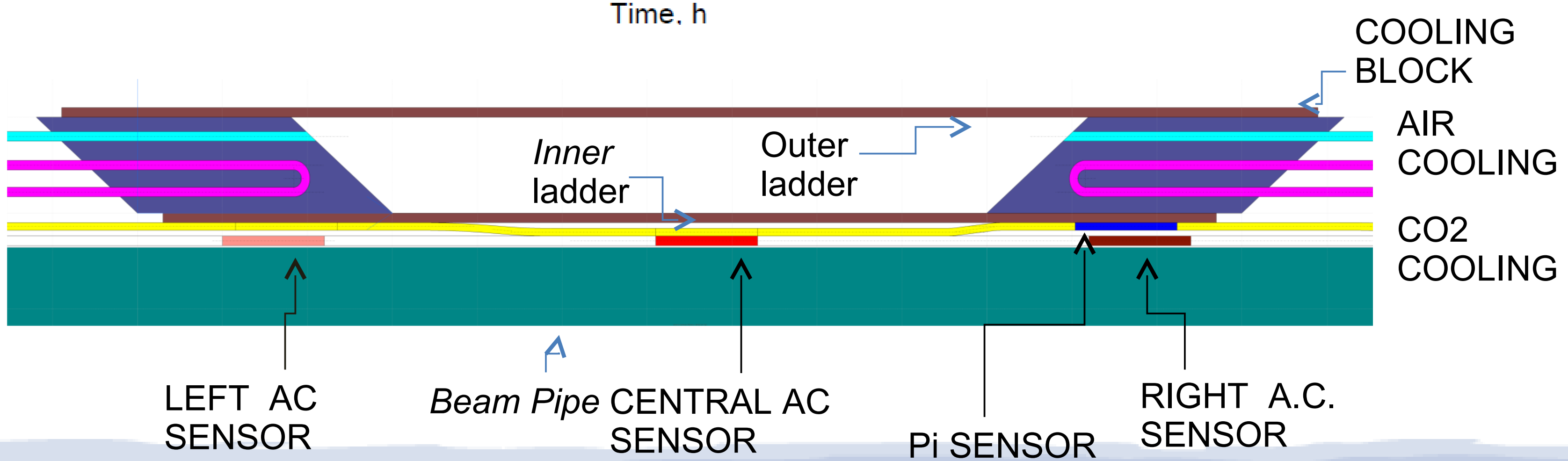


Beam pipe monitoring

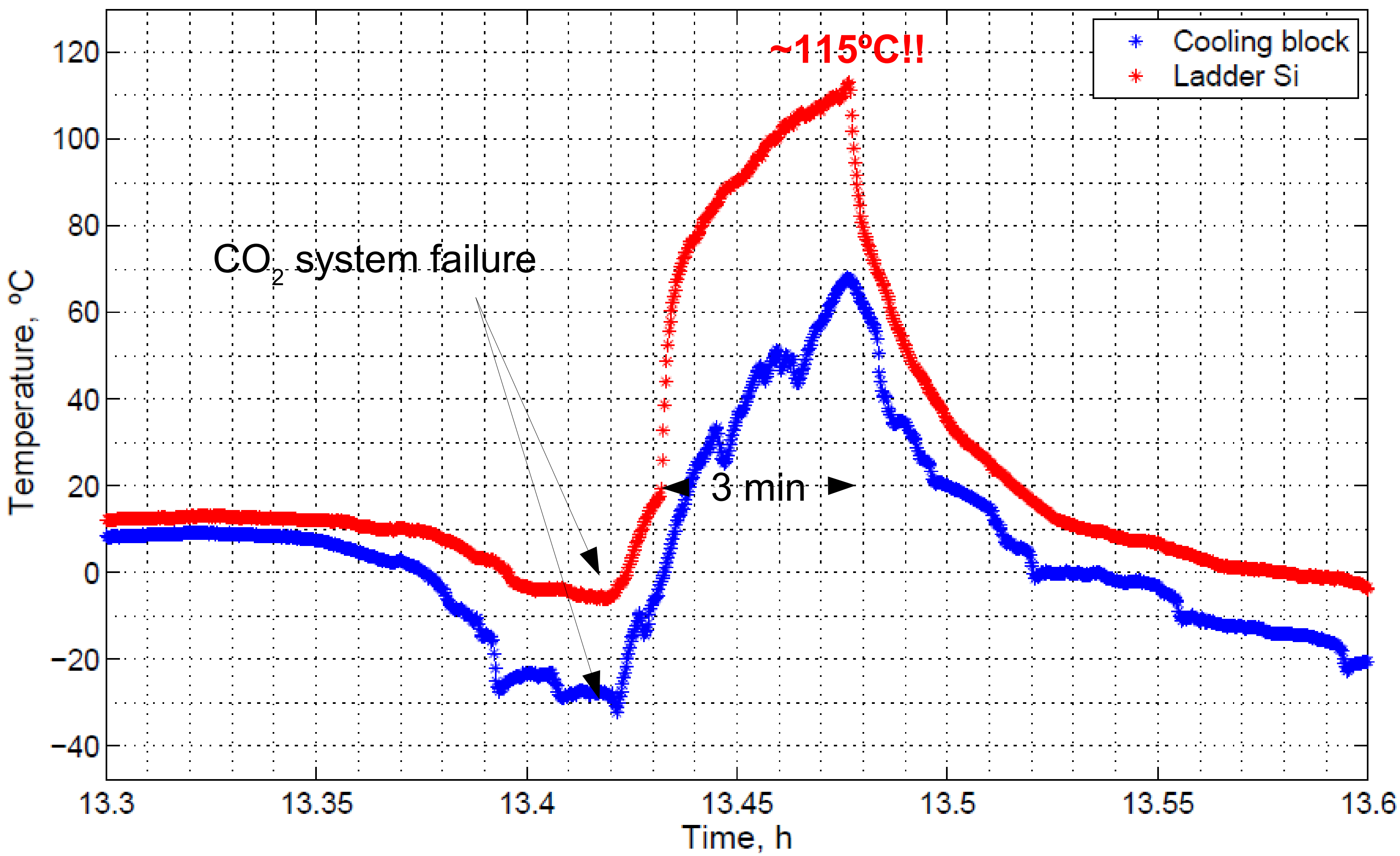


PT100 measurements indicate temperature around 15ºC regardless of cooling and heating elements.

FBG FOS corroborate these results.

