Ultra Low Mass Cooling for Fine Pixel Detectors

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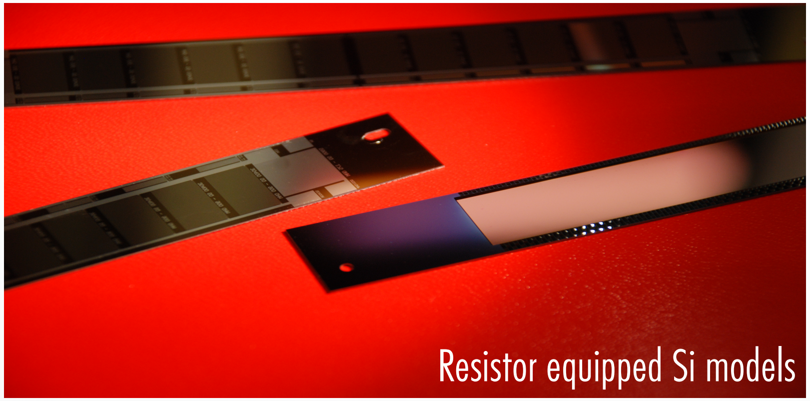
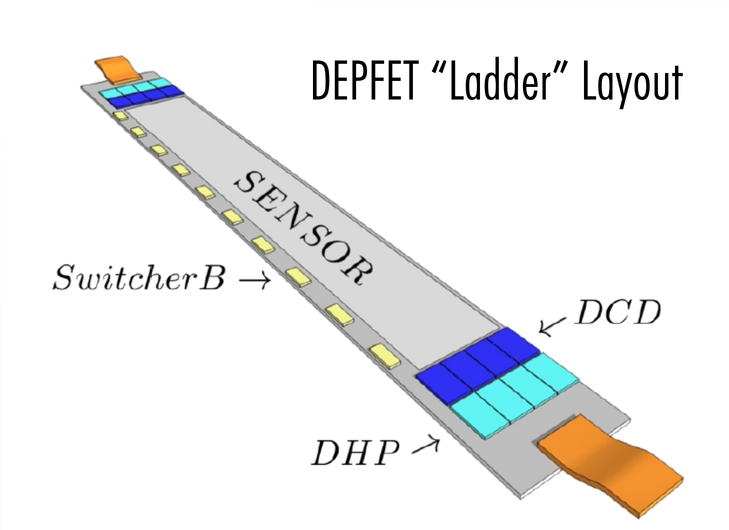
Outline

- Motivation
- Thermal Dissipation studies:
  - Setup
  - Results
- Vibration and deformation studies
- Conclusions

Motivation

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





- Traditional conductive cooling defeats the whole purpose (high material budget)

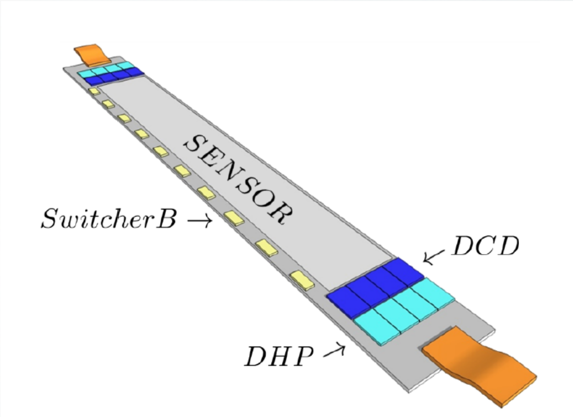
  → The solution lies in low mass systems such as injection of gaseous coolants (convective cooling)

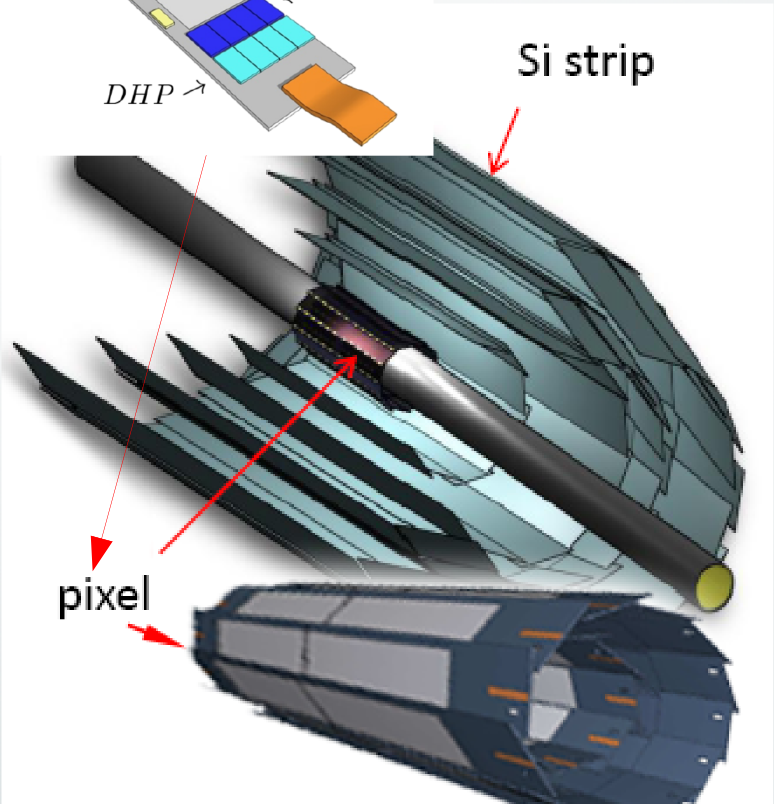
- Layout designed with the highest power dissipating elements in the end flanges

Motivation

Belle II Pixel detector (2 Layers)

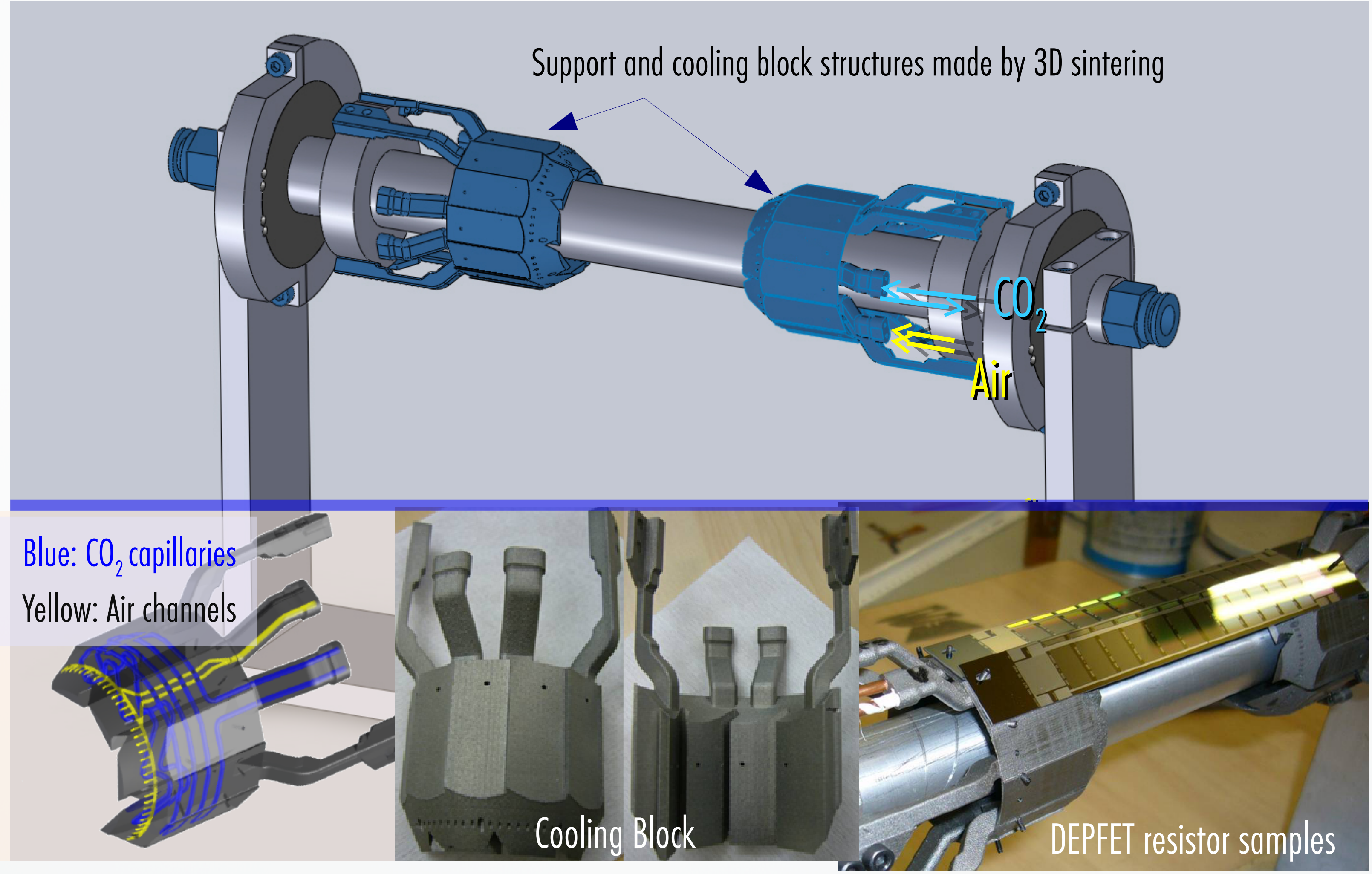
- 75 µm thin sensors in a 450 µm support frame
- 12 Ladders in the outer layer and 8 Ladders in the inner layer
- Power dissipated
  - 1 Watt in the sensor region
  - 1 W in the switchers
  - 8 W in each FEE end
- Angular acceptance ranges from 17º to 150º
- The support structure is designed allowing convective cooling in the sensor area and CO_2 active cooling out of the acceptance region



