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IAA RACT
Laser-Heating for Thermo-Mechanical Fatigue Simulation

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C. Böhm, E. Zametaev, O. Haidn,….

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Outline

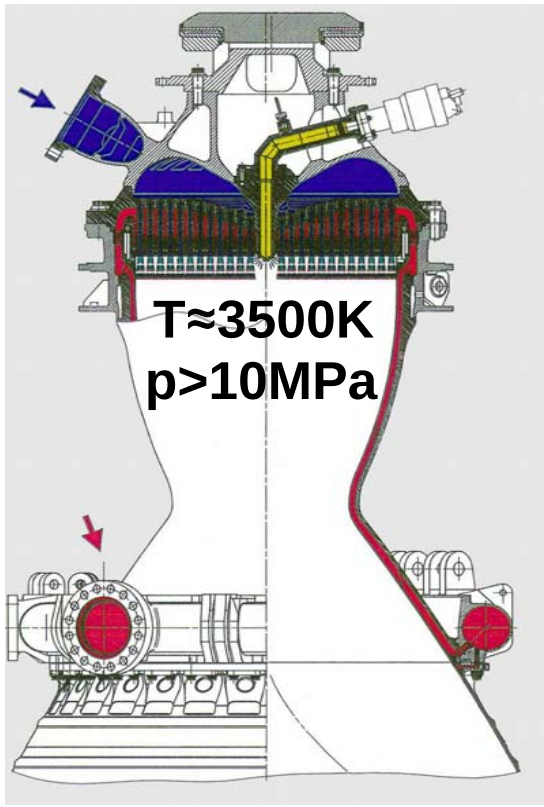
- **Motivation**
  - **General**
  - **HARCC**
- **TMF test bench**
  - **Laser**
- **Preliminary Design of a TMF Testpanel**
  - **HARCC-Geometry**
  - **EH3C Tests**
  - **Preliminary design**
- **numerical analyses of the hot run of this TMF panel**
  - **CFD analysis**
  - **thermal analysis results**
  - **structural analysis**

Background: hot gas walls of main engine of Ariane 5

Ariane 5

Vulcain II

combustion chamber



combustion chamber material: NARLoy-Z (copper basis alloy)

heat flux at nozzle throat during hot run: 80 MW / m²

Full scale tests versus panel tests

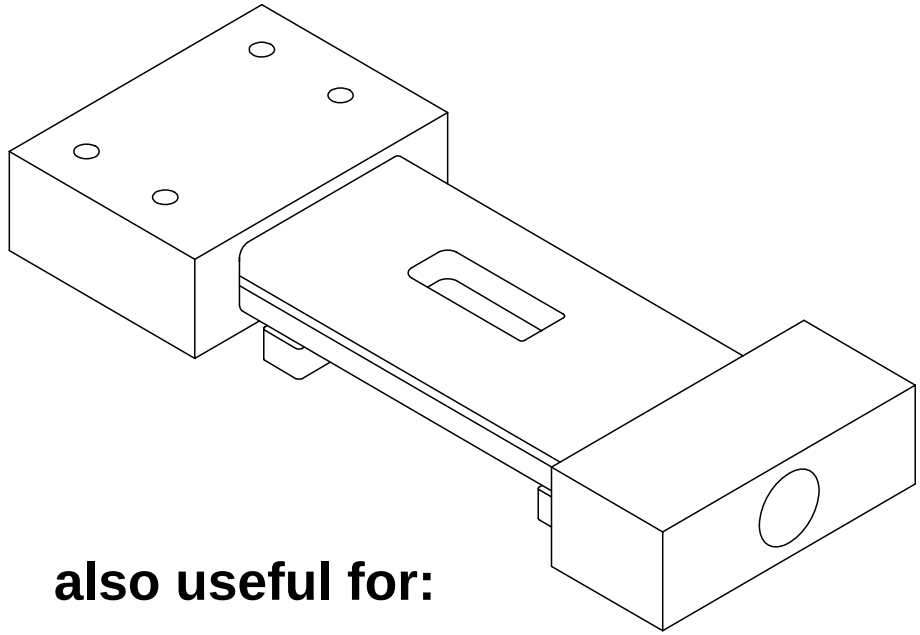
full scale tests:

- **expensive (1 M€ per test)**

LCF → many tests needed!