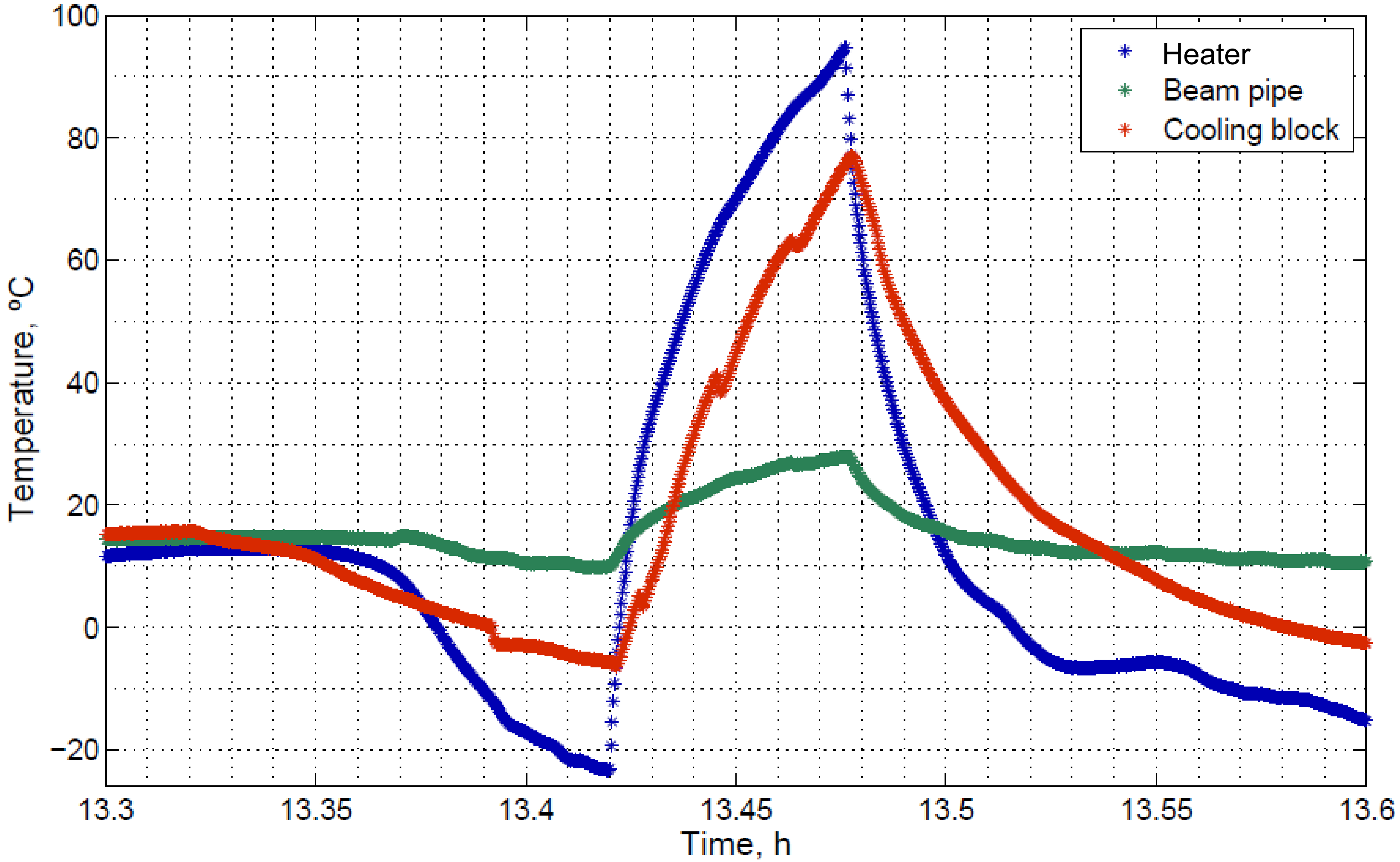


Fast response to CO_2 system failure



CO_2 system failure

(as seen by the beam pipe sensors)



DCD-DHP Temperatures

Step	T(ºC)	Date: 16/5/2012	T(ºC)	Date: 17/5/2012
Background	25,8		23,7	
Beam pipe (15ºC)	24,0		23,6	
CO2 (2 mins)	14,6		-	
After 3 mins	0,1		-	
After 4 mins	Frosted		-	
Heaters @6W	Frosted		-1,4	
Ladder (low power)	Frosted		-	
N2 injection (5 mins)	6,4		-	
After 10 mins	6,8		-	
After 15 mins	6,9		-	
Heaters & Ladder @ full power,	-		12,3	
N2 5 mins	6,7		11,7	
After 15 mins	6,5		11,1	
After 25 mins	6,5		10,2	

Vibrations & Deformation

Experimental setup

- Fully enclosed volume with Cu dummies and Si resistive sample in outer layer.
- Probes

- Contact accelerometers (Piezotronics PCB 352A24)

- Capacitive sensor (Micro-Epsilon Capa NCDT 6100)