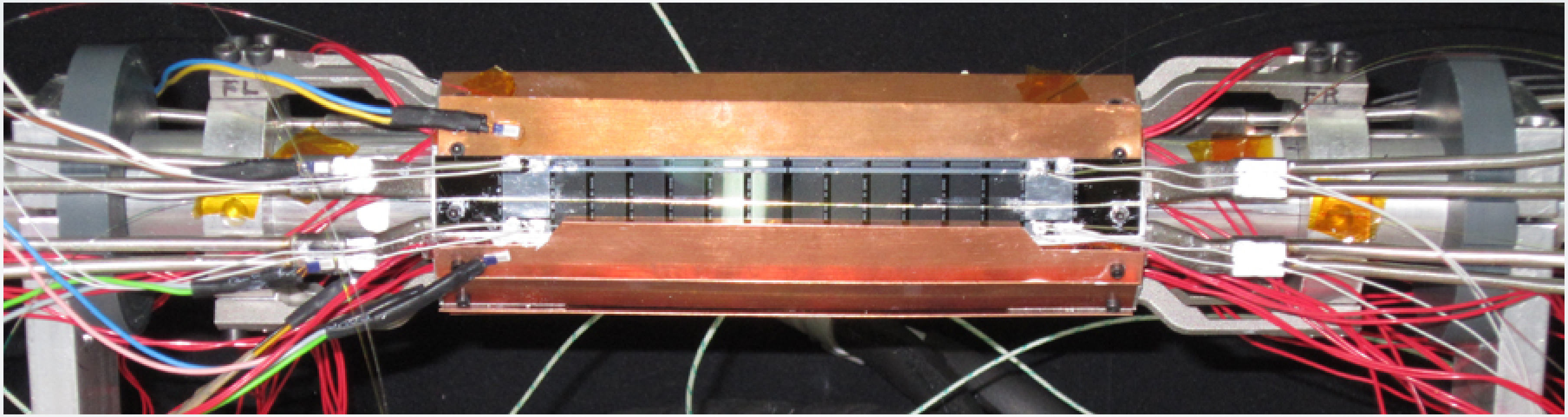


Belle II SVT and PXD

Support/Cooling Hybrid Structure

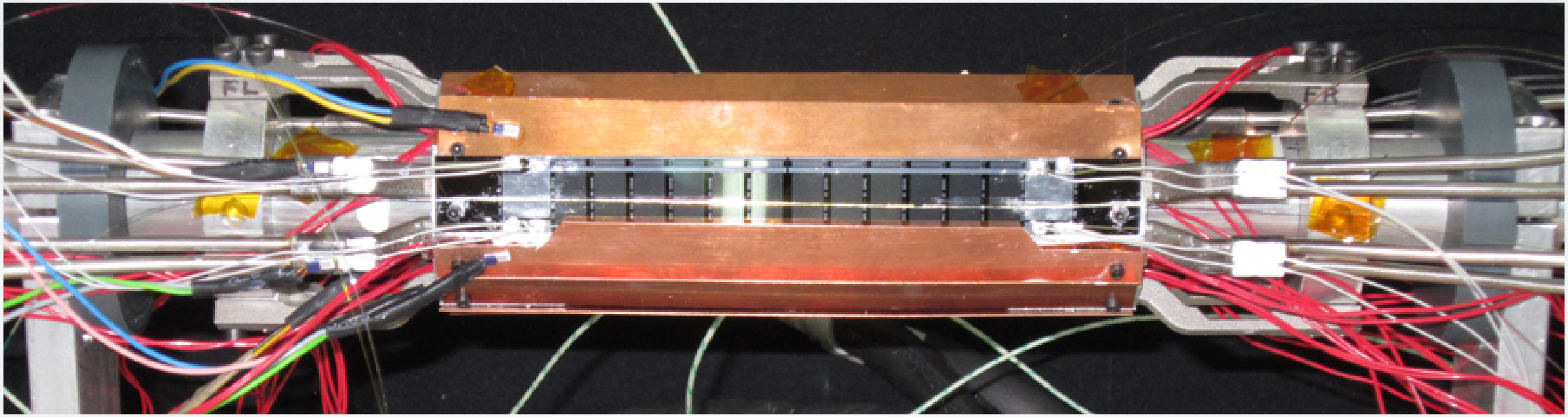


Experimental Setup



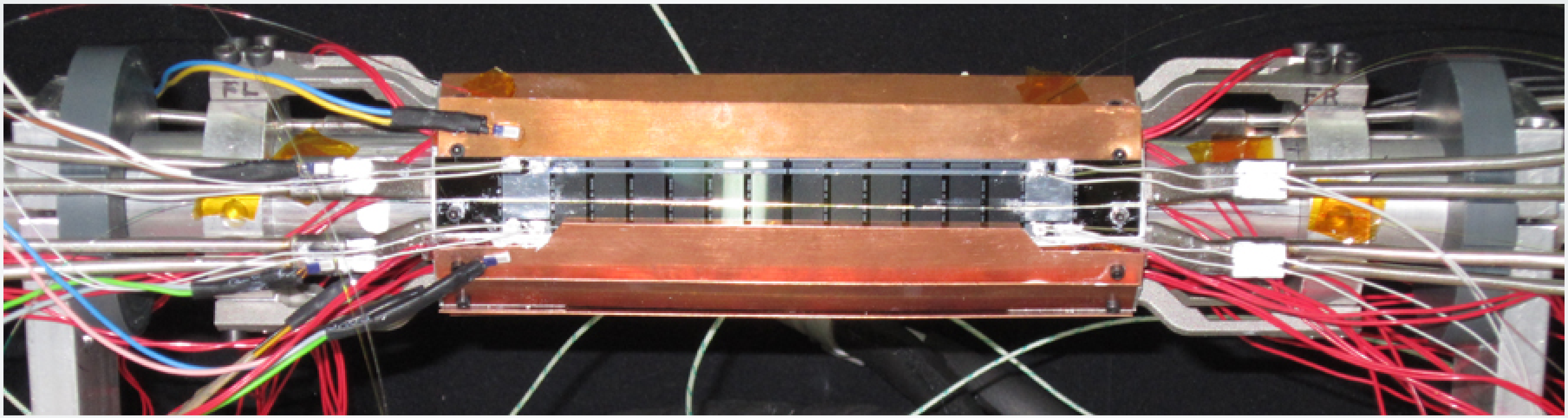
- Valencia PXD Mockup
  - Stainless Steel Cooling Blocks
  - Enclosed with copper foil ladders equipped with resistive heaters in the end flanges for both layers
  - A single Si thinned detector with printed Al resistors

Experimental Setup



- Cooling:
  - Liquid CO_2 circulated in the Cooling Blocks at -35ºC
  - Injection of cooled (~0ºC) N_2 Gas towards the sensor region at 3 bar and 15 L/min flow rate
  - Beam Pipe kept at 15ºC with a composite liquid coolant.