→ need for panel tests

Thermo-Mechanical Fatigue (TMF) test panel:

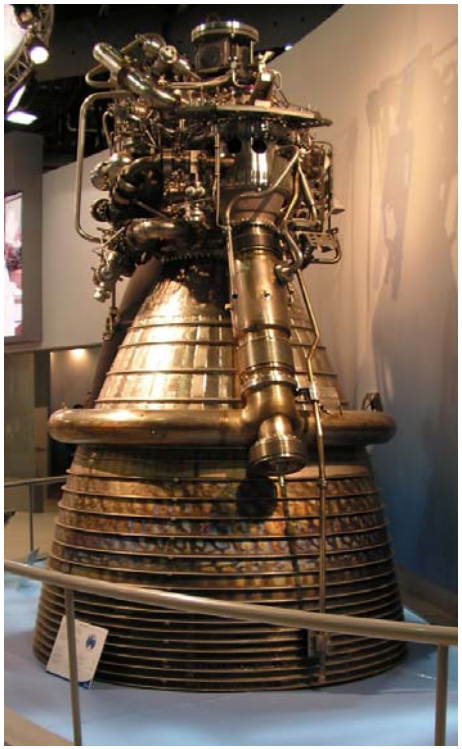


also useful for:

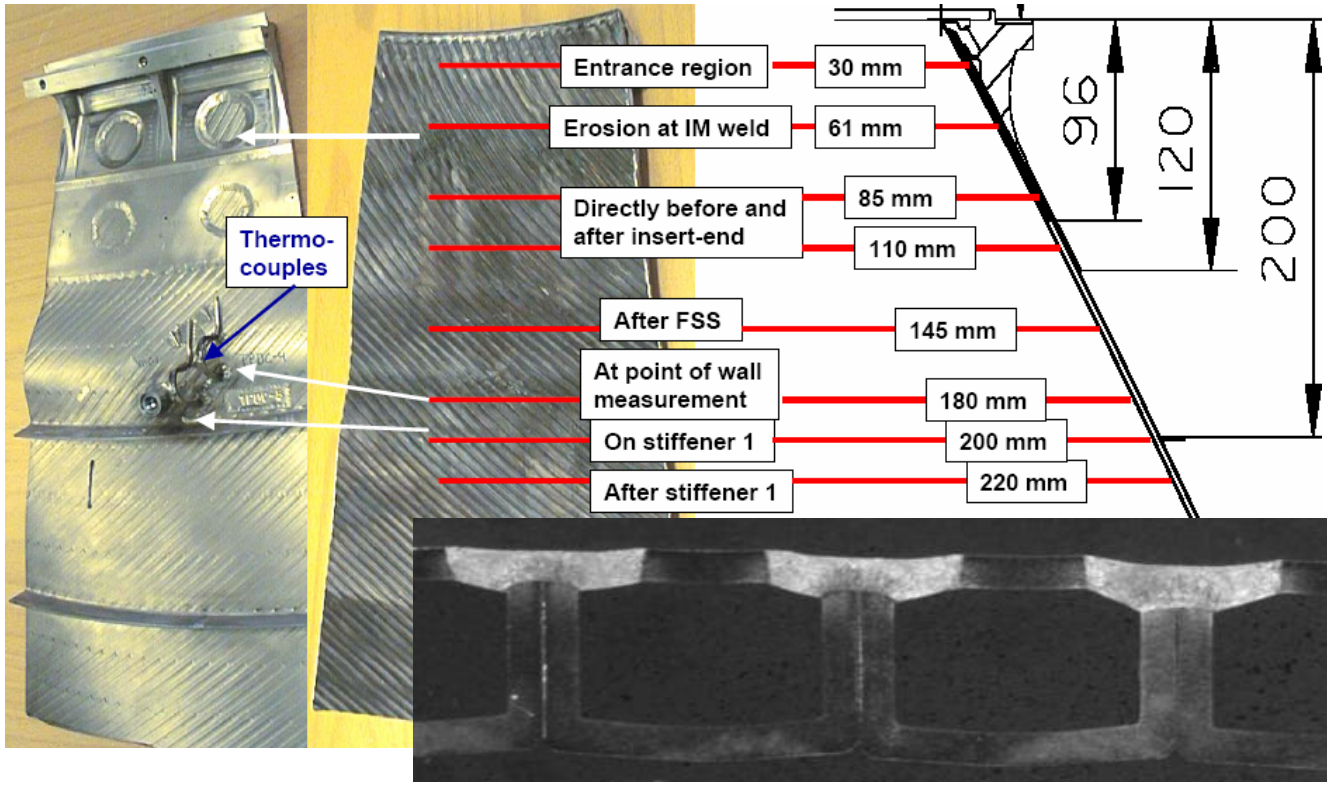
→ validation of CFD-, structural analysis- and life time-models for cooling channels