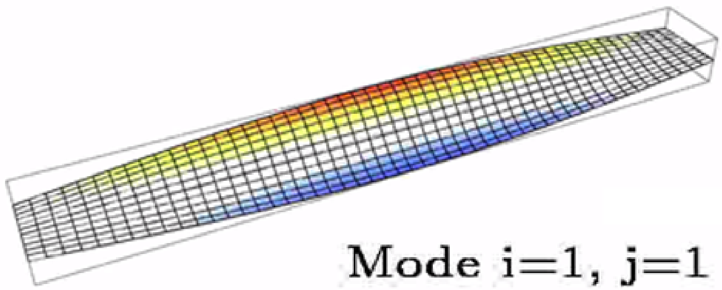
- Sensitivities:

Capacitive sensor: 0.15µm

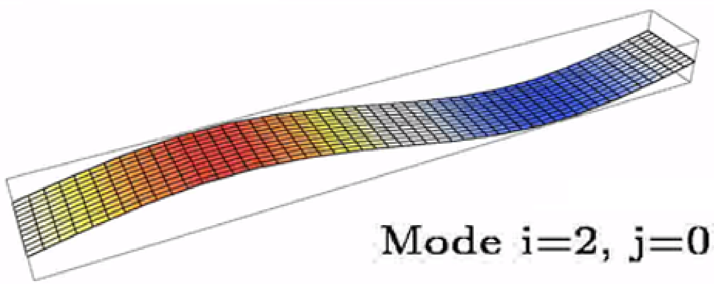
Accelerometers: 0.002 m/s^2

Vibrational modes

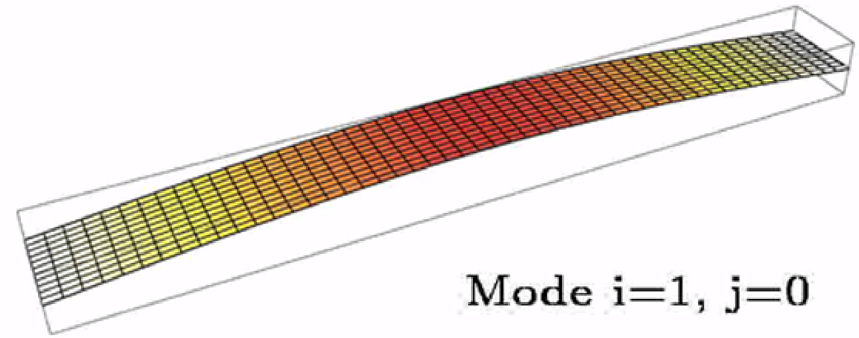
Vibrations of a DEPFET ladder



Mode i=1, j=1



Mode i=2, j=0



Mode i=1, j=0

Courtesy of M. Nebot

$$L_x / L_y \simeq 9$$

$$\omega_{ij} = \pi \sqrt{\frac{\tau}{\rho}} \sqrt{\frac{i^2}{L_x^2} + \frac{j^2}{L_y^2}}$$

$$\eta_{ij}(x, y) = \sin\left(\frac{i\,\pi\,x}{L_x}\right) \cos\left(\frac{j\,\pi\,y}{L_y}\right)$$