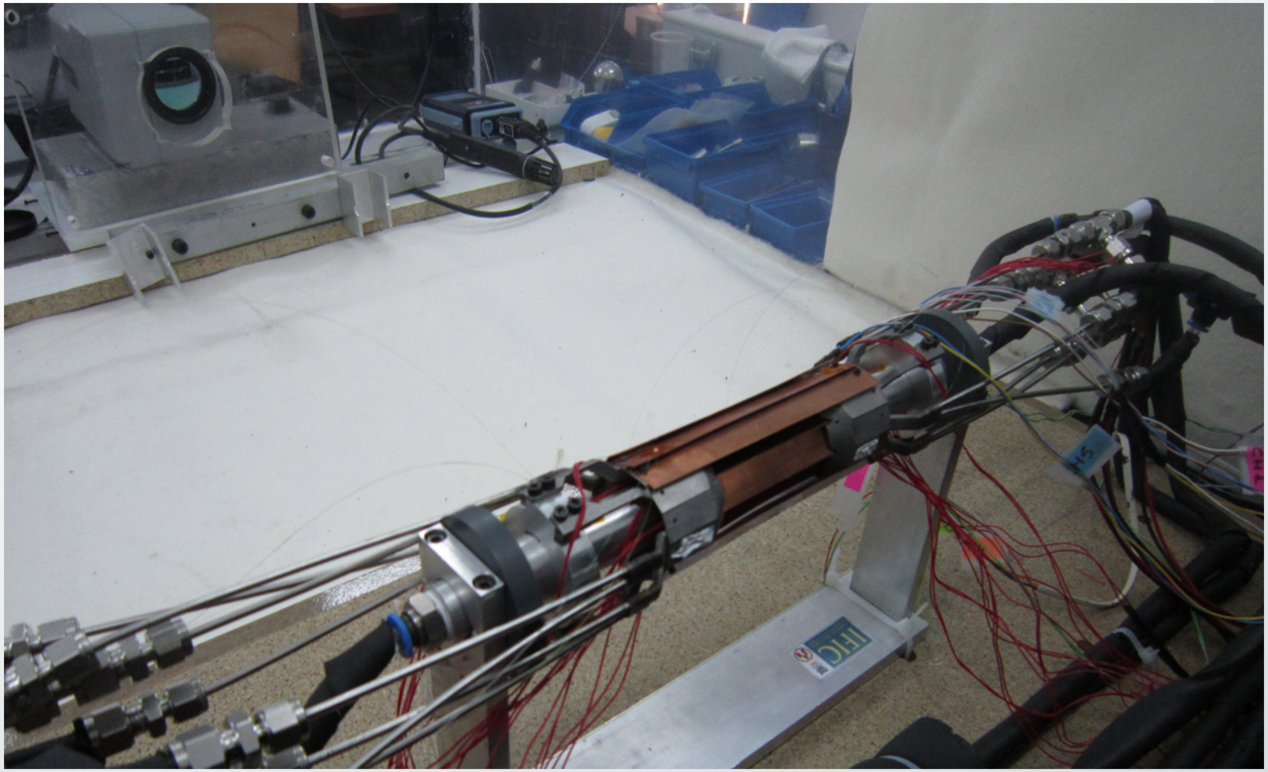
Experimental Setup



- Measurement equipment:
  - Infrared Thermal Imaging Camera
  - Fiber Bragg Grating (FBG) temperature and humidity sensors
  - Pt100 probes

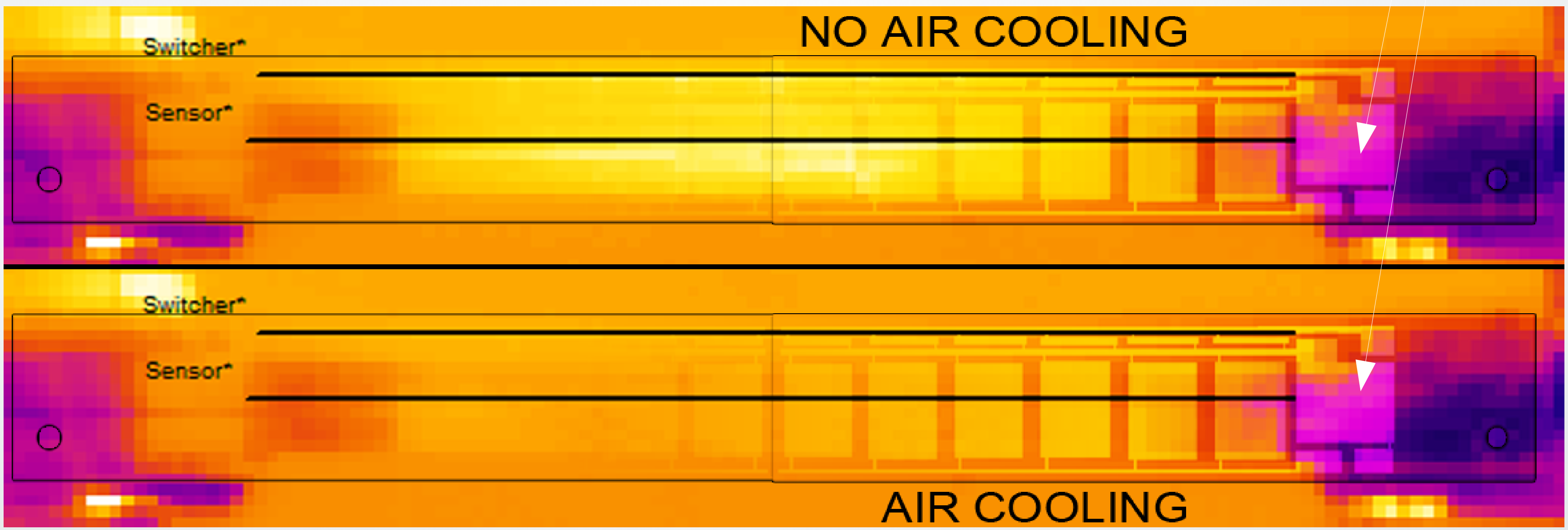
Experimental Setup

- The whole mockup is enclosed in a sealed methacrylate box, which allows control of the atmosphere
  - Humidity must kept very low to avoid frosting, which affects the emissivity and complicates infrared measurements.
  - Environment temperature is stable inside the box



Results

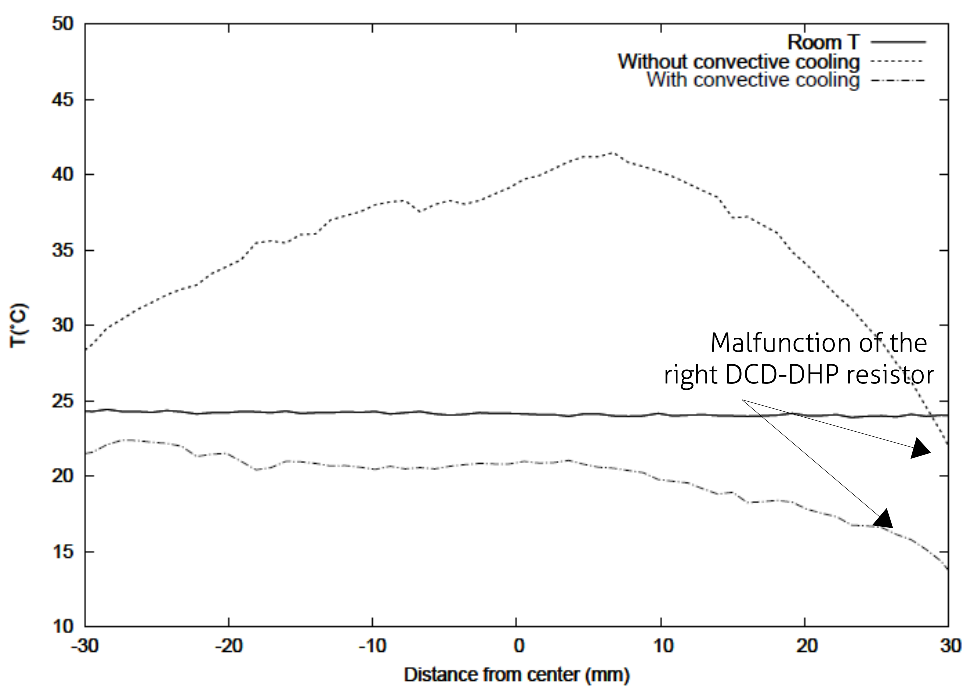
Malfunction of the
right DCD-DHP resistor



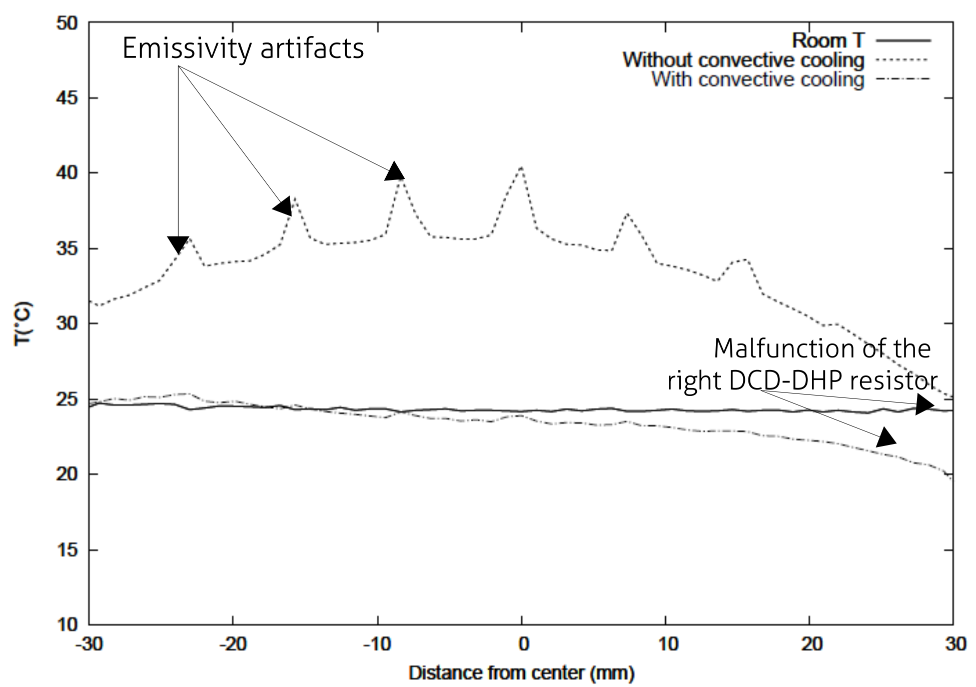
Sensor T	Ambient T = 25ºC	
Without convective cooling	T_{MAX}=~40ºC	ΔT=~15ºC
With convective cooling	T_{MAX}=~25ºC	ΔT=~5ºC