Test range: nozzle extension

Vulcain II



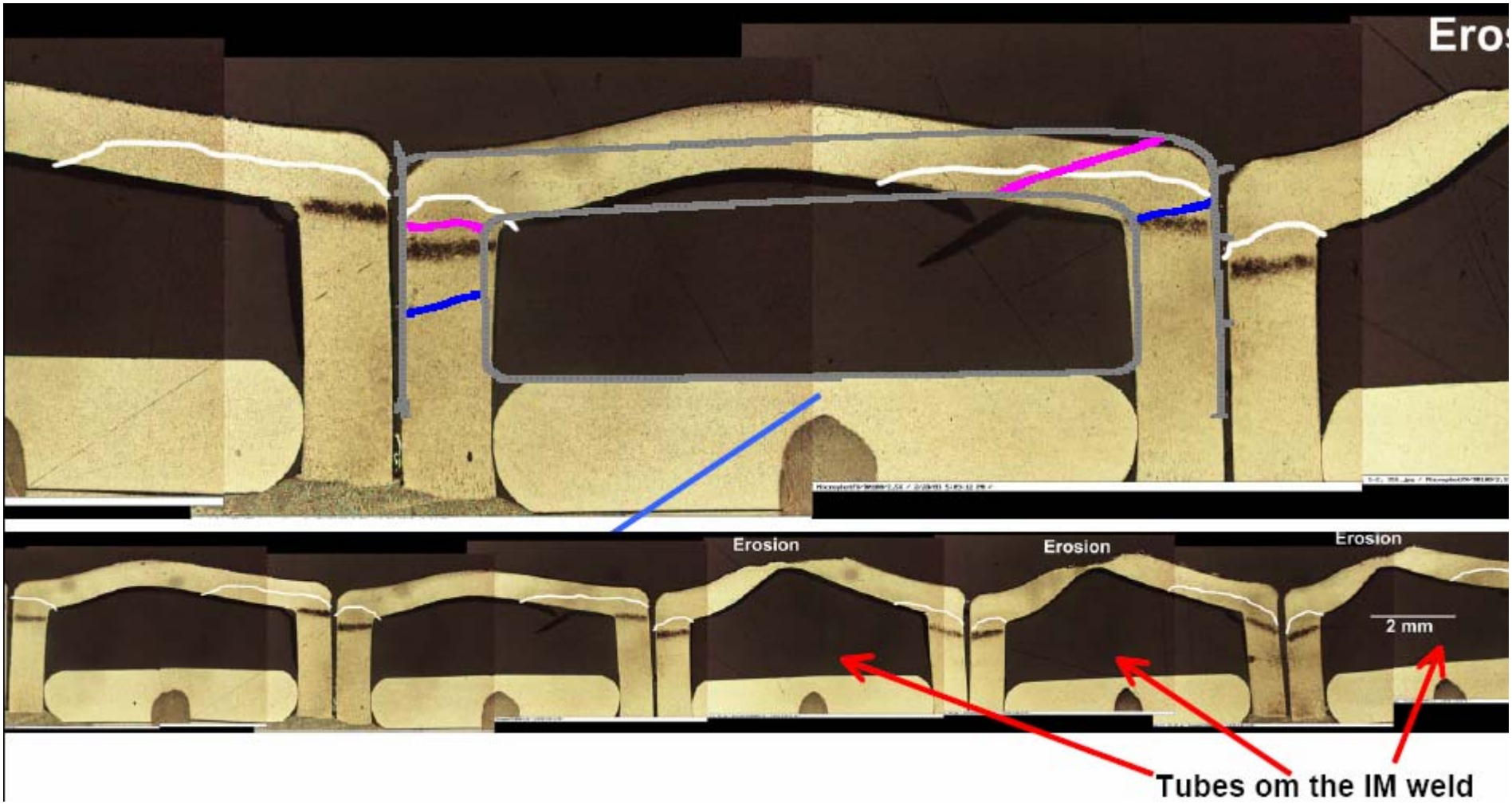
detail in upper range of nozzle extension



