Forum on Tracking Detector Mechanics – DESY, Hamburg

Cooling studies for the CLIC vertex detector

F. Duarte Ramos, on behalf of the CLICdp collaboration

June 30, 2014

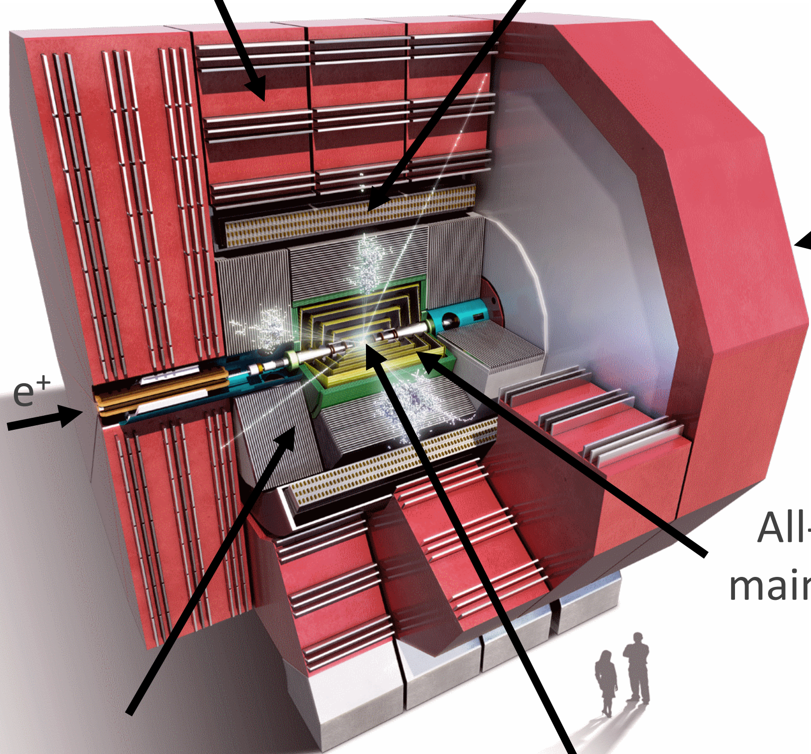
Outline

- Introduction and requirements
- Cooling strategy
- CFD simulations
- Thermo-mechanical test bench
- Summary

CLIC project

Return yoke with instrumentation for muon ID

4-5T solenoid

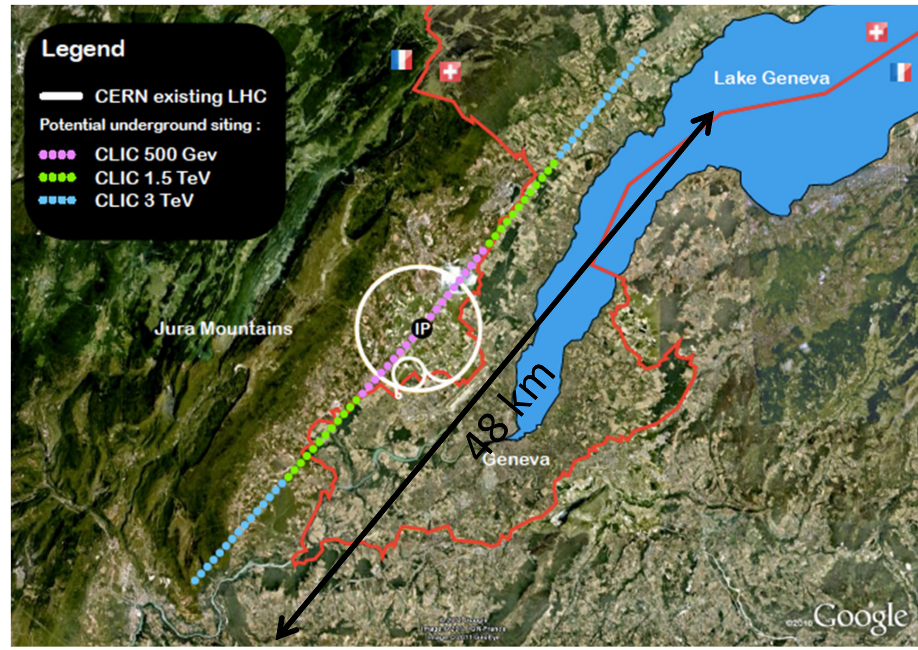


All-silicon main tracker

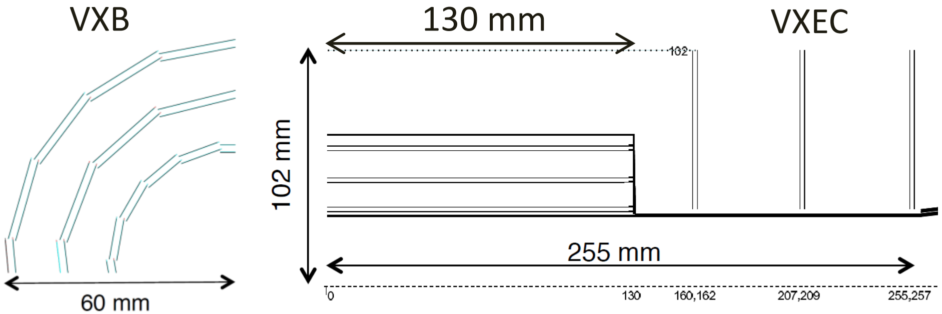
Fine grained (PFA) calorimetry, $1+7.5\lambda_i$

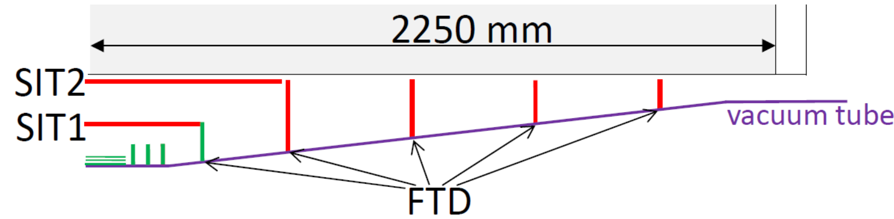
Ultra low-mass vertex detector with ~25 µm pixels

Implementation



Detector inner region layout (VTX & Tracking)





- Vertex detector:
  - **Barrel** – 3 double sided silicon pixel layers;
  - **Endcaps** – 3 double sided silicon pixel disks;
- Inner tracker:
  - **Barrel** – 2 silicon micro-strip layers;
  - **FTD** – 1 silicon pixel & 4 silicon micro-strip disks;

Average heat dissipated (w/ power pulsing*)

Pixel layers – 50 mW/cm^2

Micro-strip layers – 1 mW/cm^2

For more details about the power pulsing scheme see: G. Blanchot and C. Fuentes., "Power pulsing schemes for vertex detectors at CLIC", Journal of Instrumentation, vol. 8(01) p. C01057, 2013

Requirements

- Low material budget – 0.2% X_0 per layer in the VTX barrel (including 0.11% for silicon):
  - Low-mass support structures – 0.05% X_0 per double layer (see F.-X. Nuiry talk tomorrow);
  - Low-mass cooling system – 500 W and $T_{operation}$<40 ^oC;

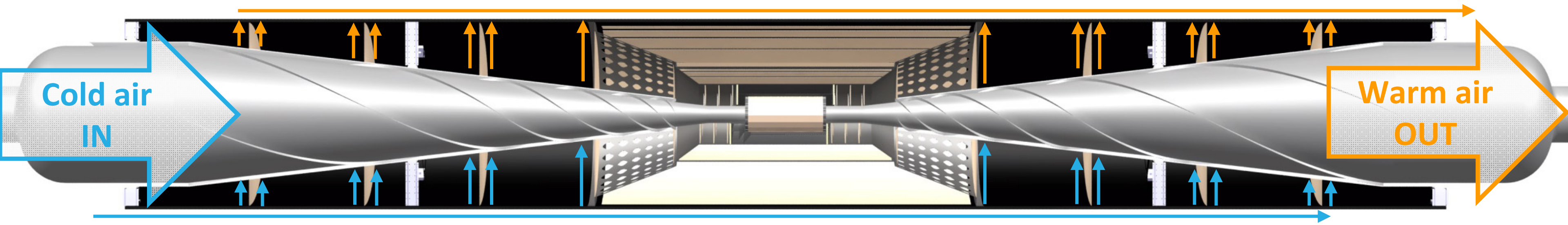
- Currently evaluating the feasibility of a (dry) air cooling strategy.

Approach

- Phase I
  - Conceptual design of a cooling strategy;
  - First order thermal-fluid simulations;
- Phase II
  - Development of thermo-mechanical test bench;
  - Measurement of cooling performance/vibration;
  - Thermal-fluid models validation.

Cooling distribution

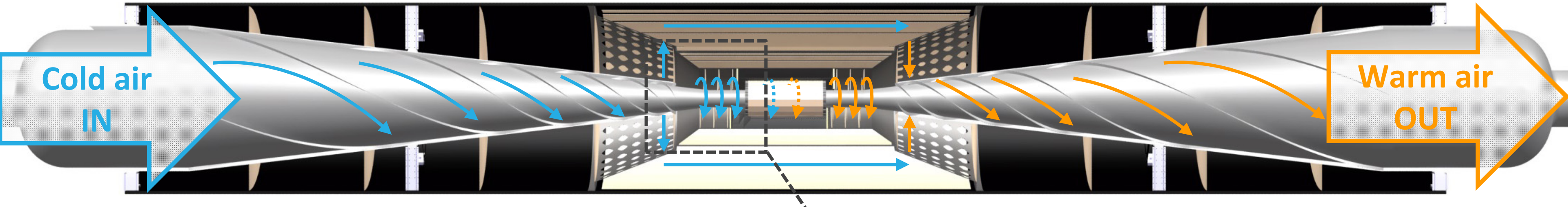
Outer stream



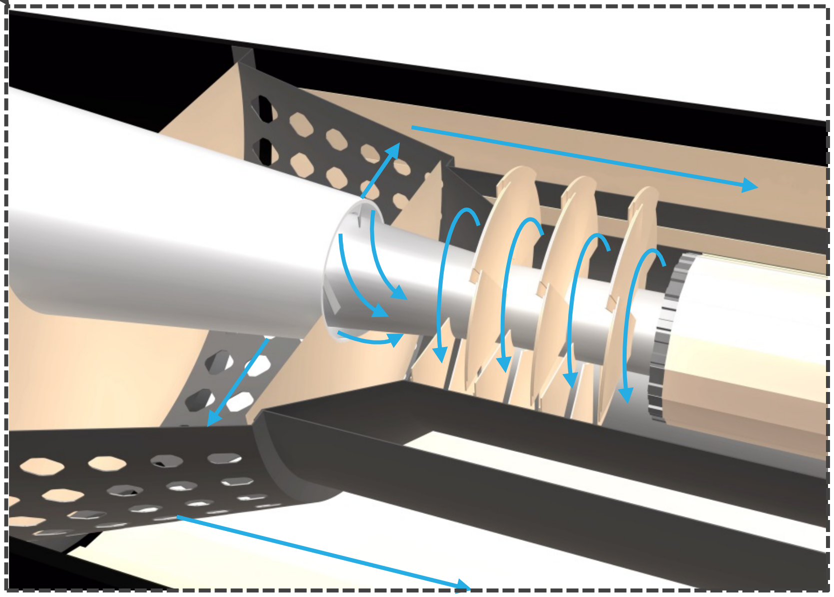
- Cooling of FTDs 1-5;
- Low heat load (silicon micro-strips);
- Natural convection/low velocity forced convection;
- Air delivered/extracted through openings in the CFRP support tube.