Results

Sensor surface



Switcher surface



Sensor T	Ambient T = 25ºC	
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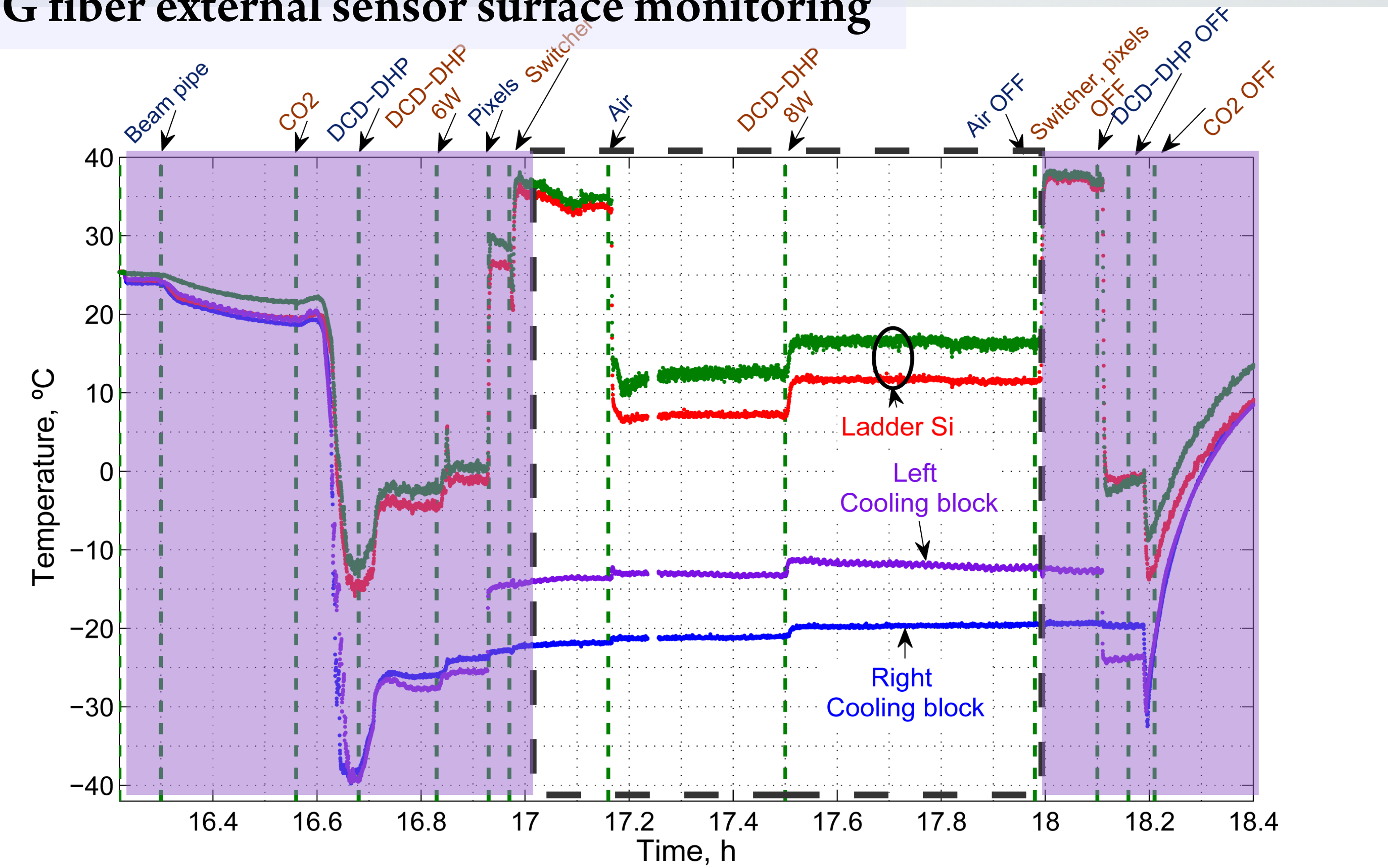
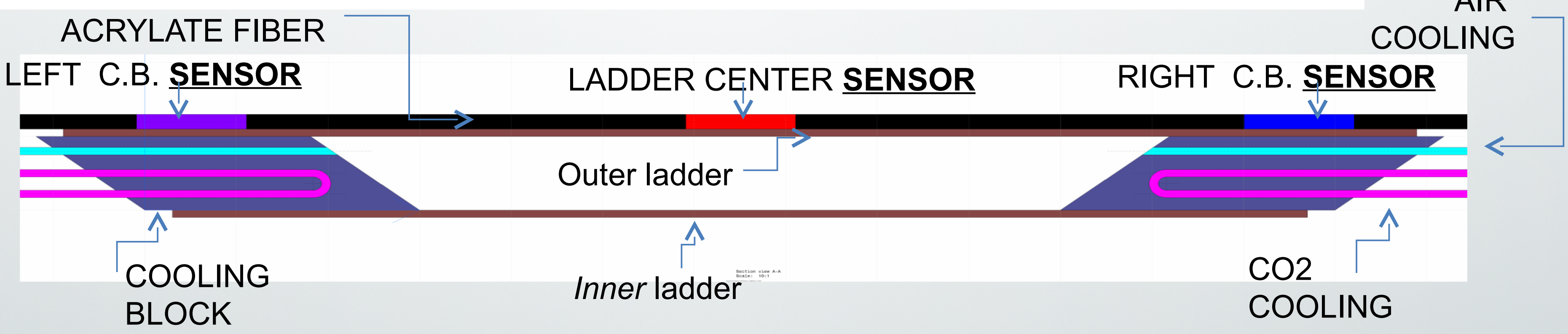
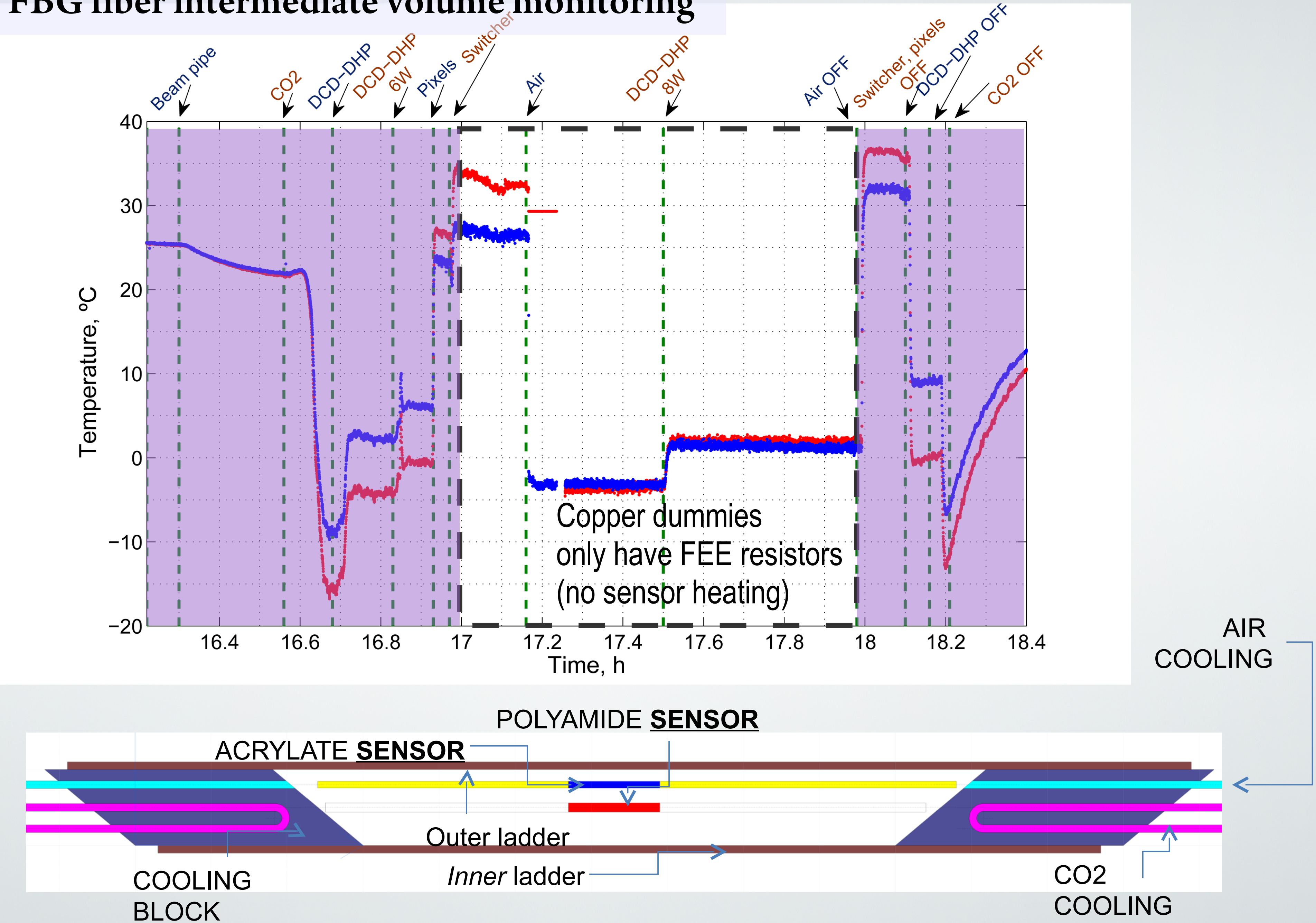
FBG fiber external sensor surface monitoring