material: Inconel 600 (nickel basis alloy)

heat flux during hot run: $5-8 MW/m^2$

Thermally induced failure of the nozzle extension wall

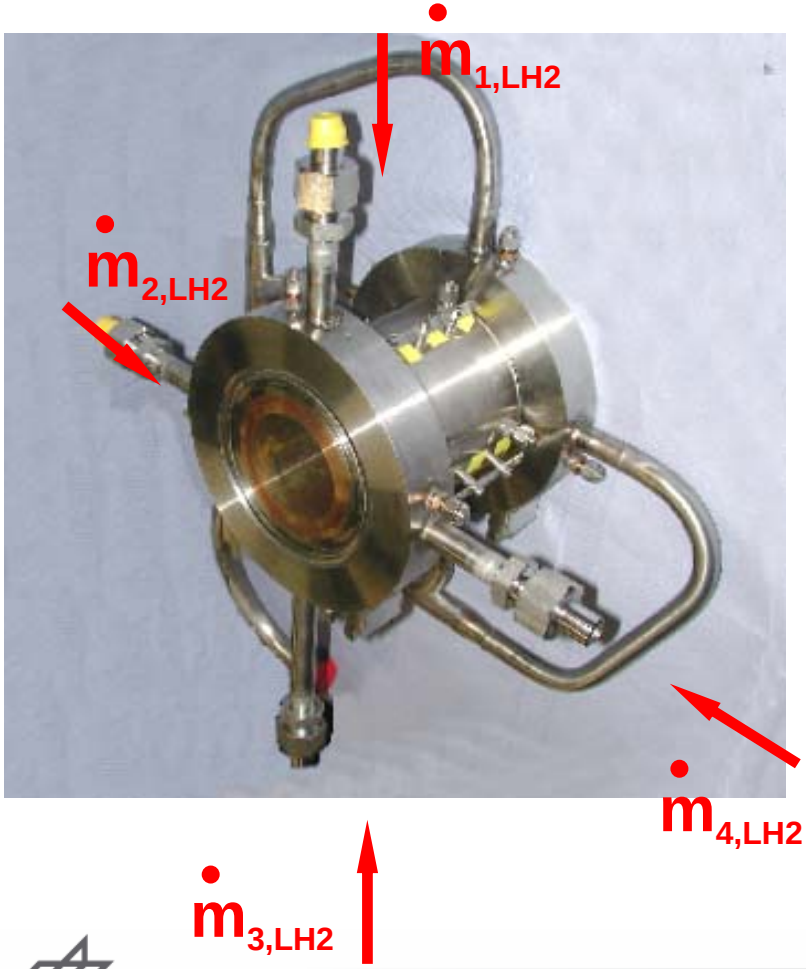


Failure mechanisms: creep; bulging; high temperature erosion

Motivation for TMF-Tests with HARCC-Geometry:

HARCC-segment of the L42-combustion chamber

tested at P8 with LH2 as coolant



- **four different segments with different cooling cannel geometries**

step 1:

- **experimental determination of the influence of the cooling channel geometry on the coolant side heat transfer**

step 2:

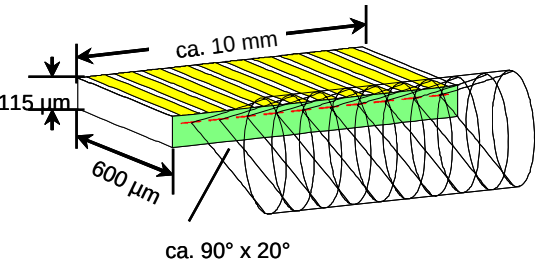
- **numerical modeling of the coolant side heat transfer and the structural deformation of the chamber wall**

step 3:

- **numerical EH3C-tests and TMF-Tests with identical coolant side geometries**

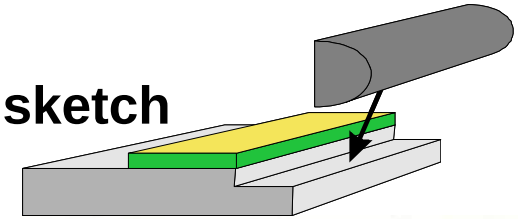
Heating of the TMF panel: by LASER

10 Laser diodes (wave length: 940 nm)



brazed on a copper plate + cylindrical lens = 1 Laser bar

sketch

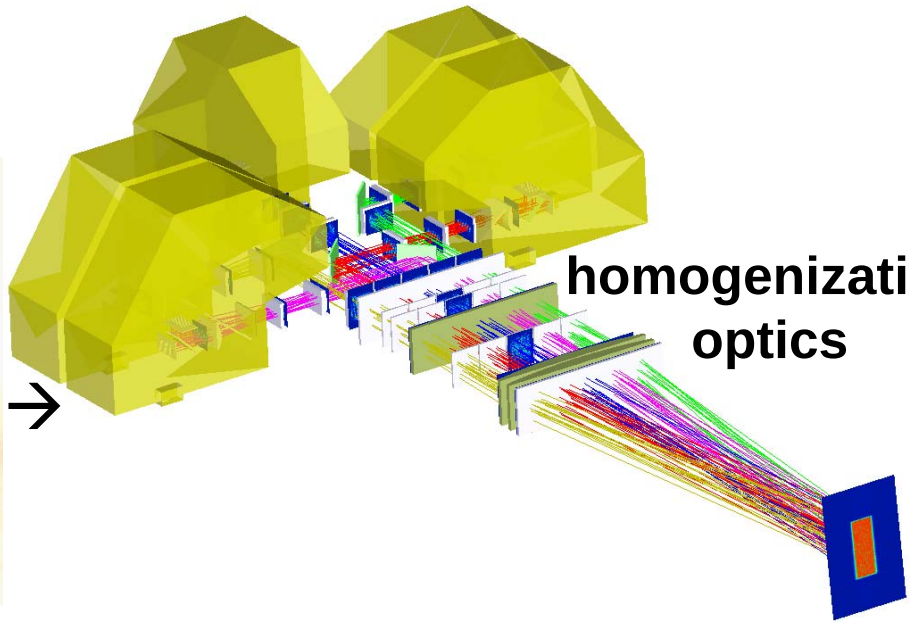


photo

10 Laser bars = single 550 W module

conception & production:
DILAS Diodenlaser GmbH
55129 Mainz

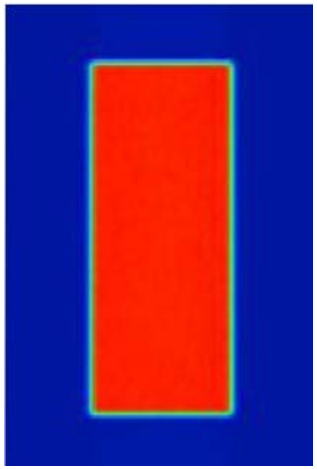
20 combined 550 W modules
= 200 Laser bars
= 2000 Laser diodes