Cooling distribution

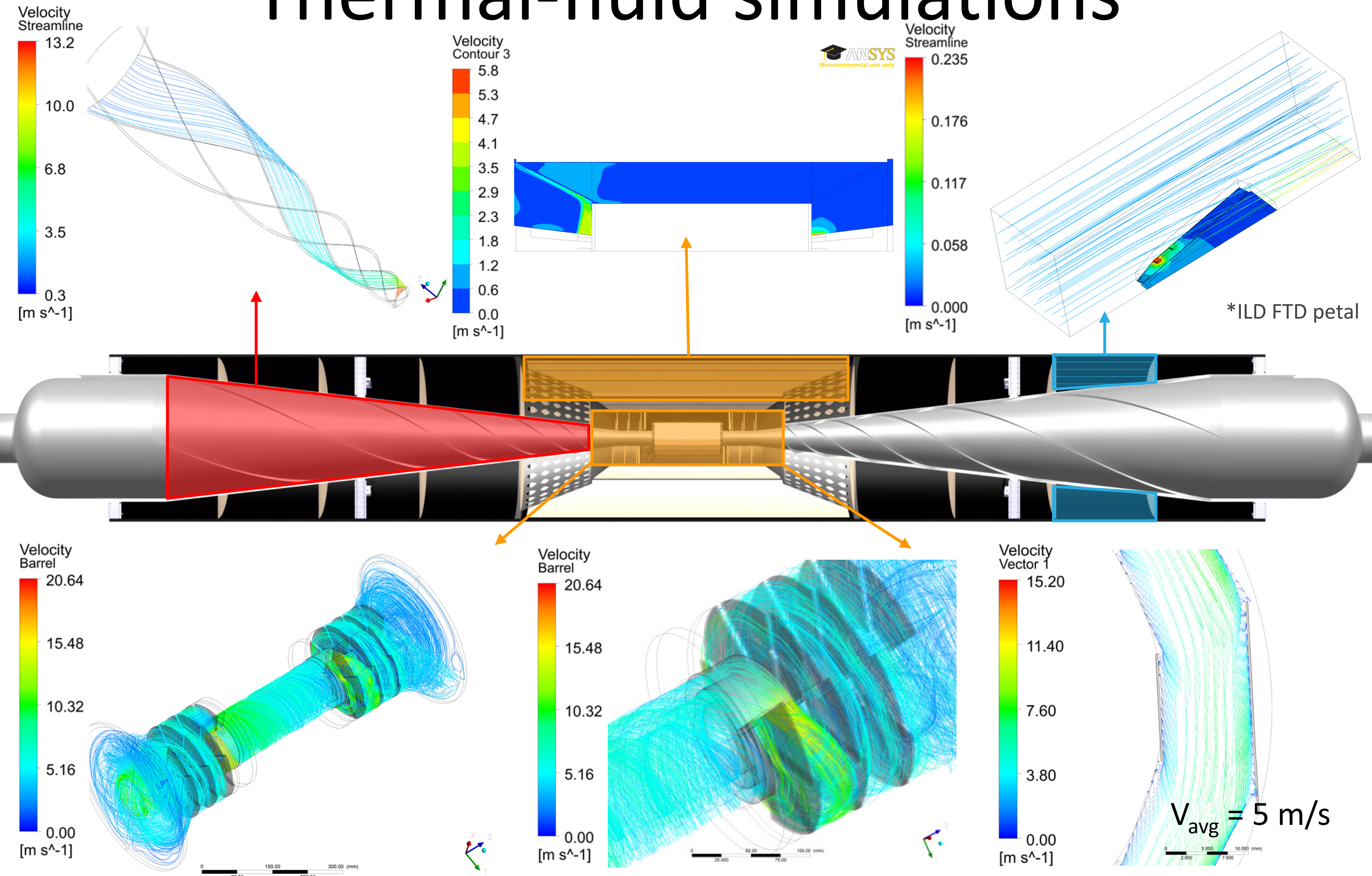
Inner stream



- Cooling of VTX and SIT;
- High heat load (silicon pixel + micro-strips);
- Moderate velocity forced convection;
- Dry air delivered/extracted through channel between beampipe and conical shield.

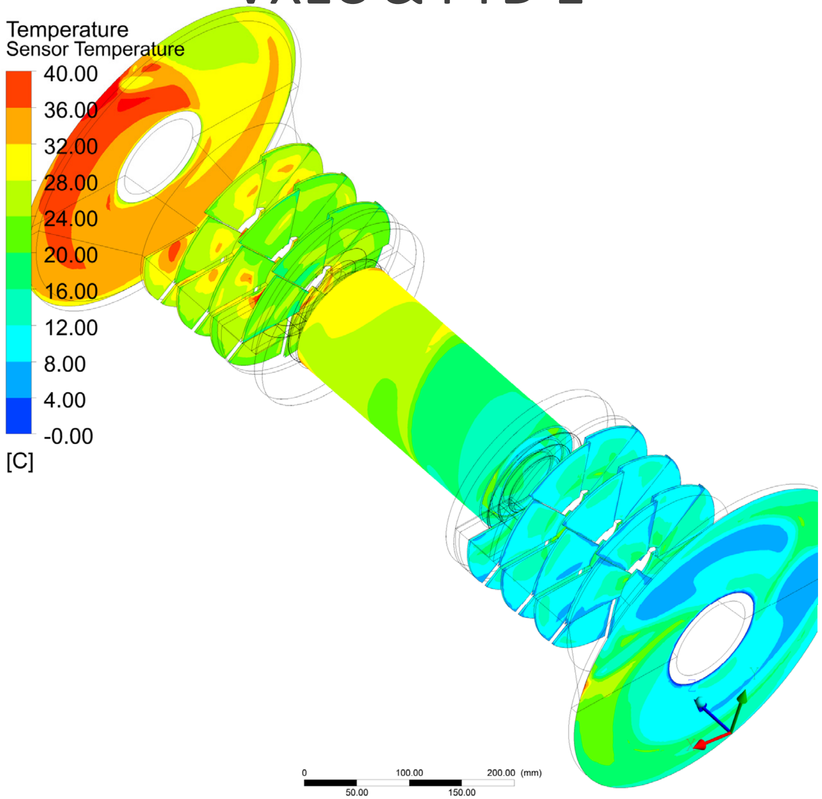


Thermal-fluid simulations

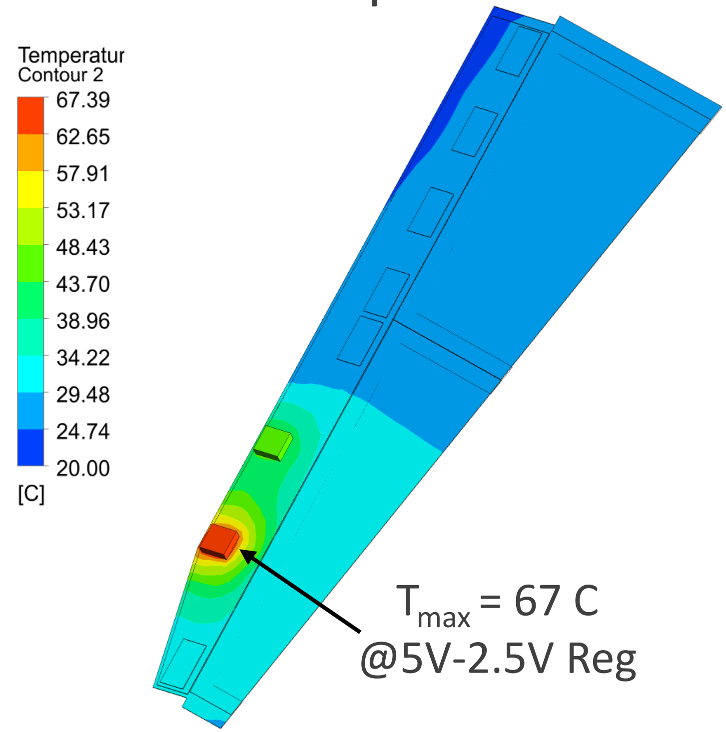


Thermal-fluid simulations

VXEC & FTD 1



ILD FTD petal



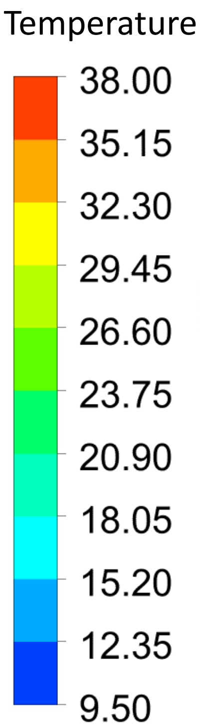
VTX detector model details:

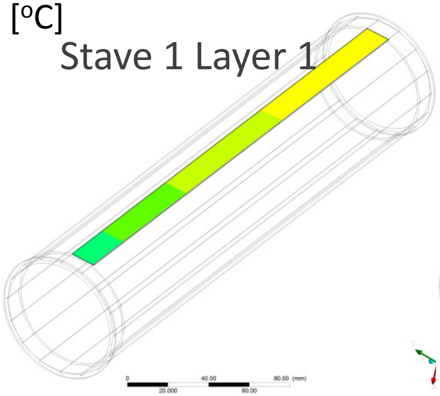
- Convection heat transfer only;
- No heat transfer between layers;
- Boundary conditions:
  - Inlet: Temperature (0 ^{o}C) and air velocity and direction;
  - Outlet: Pressure;
  - 50mW/cm^2.