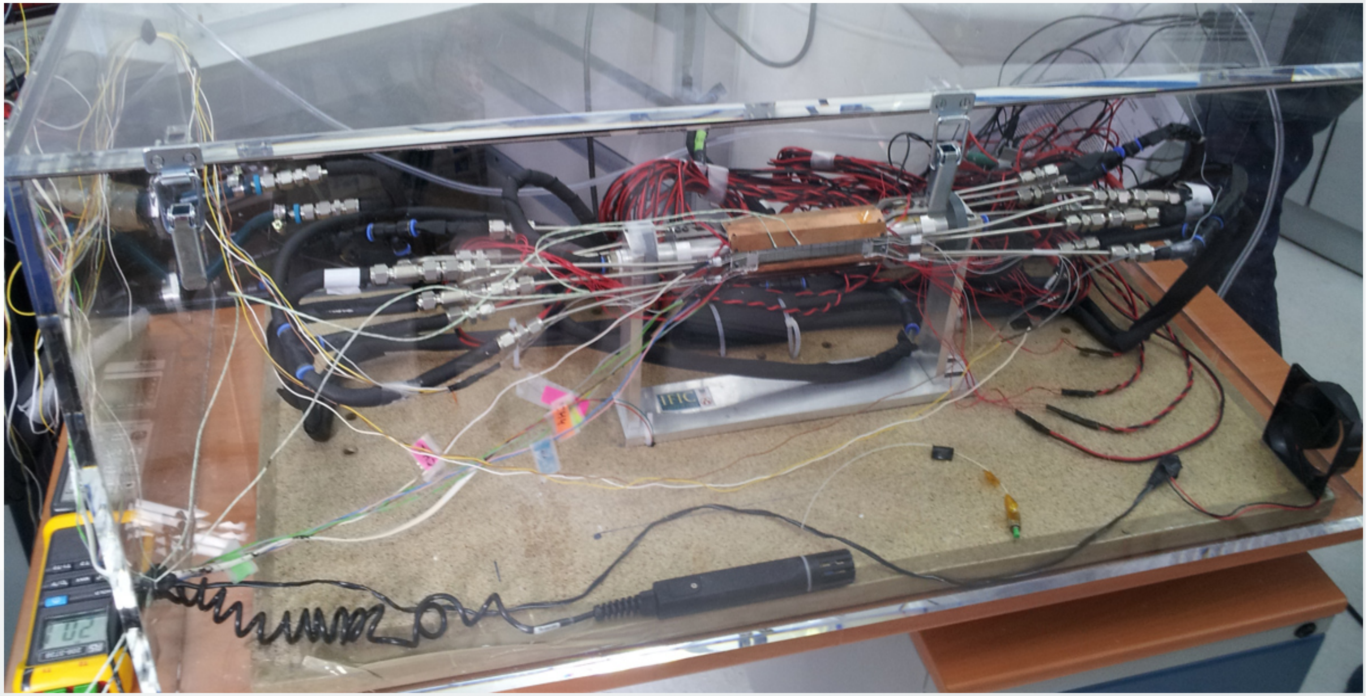


FBG fiber intermediate volume monitoring

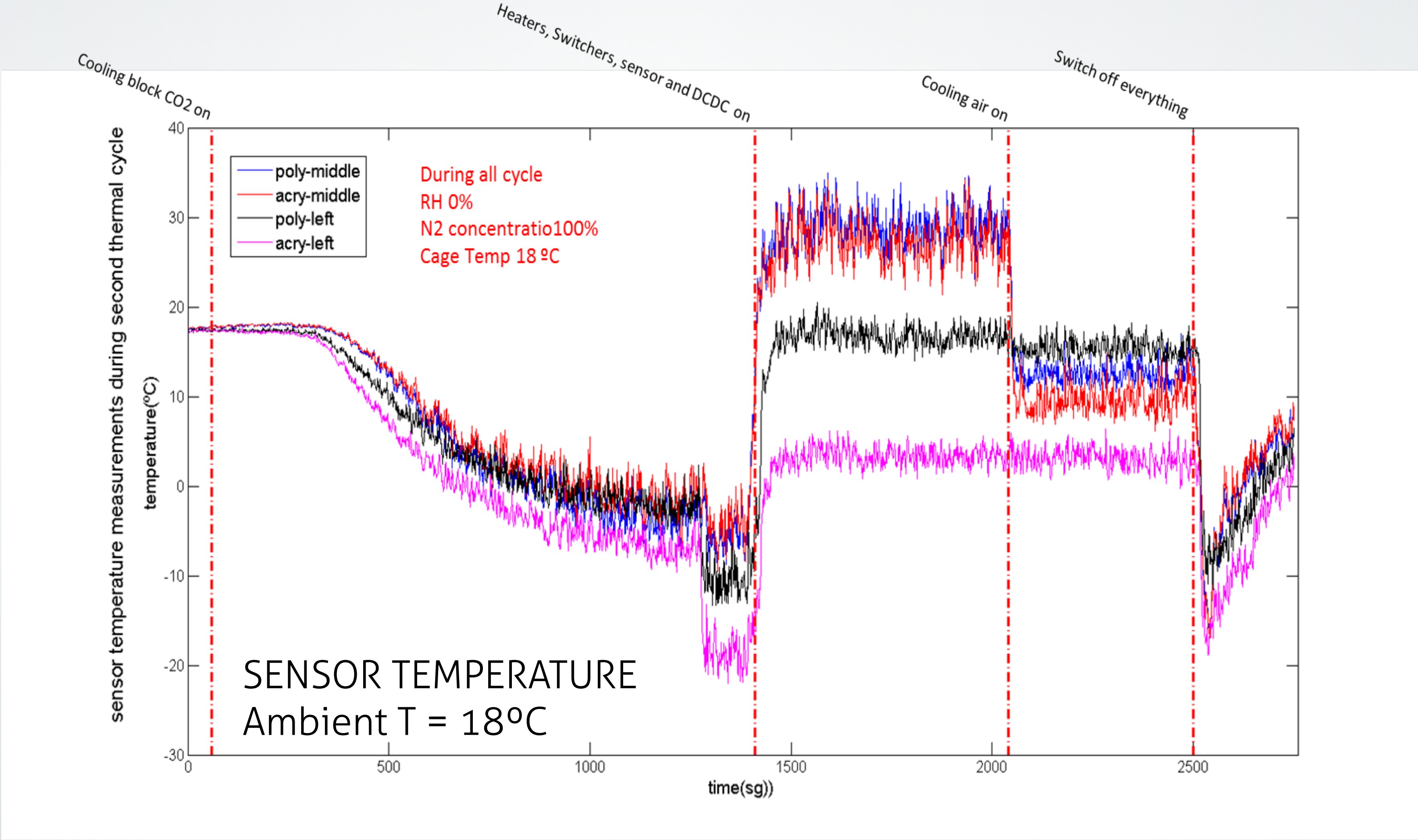


Different Environment Temperatures

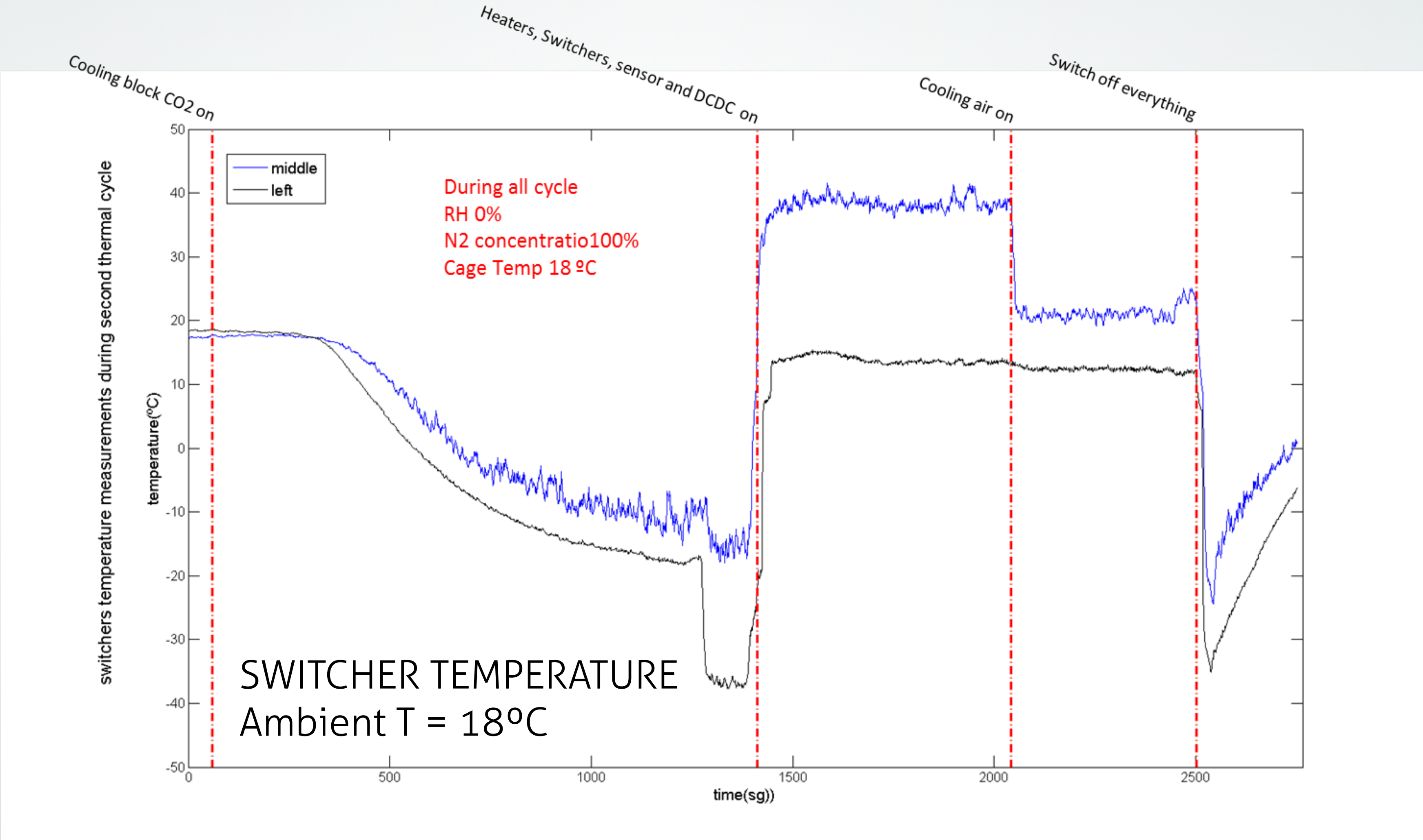
- The whole mockup was moved to a smaller box, thermally isolated
- Cooling of the environment temperature
  - Pure N_2 gas atmosphere
- No thermal imaging due to space constraints
  - FBG cross referenced with Pt100s