Fundamental mode: ω_{10}

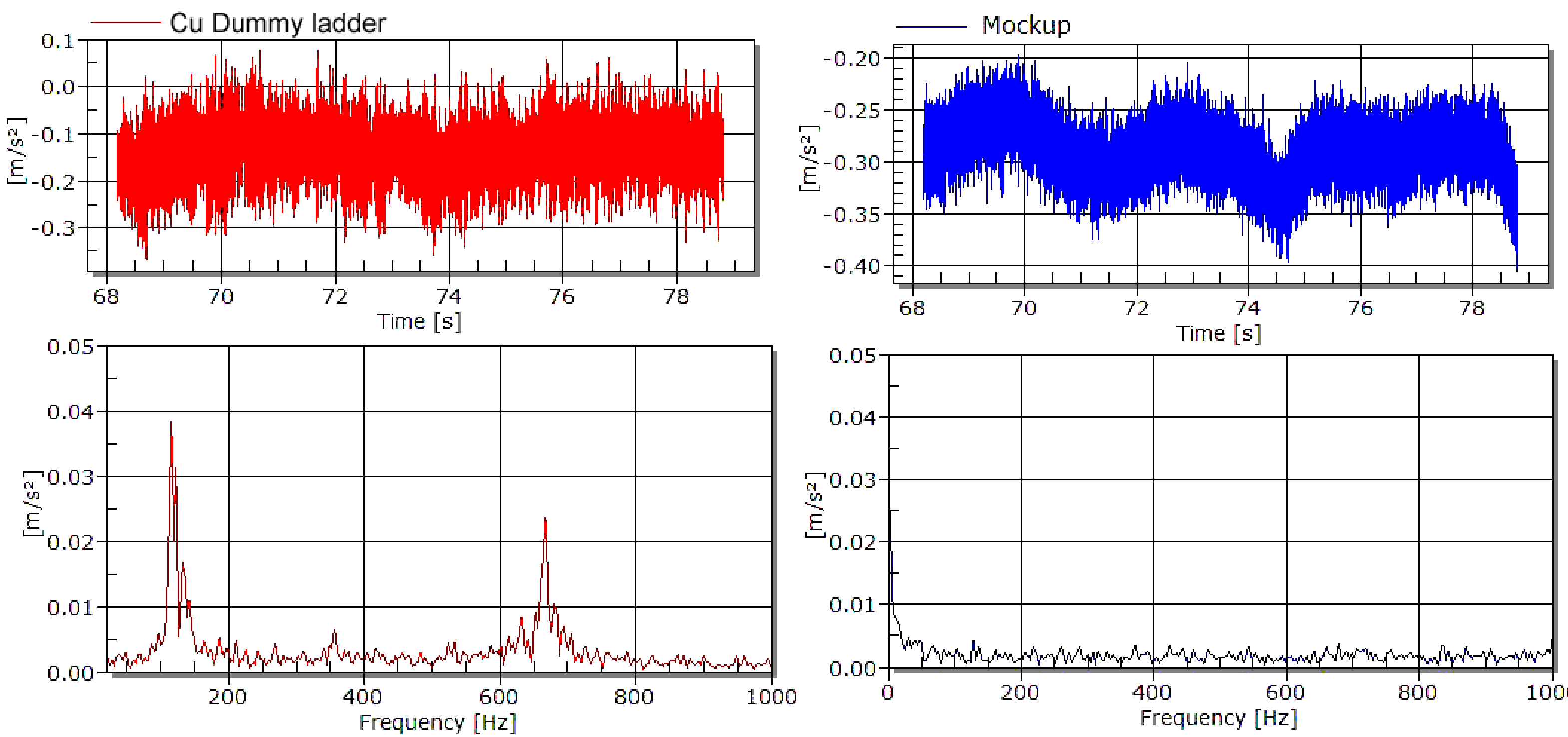
First few modes:

$\omega_{20}/\omega_{10}=2$, $\omega_{30}/\omega_{10}=3$... $\omega_{n0}/\omega_{10}=n$