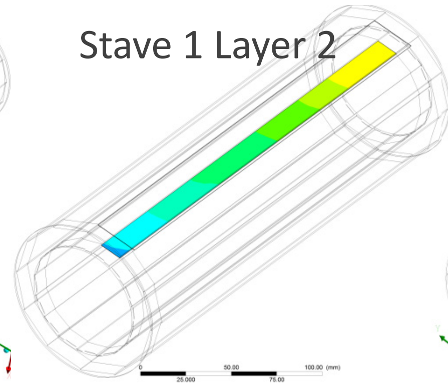
ILD FTP petal model details:

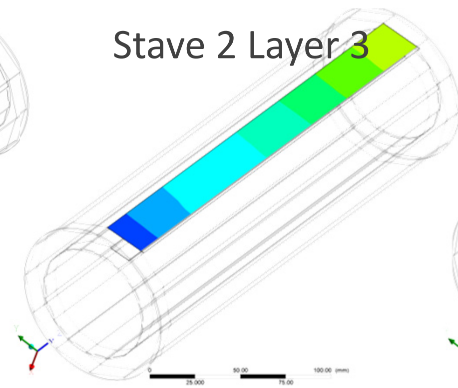
- Conduction and convection heat transfer only;
- Buoyancy option and symmetry activated;
- Boundary conditions:
  - 365mW on 2.5V reg.; 86mW on 1.25V reg.; 9mW on chips;
  - $T_{ambient}$=20 ^{o}C.

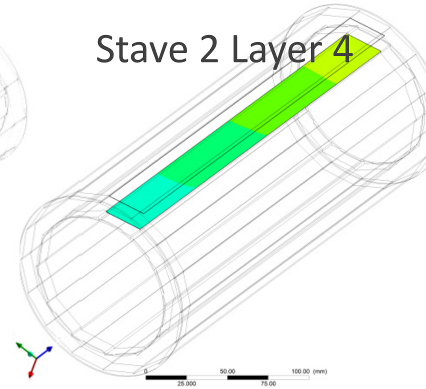
Thermal-fluid simulations

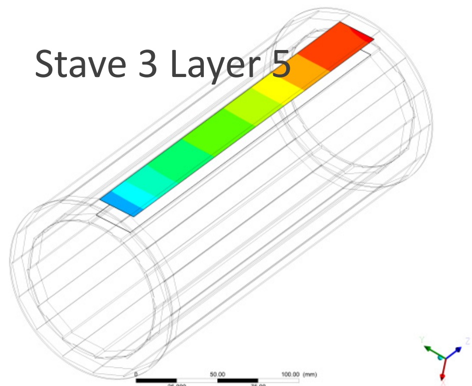


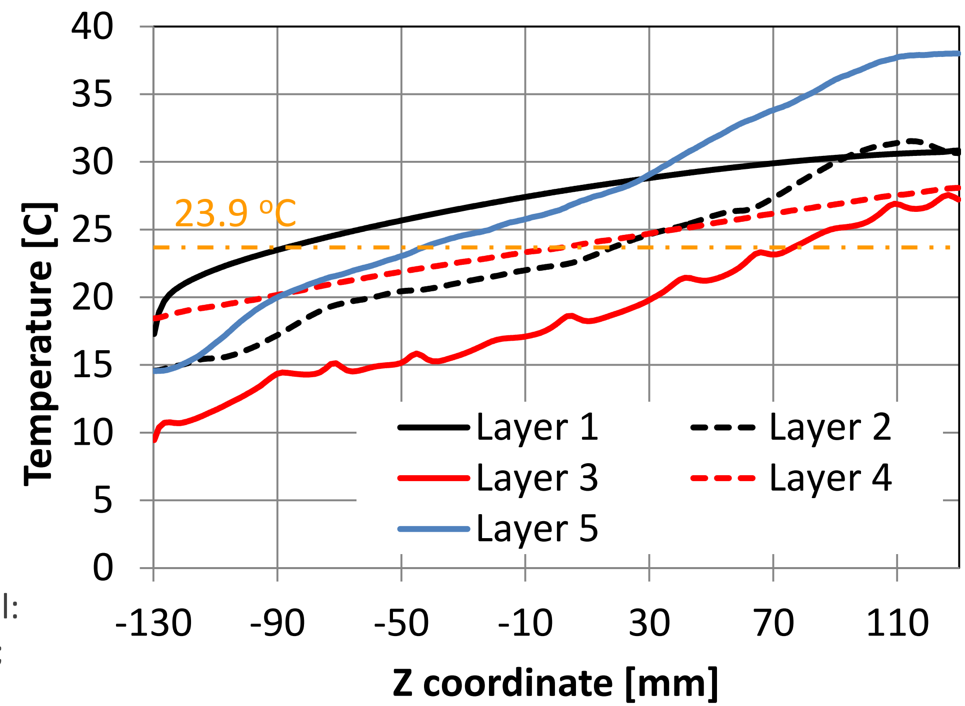












VTX barrel sub-model details:

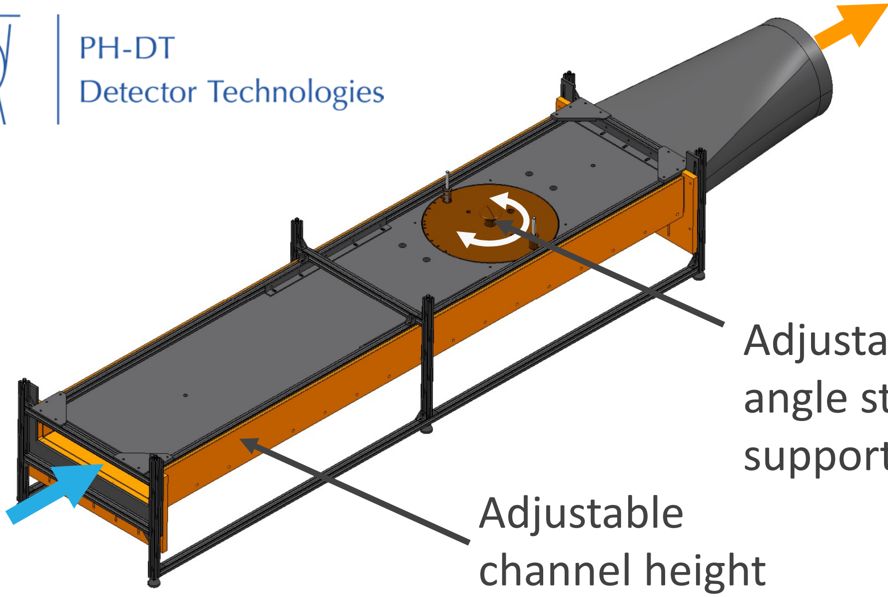
- Conduction and convection heat transfer only;
- No heat transfer between layers;
- Boundary conditions coming from the larger CFD model:
    - Inlet: Temperature and air velocity and direction;
    - Outlet: Pressure;

Note: Stave 3 layer 6 not shown as temperatures are not realistic (barrel outer envelope too big, low air velocity).