Results


Cooling block CO2 on
Heaters, Switchers, sensor and DCDC on
Cooling air on
Switch off everything
sensor temperature measurements during second thermal cycle
temperature(ºC)
time(sg))
poly-middle
acry-middle
poly-left
acry-left
During all cycle
RH 0%
N2 concentratio100%
Cage Temp 18 ºC
SENSOR TEMPERATURE
Ambient T = 18ºC
40
30
20
10
0
-10
-20
-30
0
500
1000
1500
2000
2500

Results



Cooling block CO2 on
Heaters, Switchers, sensor and DCDC on
Cooling air on
Switch off everything
middle
left
During all cycle
RH 0%
N2 concentratio100%
Cage Temp 18 ºC
SWITCHER TEMPERATURE
Ambient T = 18ºC
switchers temperature measurements during second thermal cycle
temperature(ºC)
time(sg))
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
500
1000
1500
2000
2500

Results

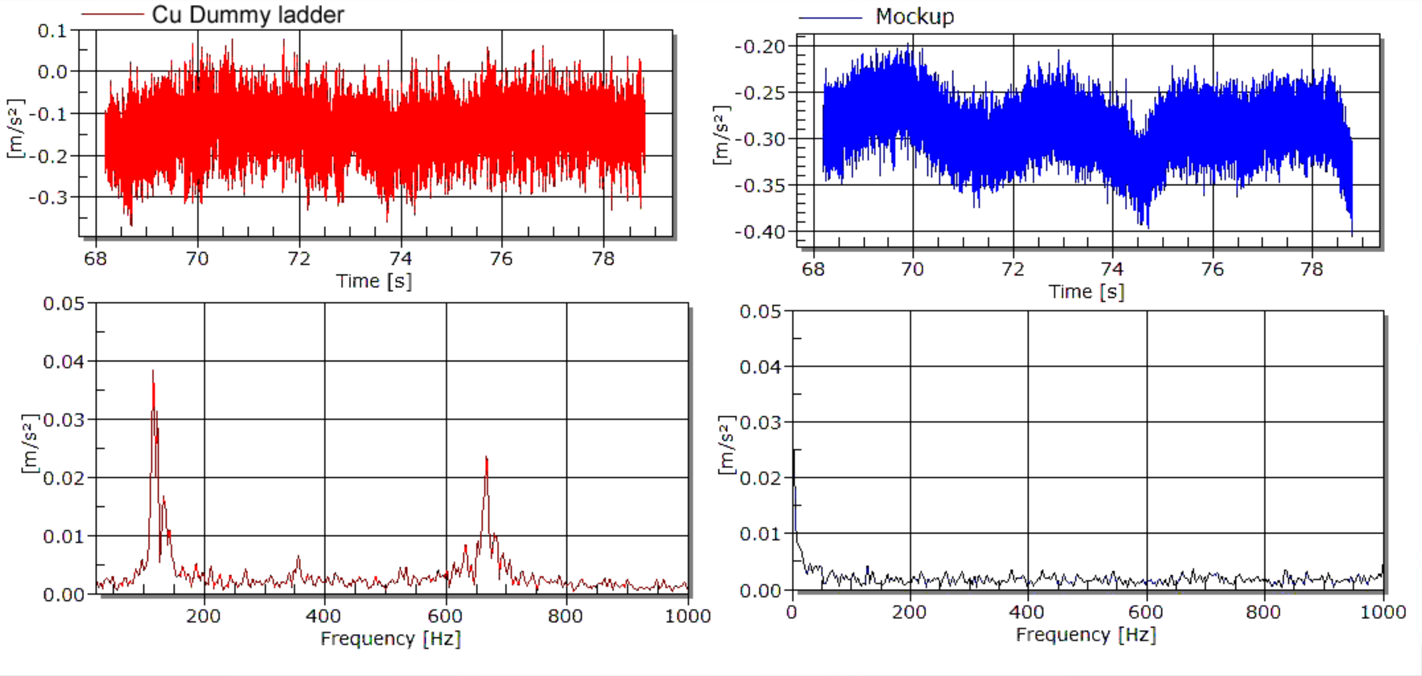
- Sensor temperature with convective cooling depends on the ambient temperature

Ambient T (±2 °C)	No air cooling T(±2°C)		Air cooling T(±2°C)		T_{hot}-T_{cool}(±3°C)	
	Sensor	Switcher	Sensor	Switcher	**Sensor**	**Switcher**
25	35	37	20	25	**15**	**12**
18	28	39	10	21	**18**	**18**
13	24	36	7	18	**17**	**18**

- Cooled N_2 gas at 3 bar and 15 L/min flow rate
- T gradient along the ladder ~5°C

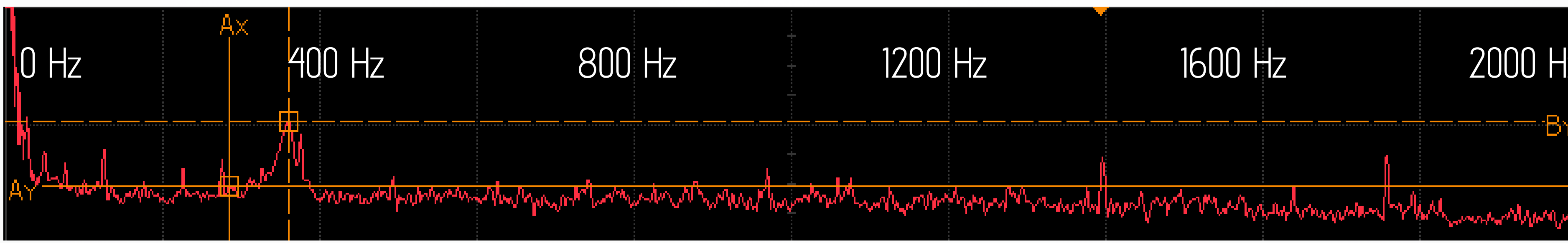
Vibration Studies

- Air injection could cause vibrations in the ladder which may compromise the physical integrity of the thin sensors.
- We measured the displacement and vibrations using capacitive distance sensors and accelerometers.
  - The whole mockup was studied to isolate the effect of the gas injection



Vibration Studies

- No vibrations were observed below 2kHz (sensor cutoff) with the cooling requirements (3 bar in the entrance pipes).
  - A ~400Hz peak appears at p=4 bar and above, amplitude 0.7μm rms



Conclusions

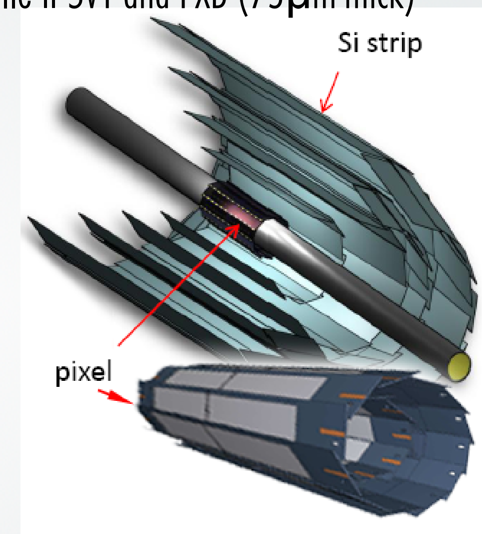
- Cooling of a working fine pixel sensor works properly
  - Combining contact and convective cooling