homogenization optics

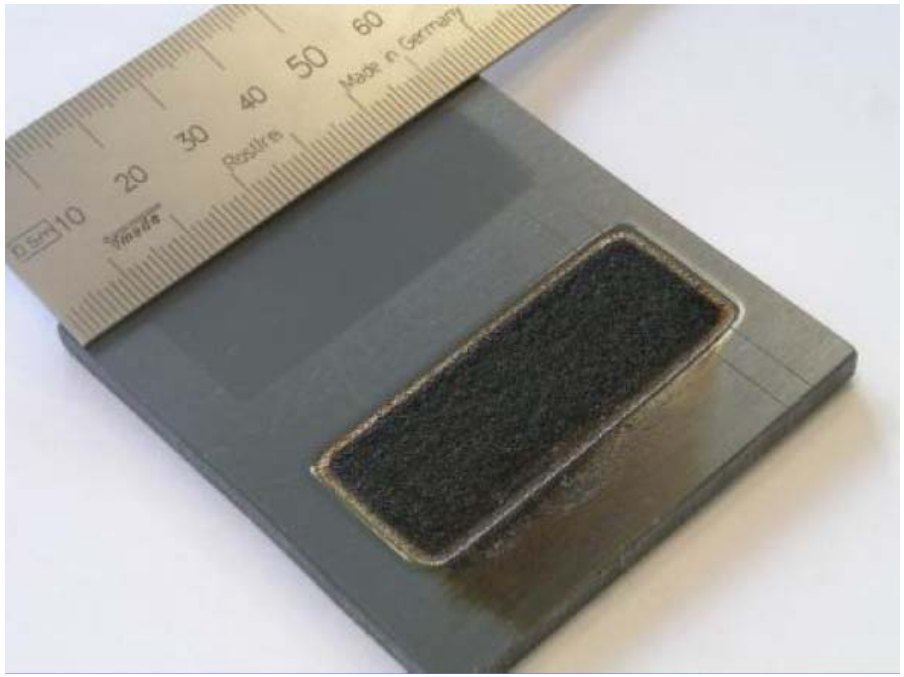
Analysis of the LASER beam at the focus area

simulation



short time operation

burn-in mark (plastic): 1s@150W

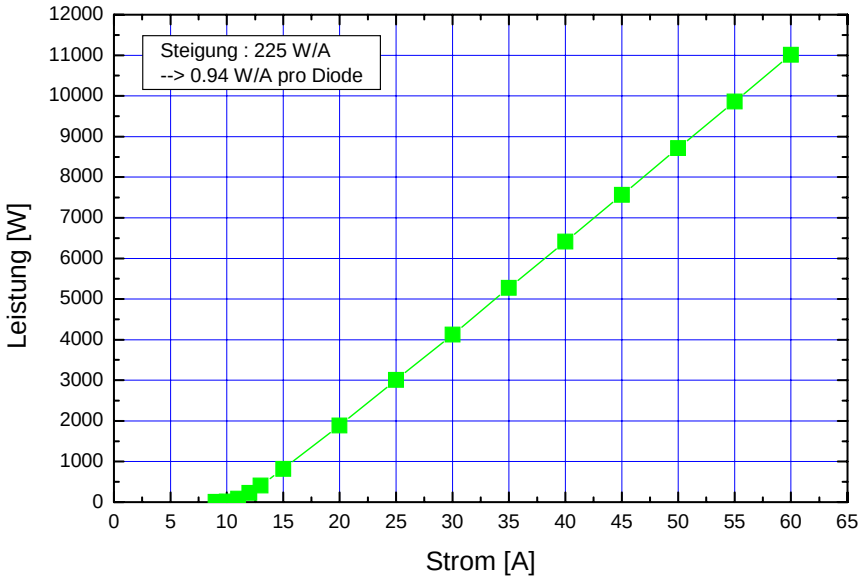


cw operation

optical output(cw):11kW

total size of focus area (measured, mm): 23 x 56
plateau area (measured, mm): 19 x 51

Measurement of the Laser power



power measure-ment head (by Coherent)

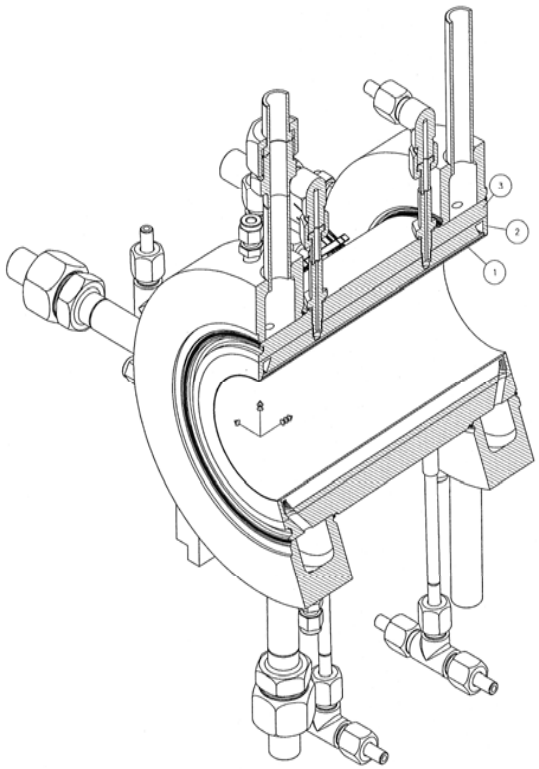
power monitor (by Primes)