Thermo-mechanical test bench

PH-DT
Detector Technologies

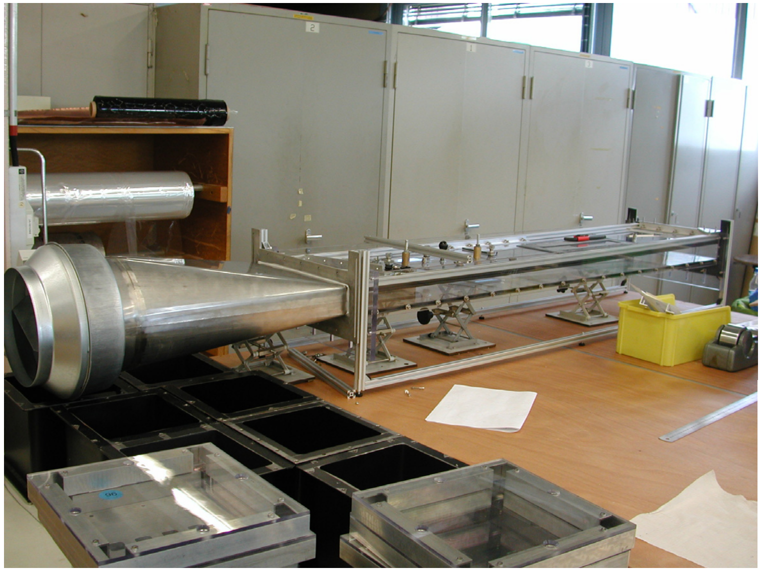
Outlet



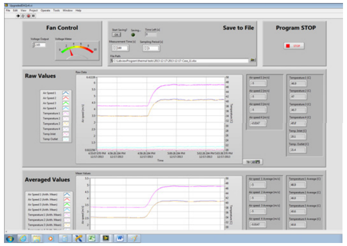
Adjustable angle stave support

Adjustable channel height

Inlet

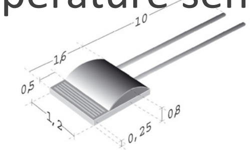


LabVIEW interface



Schmidt anemometer

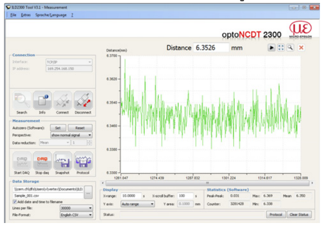
Temperature sensors

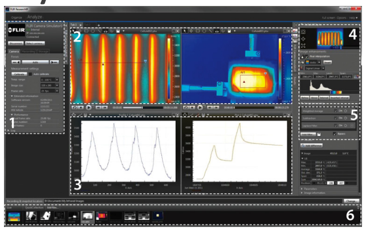


Micro-Epsilon vibration sensor

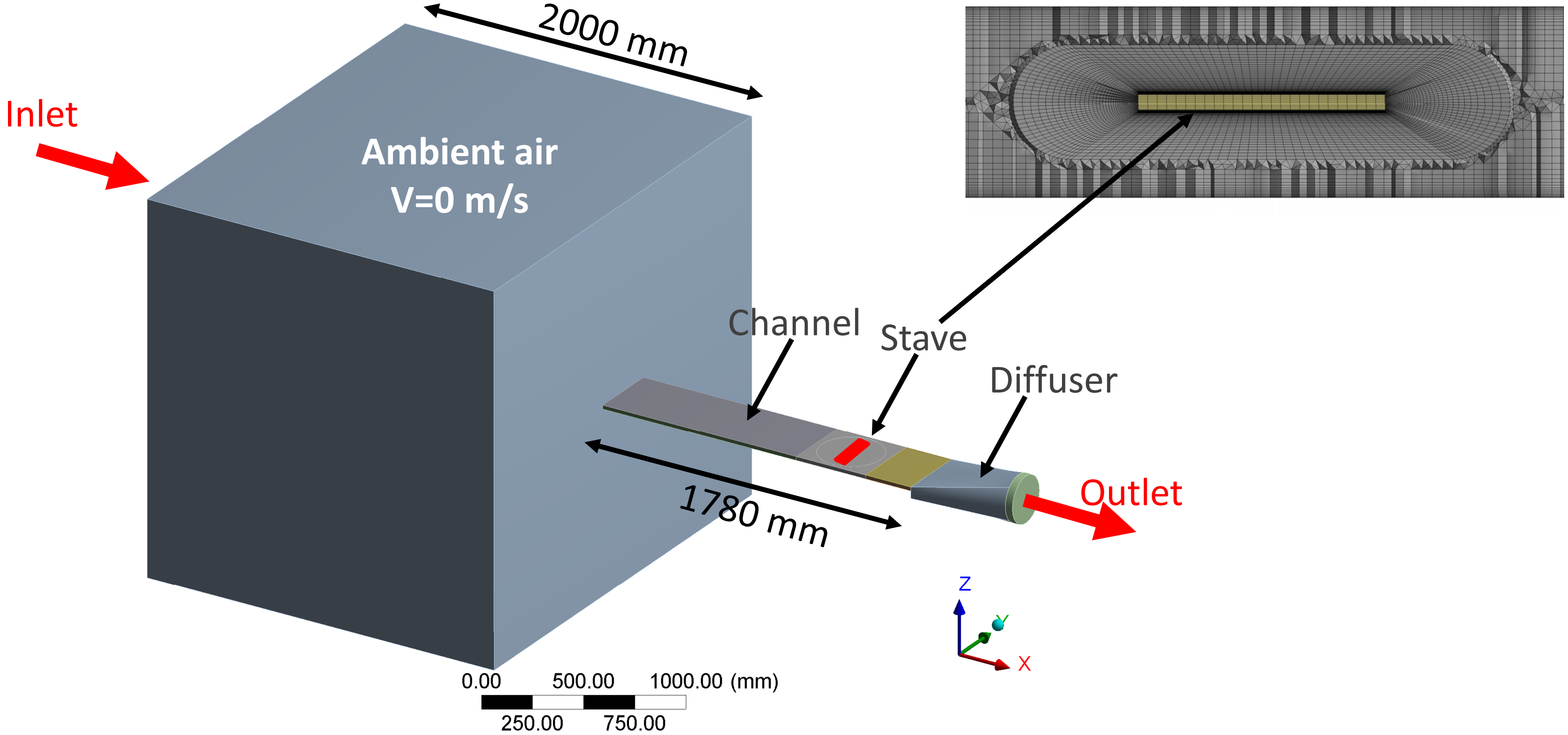
FLIR thermal camera

Proprietary software





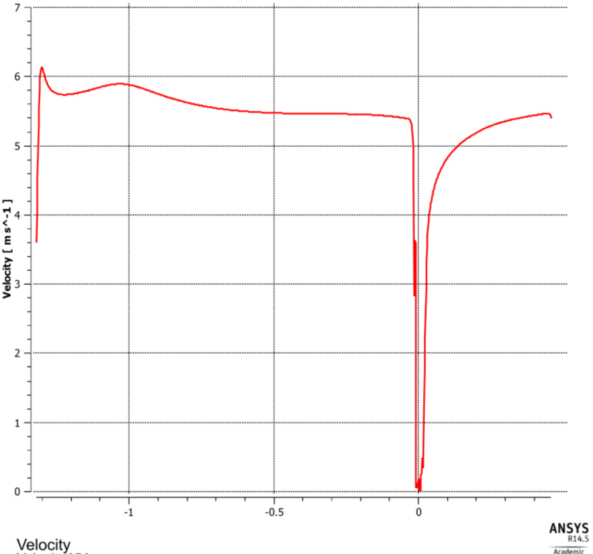
Test bench design simulations



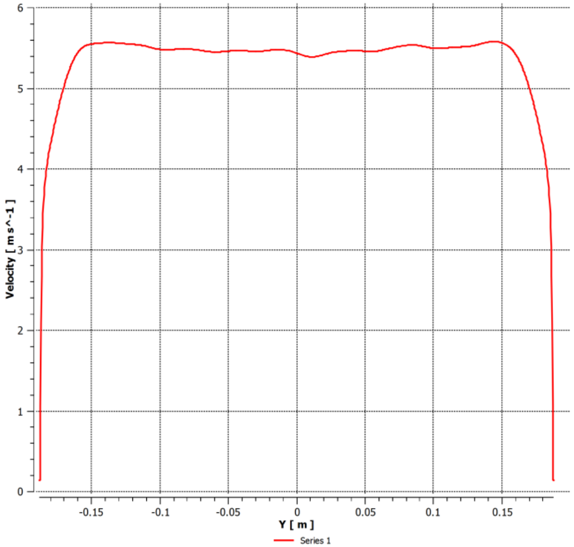
Velocity profiles

Example for 20mm channel height

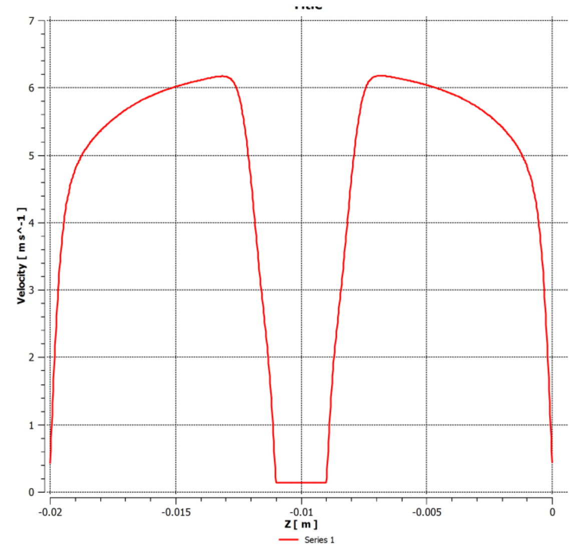
Longitudinal
(y=0mm; z=-10mm)

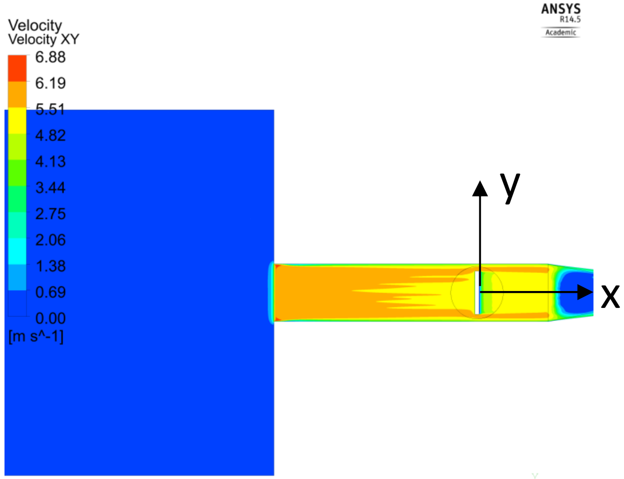


Transverse
(x=-180mm; z=-10mm)



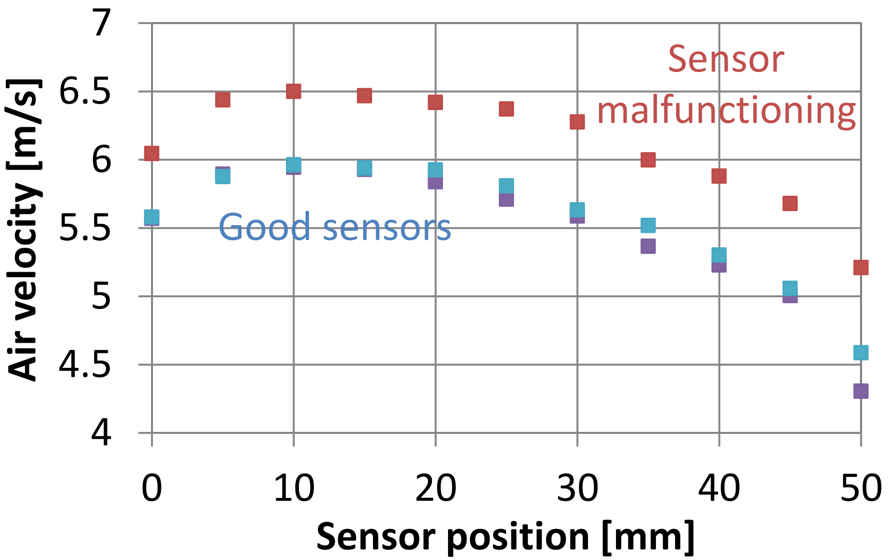
Vertical
(x=0mm; y=0mm)