- No vibrations observed at the pressures studied for cooling

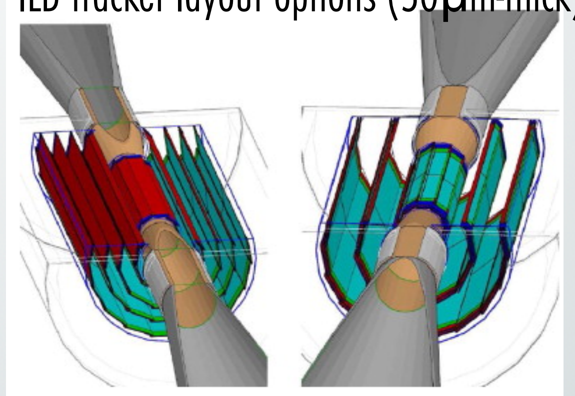
Relevance for ILD

- Belle II
  - 360 W entire pixel detector
  - Convective cooling in the thin sensor area
  - CO_2 active cooling out of the acceptance
- ILD
  - Naively ~900 to ~1080 W total
  - ~4 to 5 W with power pulsing (ideal 1:200 duty cycle)
  - No active cooling due to angular acceptance requirements
    - **Convective cooling (performance demonstrated in Belle II)**

Belle II SVT and PXD (75μm-thick)



ILD tracker layout options (50μm-thick)



Single sided
5 Layers

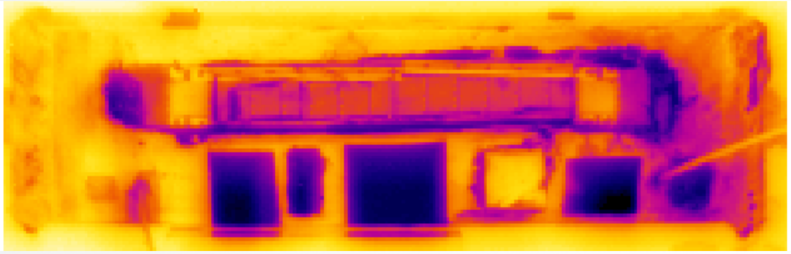
Double sided
3 Layers

Thank you very much

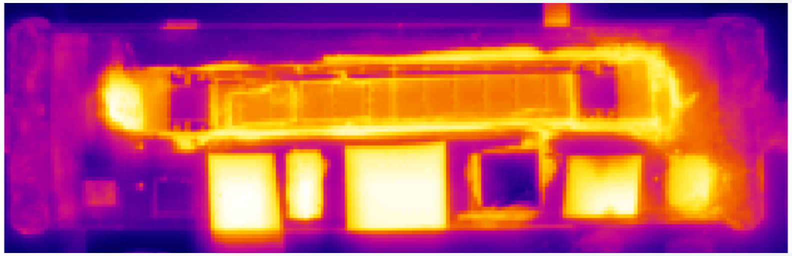
Backup

Emissivity calibration

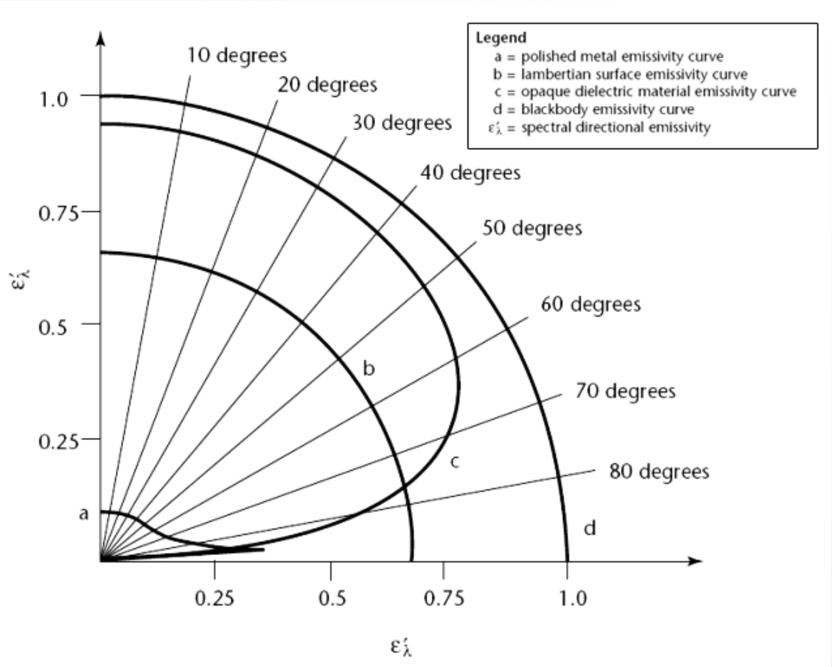
Variable temperature box with different surface samples, measured normal incidence emissivities at different temperatures and found no significant behavior with temperature. Emissivity corrections are done by adjusting ε until temperature is consistent with Pt100/thermocouple measurements



-20ºC



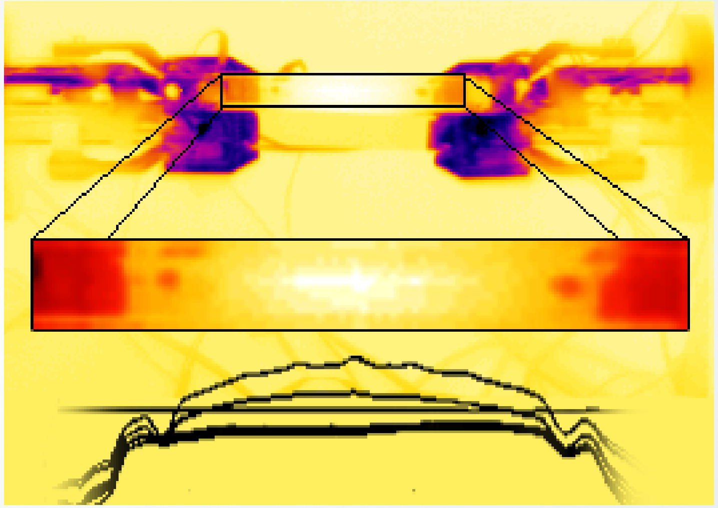
95ºC

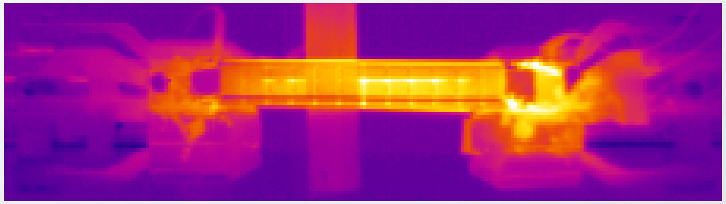


Material	Normal Emissivity
Sensor surface	0,67±0,03
DCD-DHP	0,34±0,04
Tipp-ex	0,97±0,09
Al	0,26±0,12
Cu	0,22±0,12
Thermal paste	0,88±0,09
Kapton Tape	0,99±0,10

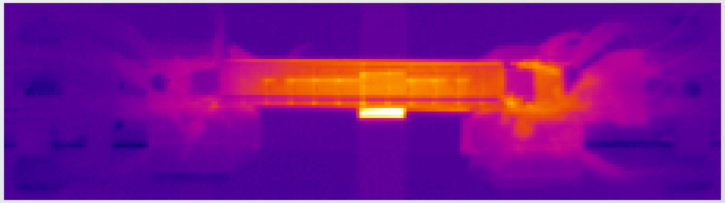
Transparency of the Si sensor

- 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.