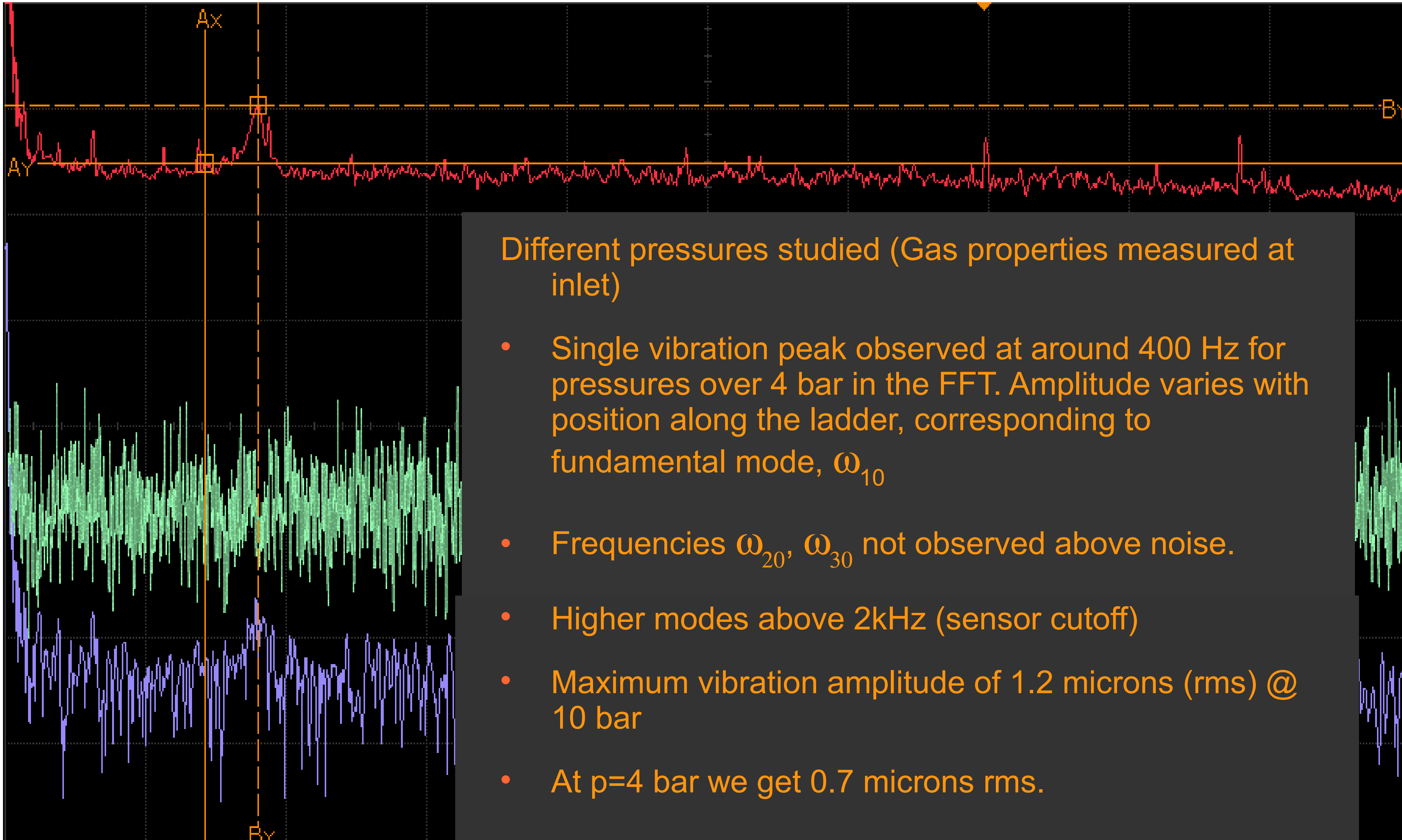
$\omega_{11}/\omega_{10}\sim 9{,}1$

Vibration studies

- Environmental effects characterized by measuring vibrations with accelerometers in other points of the mockup (Cu dummies, support structure, gas pipes)