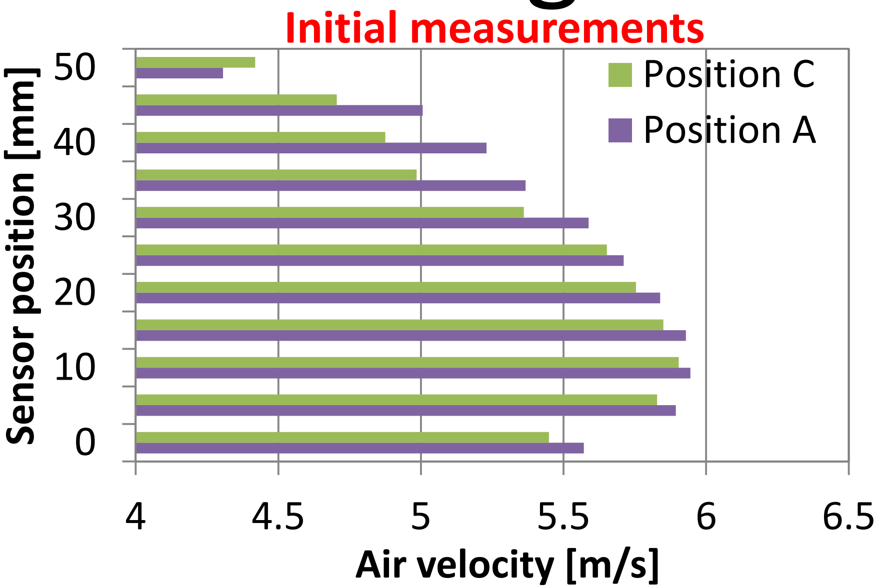


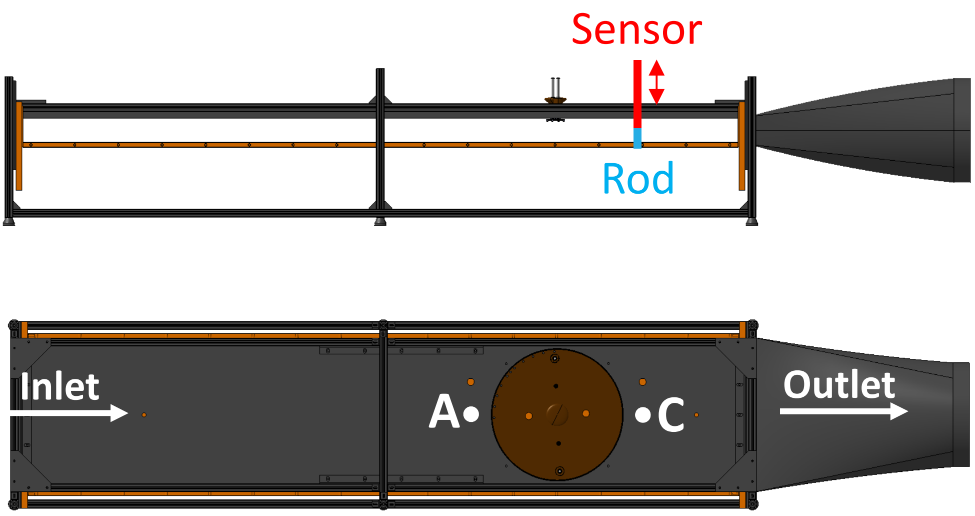


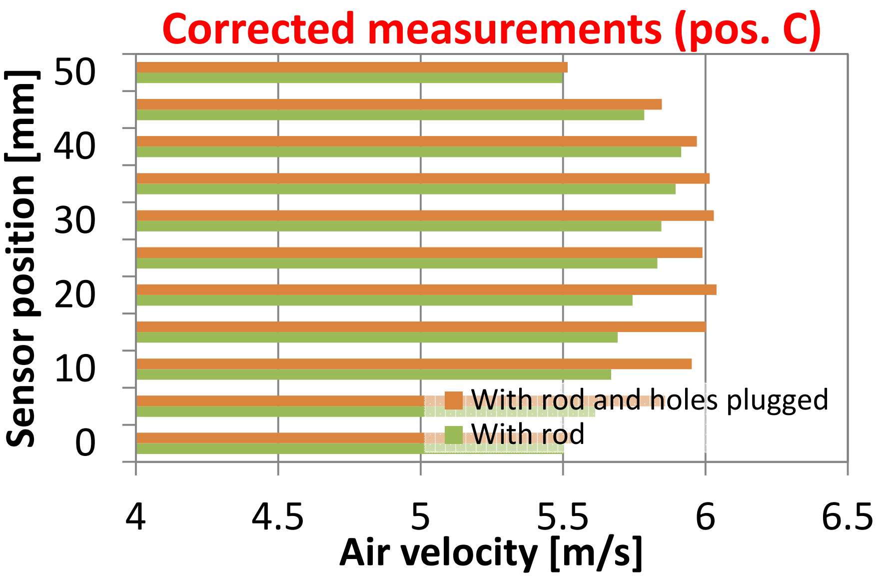
Channel designed to ensure stabilized flow at the stave's location