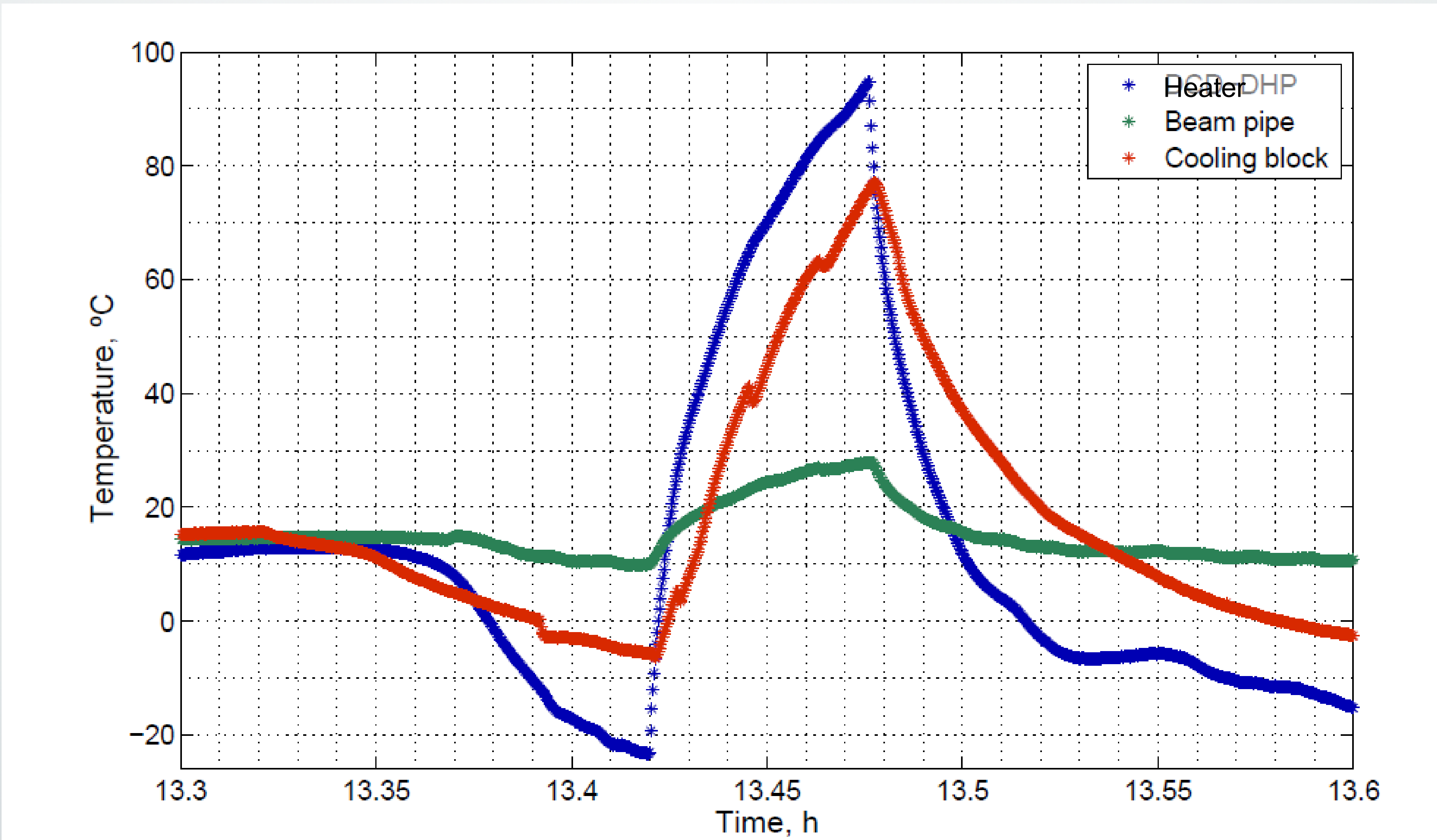
A



B

CO_2 system failure

(as seen by the beam pipe sensors)



Vibrations & Deformation

Experimental setup

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

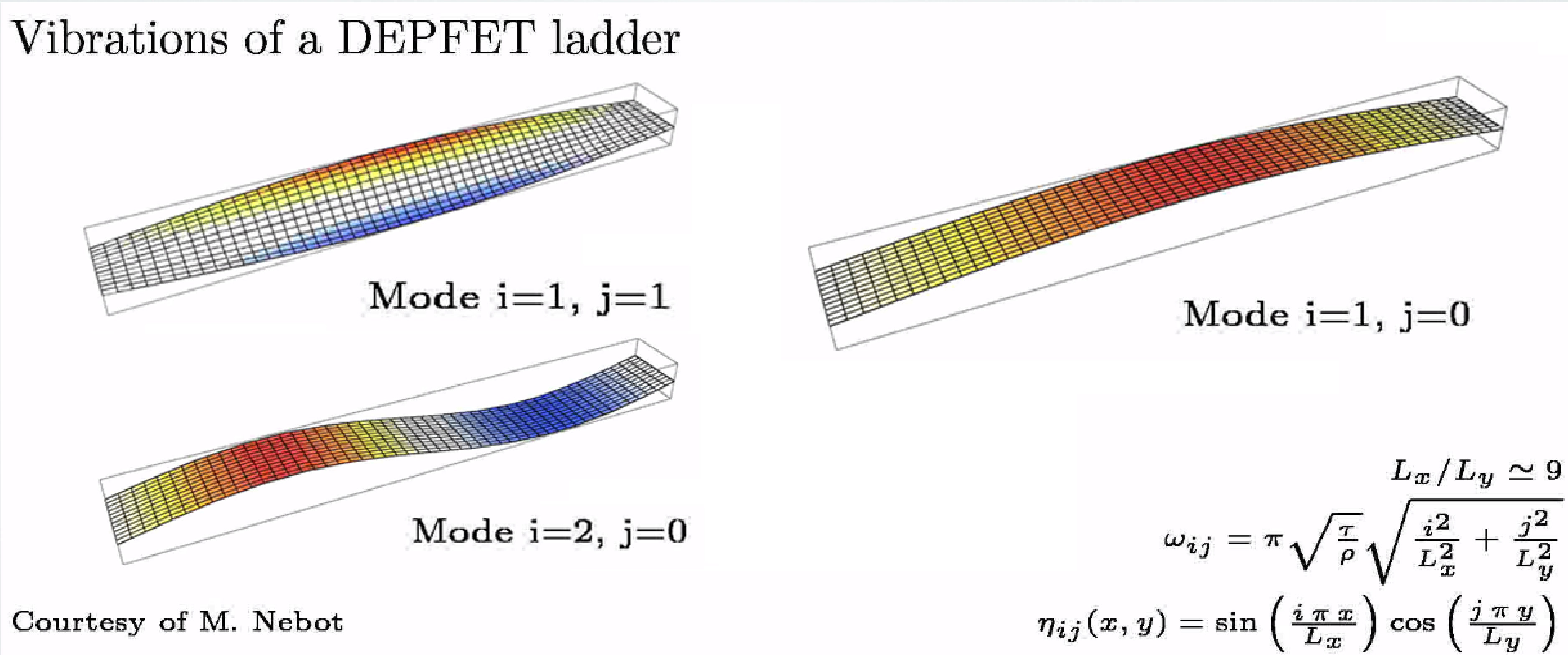
  - Contact accelerometers (Piezotronics PCB 352A24)
  - Capacitive sensor (Micro-Epsilon Capa NCDT 6100)

Sensitivities:

Capacitive sensor: 0.15µm

Accelerometers: 0.002 m/s^2

Vibrational modes



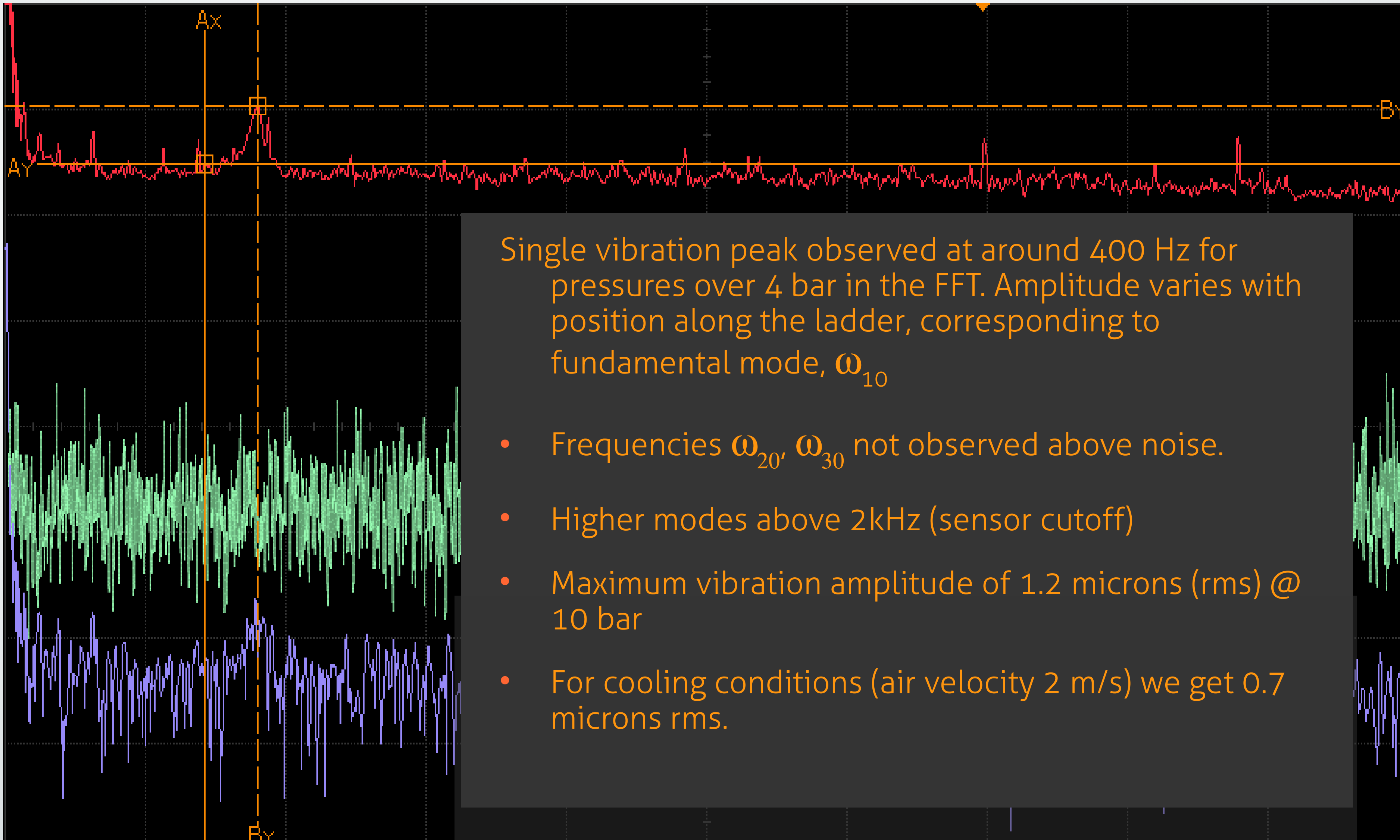
Fundamental mode: ω_{10}

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



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
- For cooling conditions (air velocity 2 m/s) we get 0.7 microns rms.

More info

- Thermomechanical characterization of the Belle II Pixel detector (PXD)
  - http://digital.csic.es/handle/10261/64311