measured Laser power : **11014 W @ 60 A**
10000 W @ 55.7 A

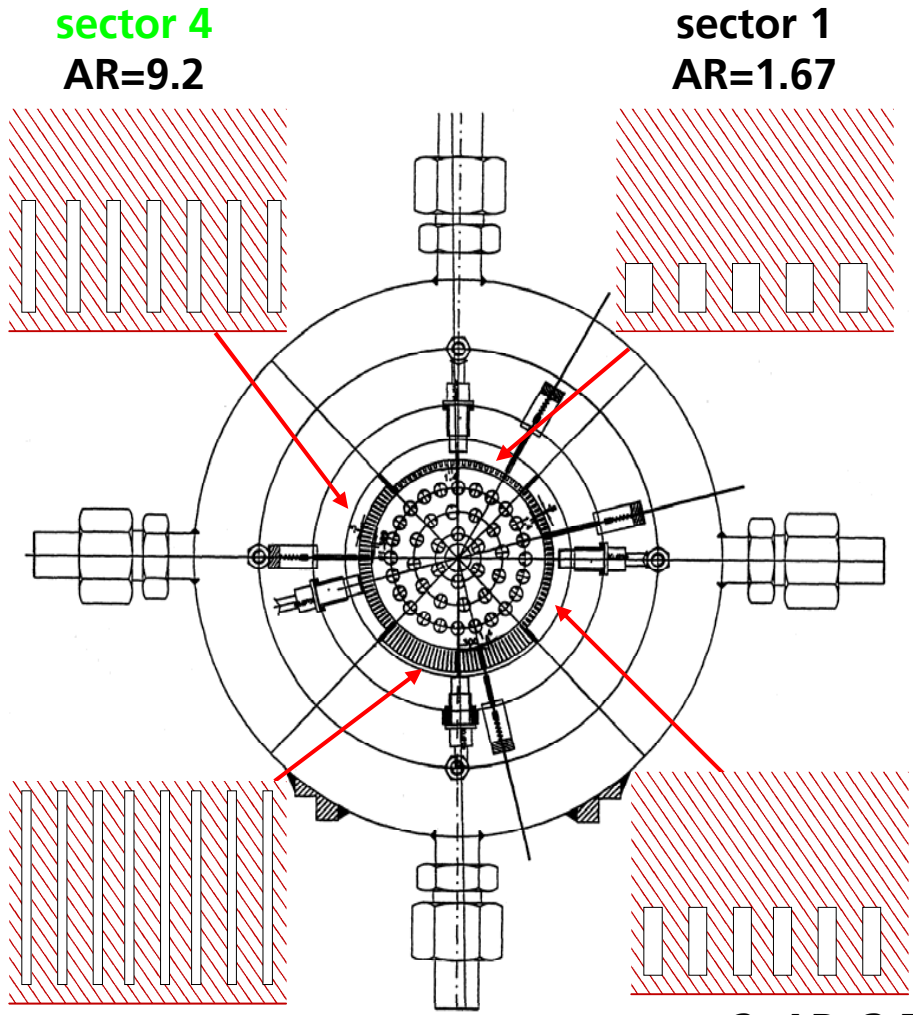
resulting power per area : more than 8 MW/m² @ 60 A