Test bench commissioning



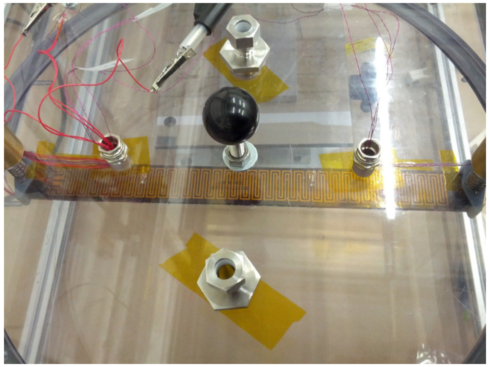




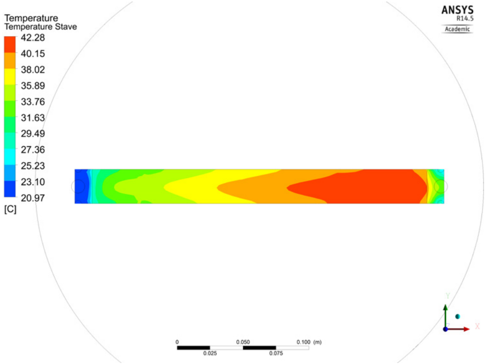


Thermal studies on dummy staves

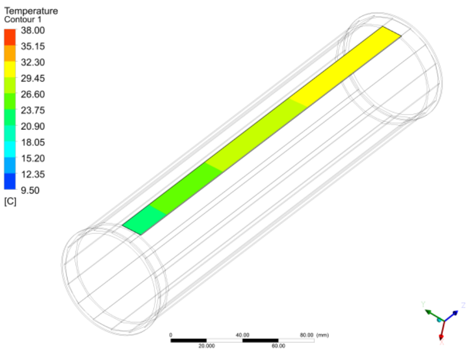
Stave temperature measurements

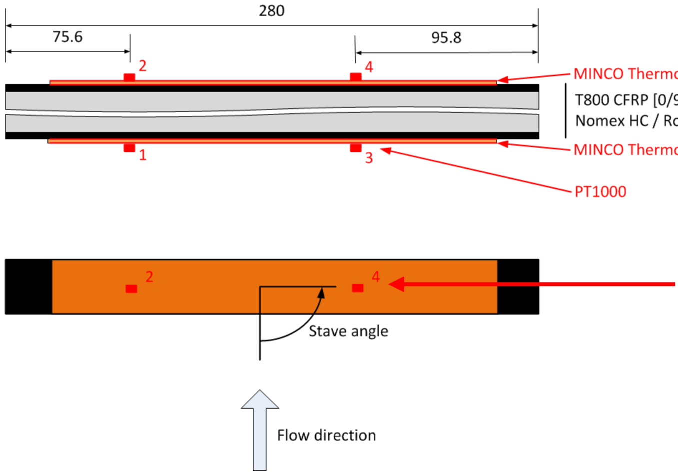


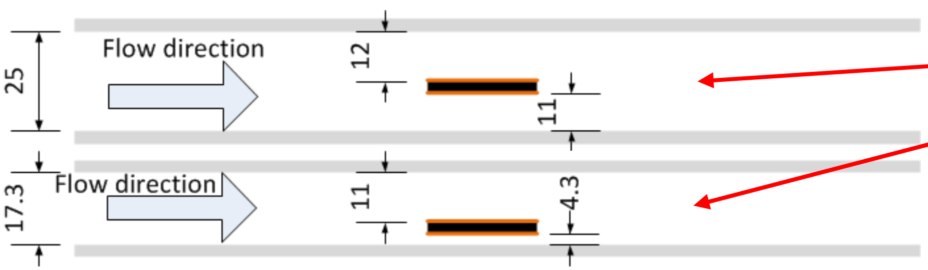
Dedicated simulations

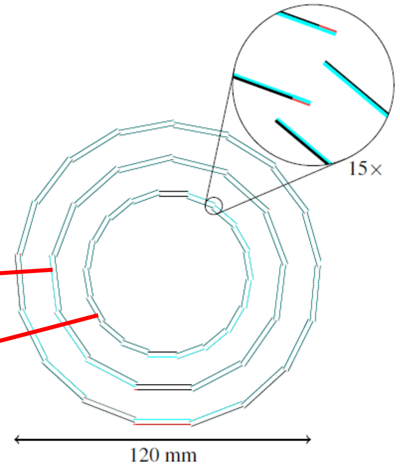


Preliminary validation



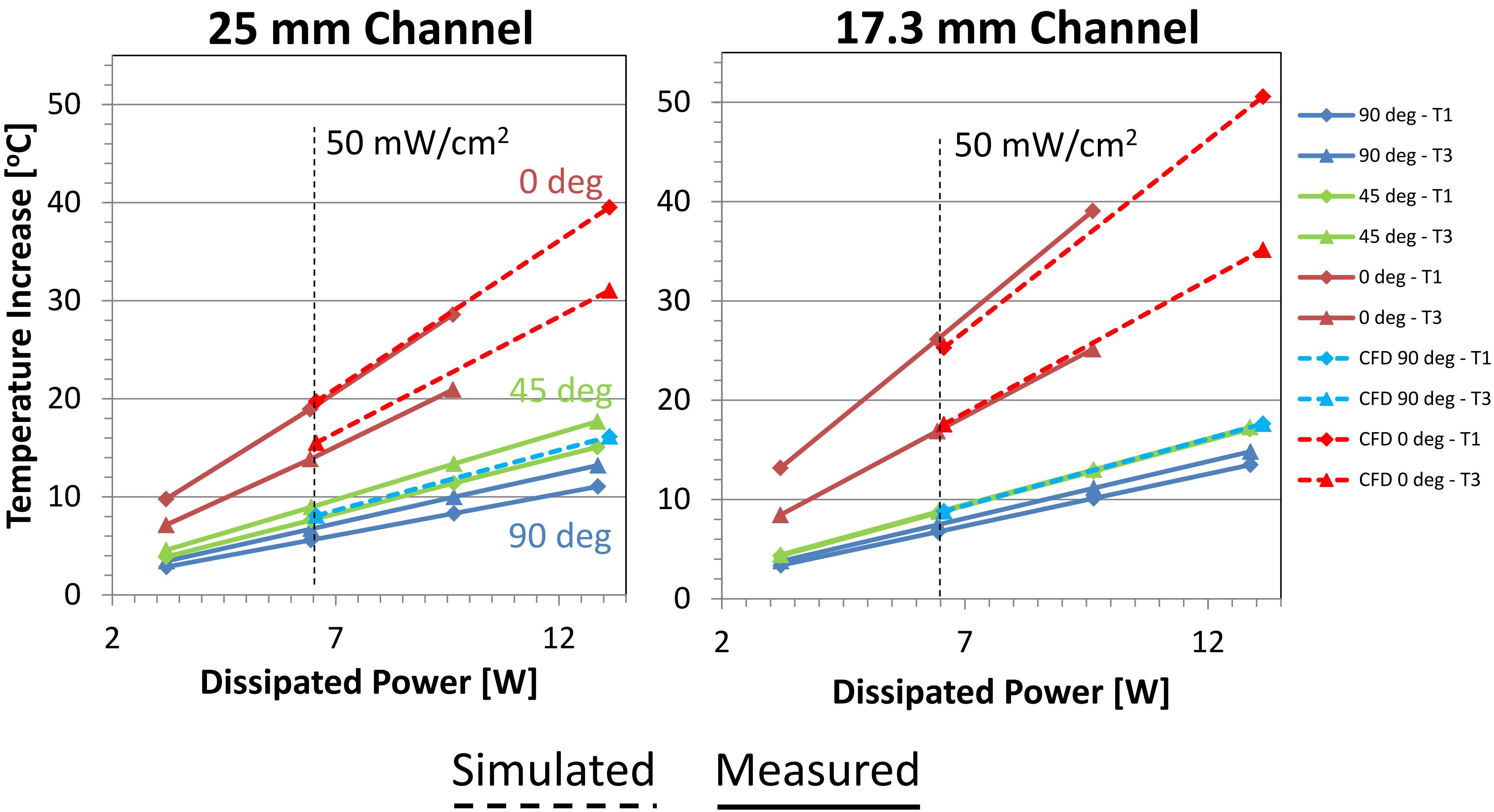






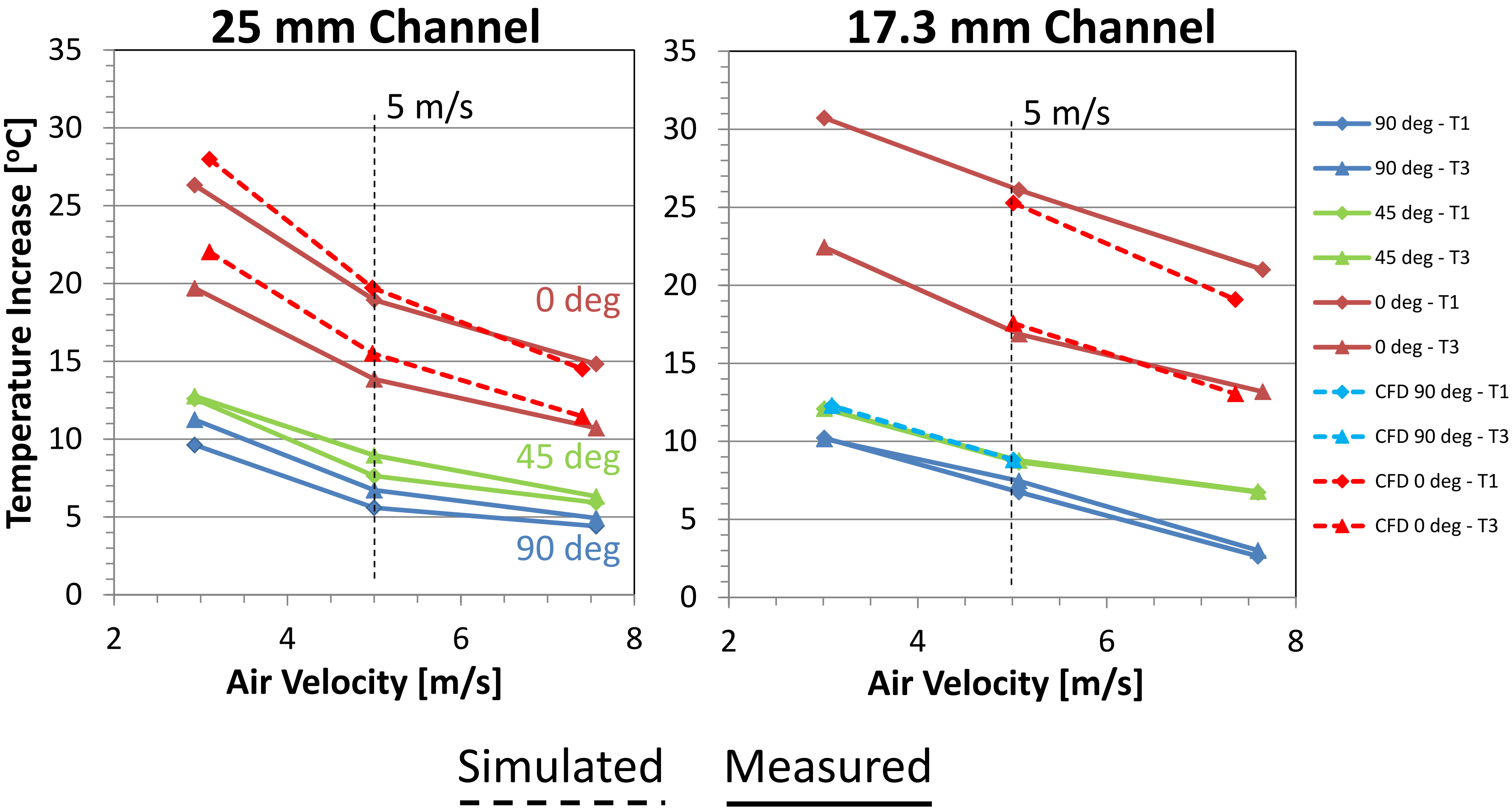
Stave thermal tests

Constant air velocity (5 m/s)



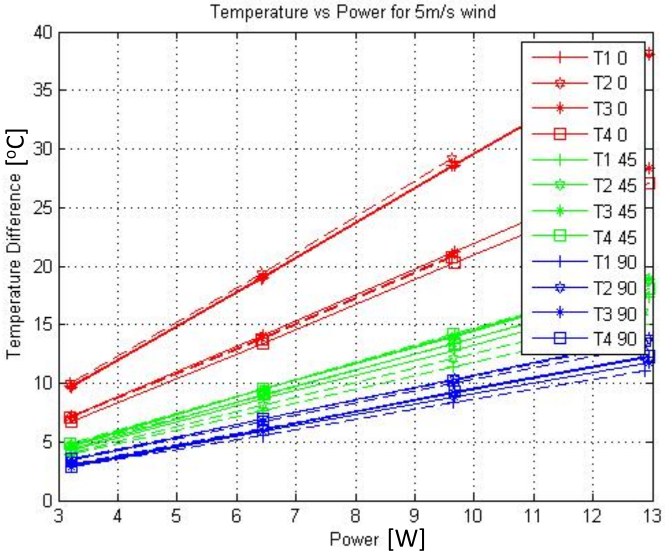
Stave thermal tests

Constant heat dissipation (50 mW/cm²)