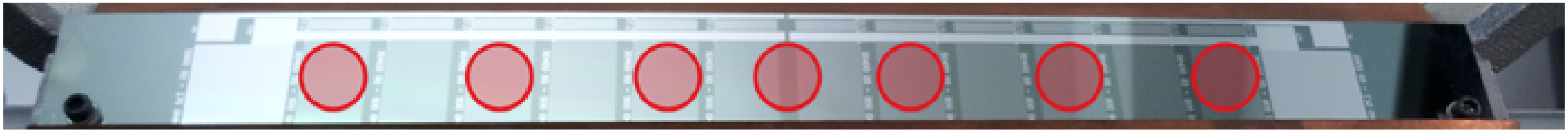
Vibration studies



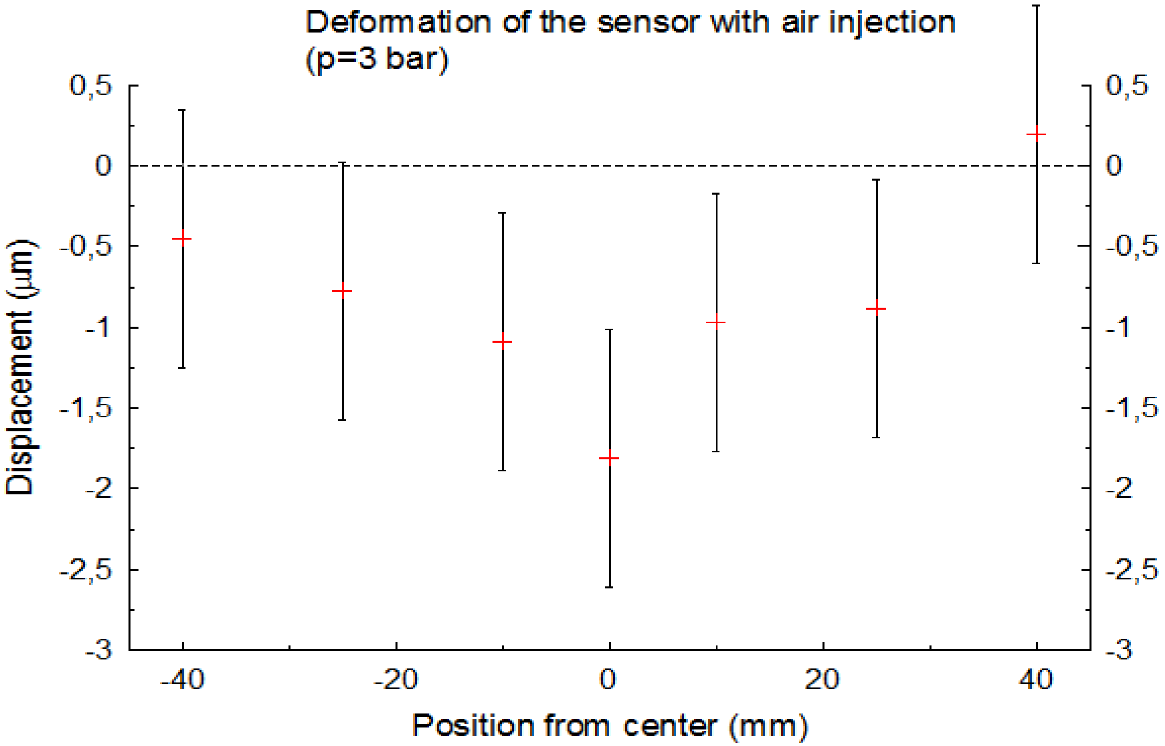
Different pressures studied (Gas properties measured at inlet)

- Single vibration peak observed at around 400 Hz for pressures over 4 bar in the FFT. Amplitude varies with position along the ladder, corresponding to fundamental mode, ω_{10}
- Frequencies ω_{20}, ω_{30} not observed above noise.
- Higher modes above 2kHz (sensor cutoff)
- Maximum vibration amplitude of 1.2 microns (rms) @ 10 bar
- At p=4 bar we get 0.7 microns rms.

Deformation studies



- Bowing deformation, scales with pressure
- Maximum deformation of 8.1±0.8 μm (@ 10 bar)
- Δy_{MAX} for cooling conditions (2 m/s, 3 bar, 15 L/min): 1.8±0.8 μm



Deformation vs pressure