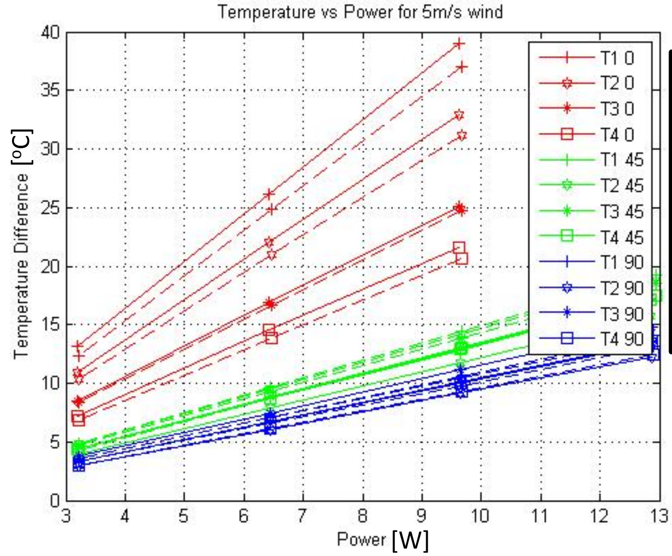


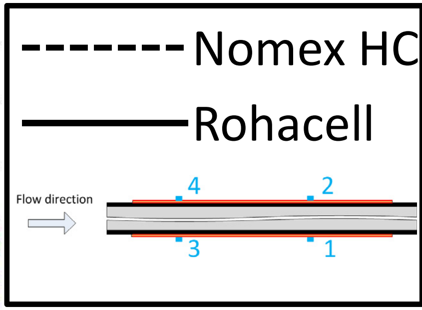
Influence of core material

25 mm channel



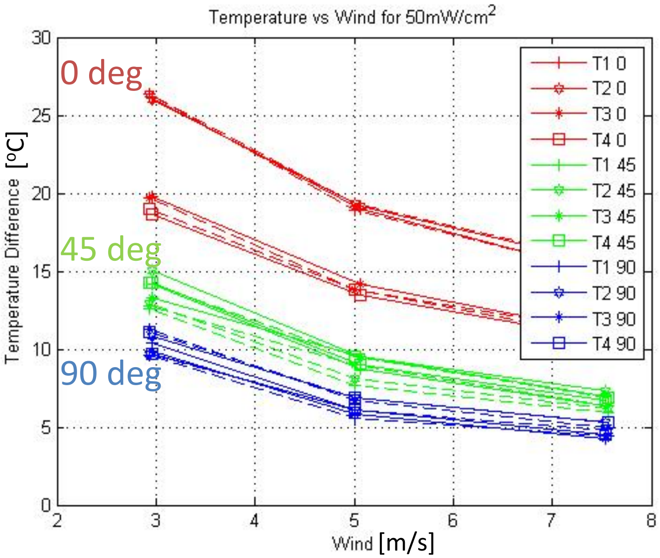
17.3 mm channel

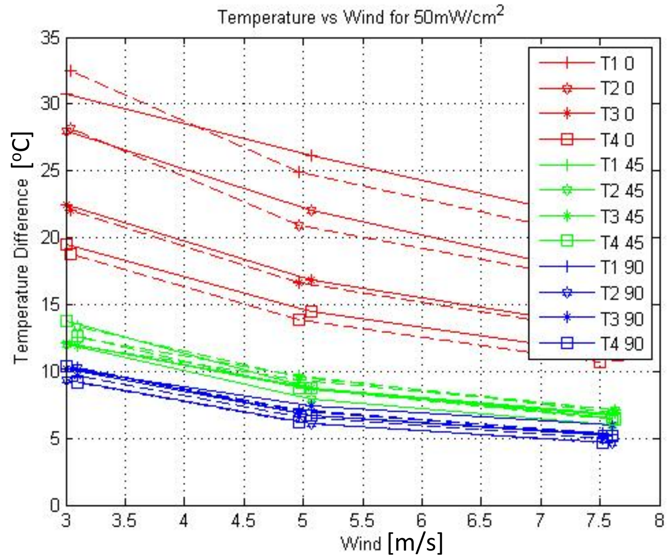




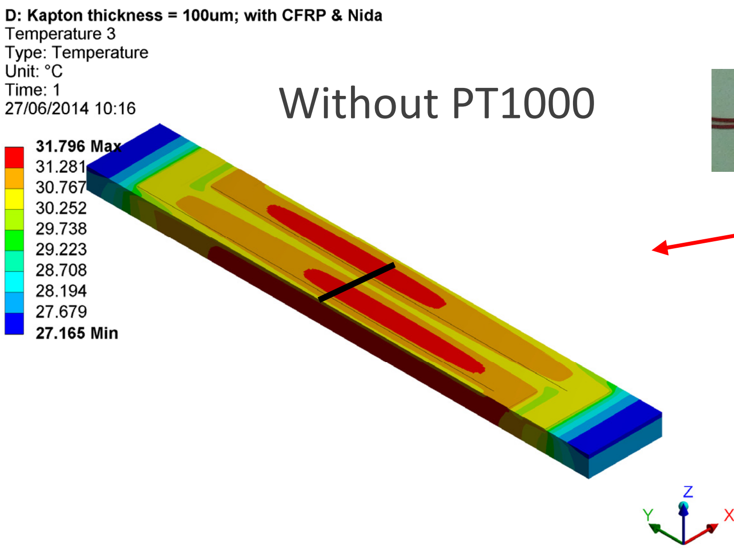
$K_{rohacell} = 0.029$ W/mK

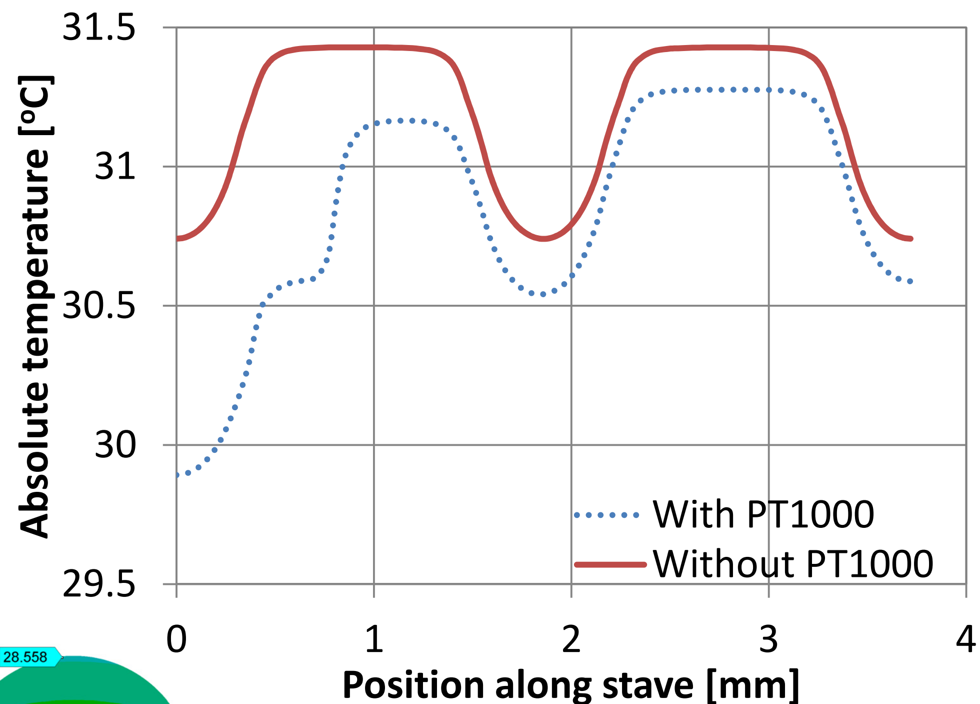
$K_{nomex\ HC} = 0.058$ W/mK

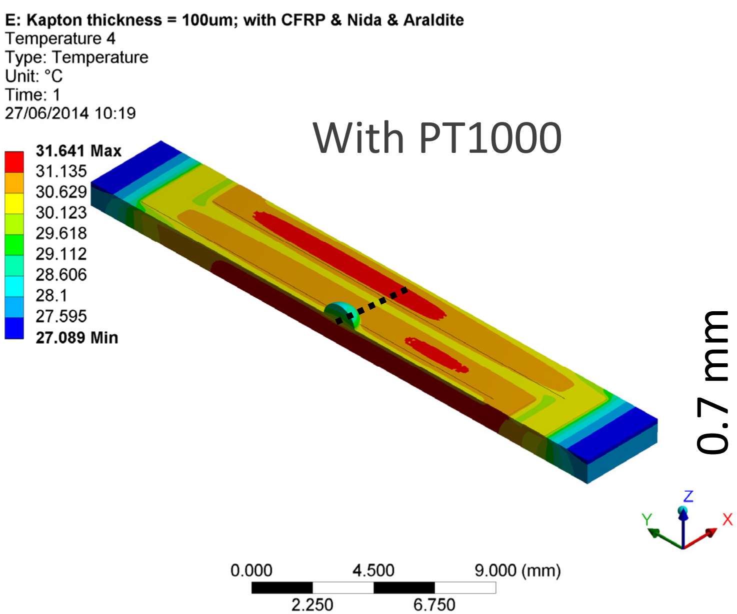


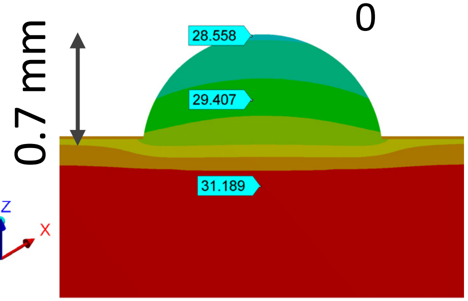


Detailed stave simulation







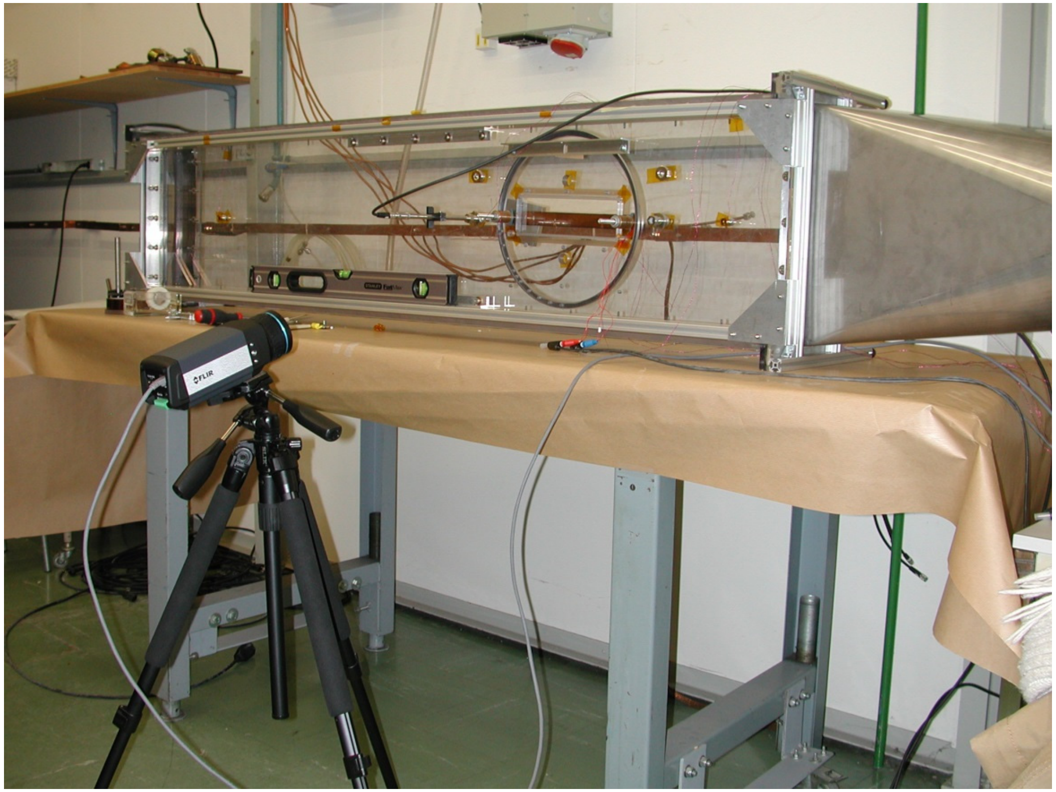


Thermal imaging

Thermal camera **FLIR A655 sc:**

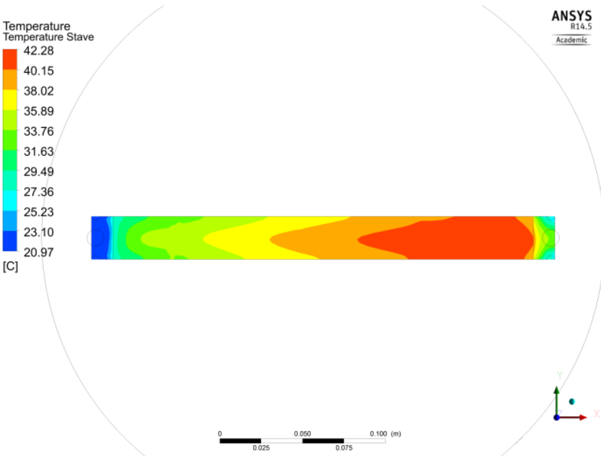
-Resolution: 640*480 pixels
-Images frequency: 50Hz
-Sensibility: < 50mK

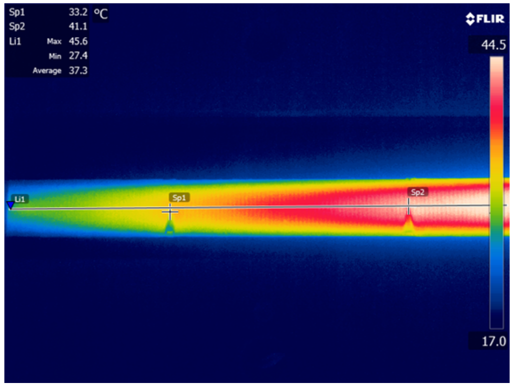
PH-DT
Detector Technologies

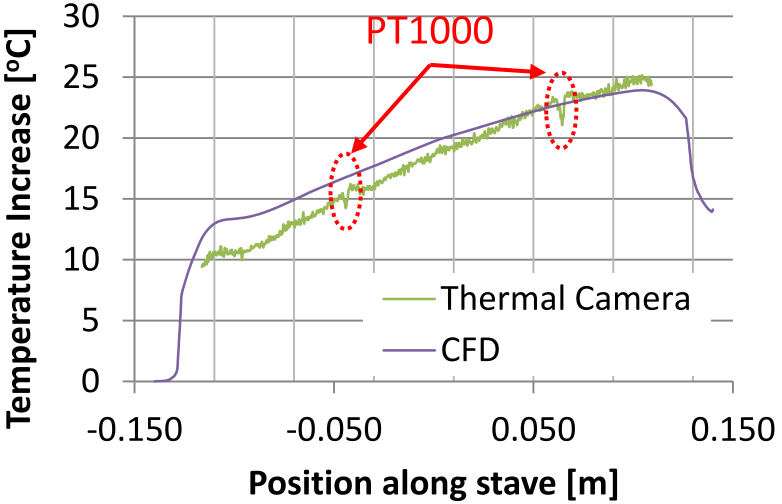


Measurements vs. simulations

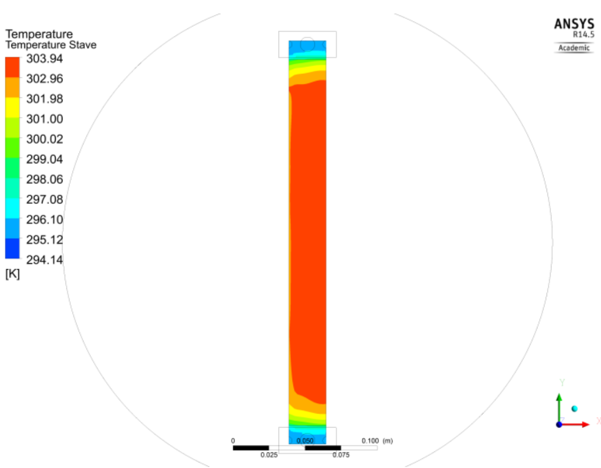
0 deg

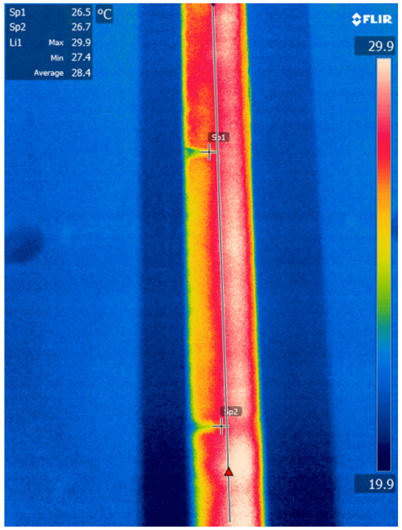


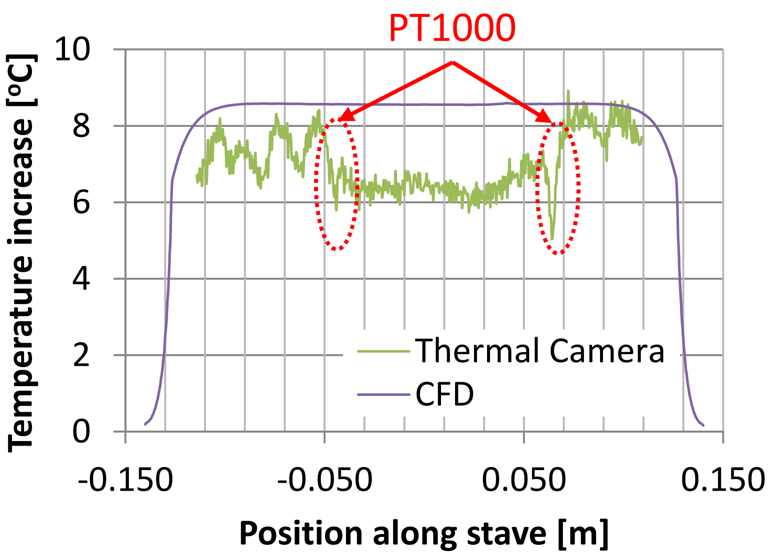




90 deg

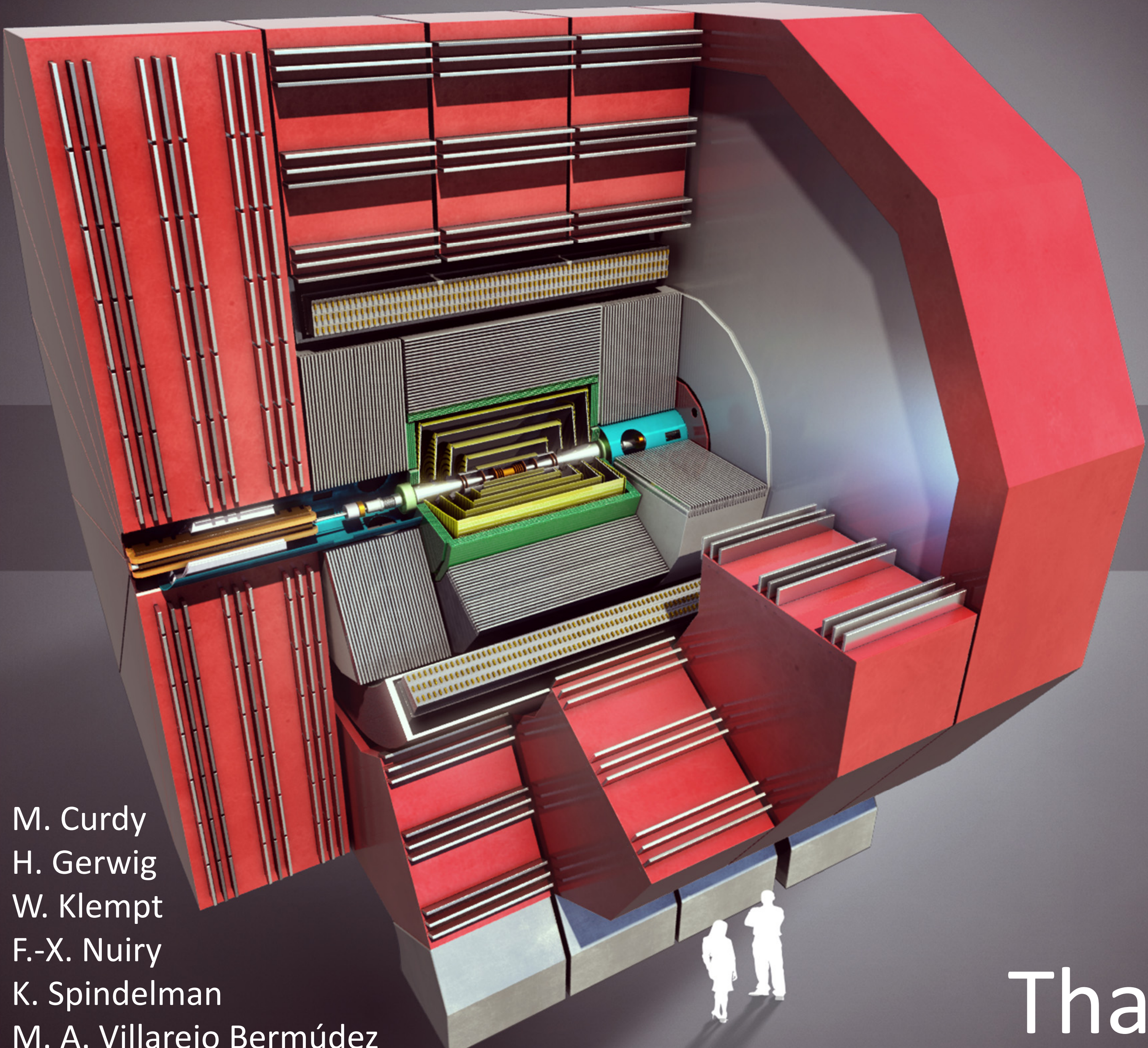






Summary

- An air cooling strategy for the inner region of the CLIC detector is currently being investigated;
- Simulations indicate that it will be possible to maintain sensor temperatures <40 ^{o}C for a nominal heat load of 50 mW/cm^2;
- A thermo-mechanical test set-up has so far confirmed the simulations' results;
- A more realistic test bench is foreseen;
- Air flow induced vibration tests on support structure prototypes have shown that amplitudes are within the acceptable range (see F.-X. Nuiry talk tomorrow);
- Many issues have not been addressed yet (temperature gradients, deformations, stave support, flow disturbances, etc.).



CLIC Detector

M. Curdy
H. Gerwig
W. Klempt
F.-X. Nuiry
K. Spindelman
M. A. Villarejo Bermúdez

Thank you