Cooling Channel Geometries of the HARCC Segment

sektor No.	width [mm]	height [mm]	aspect ratio	Fin width [mm]
1	1.2	2.0	1.67	1.4
2	0.8	2.8	3.5	1.4
3	0.3	9.0	30	1.4
4	**0.5**	**4.6**	**9.2**	**1.4**



sector 4 used also for EH3C-tests as well as for TMF-tests at DLR La



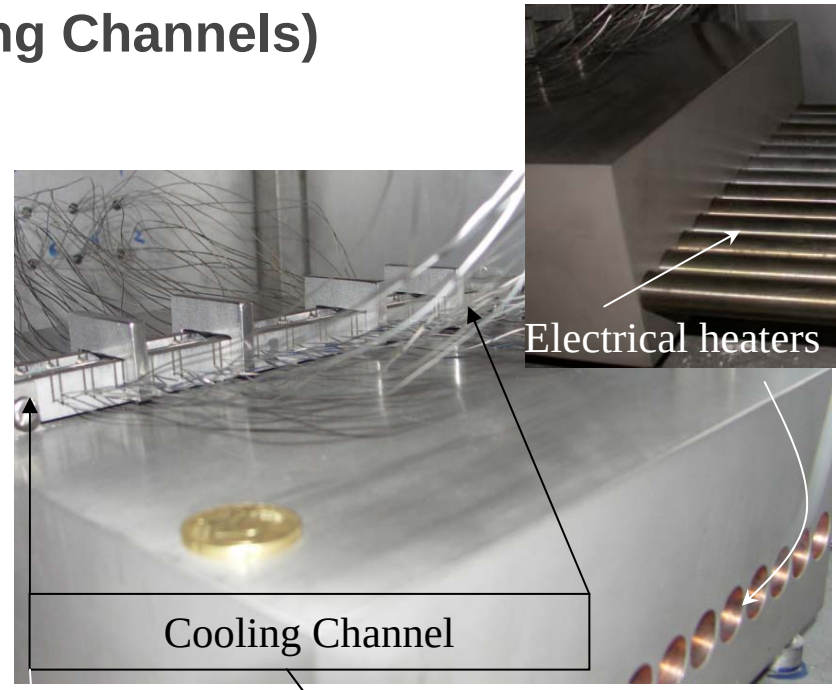
sectors 3 and 4: high ascpect ratio cooling channels (HARCC)

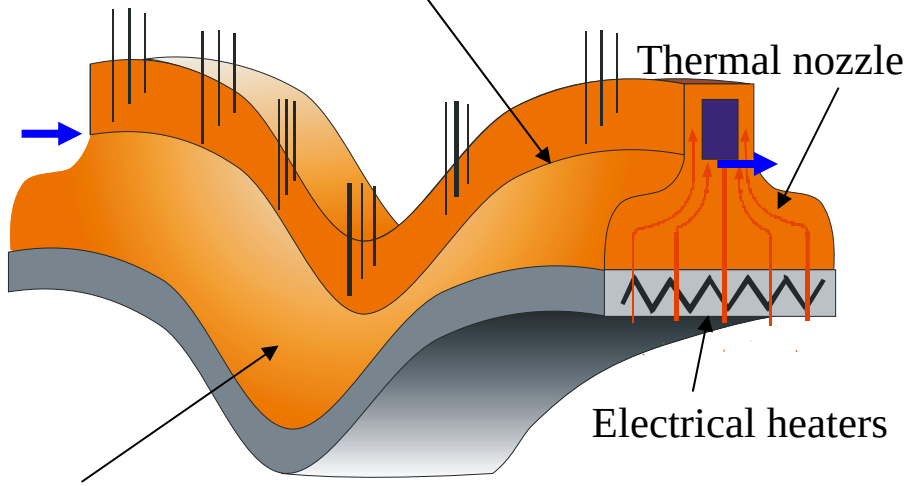
EH3C (Electrical Heated Curved Cooling Channels) experiments*

Torres, Y., Suslov, D.,…

Mailto: yohann.torres@dlr.de

- **EH3C Investigation: Curvature influence on asymmetrical heated channel with high aspect ratio**
- **Electrical asymmetrical heating:15 MW.m-2**
- **Aspect Ratio 9.2**
- **Width: 0.5 mm**
- **Height: 4.6 mm**
- **Straight and Curved test specimen for comparison**
- **Material : Copper alloy**
- **Coolants: H2 , CH4, N2, …**

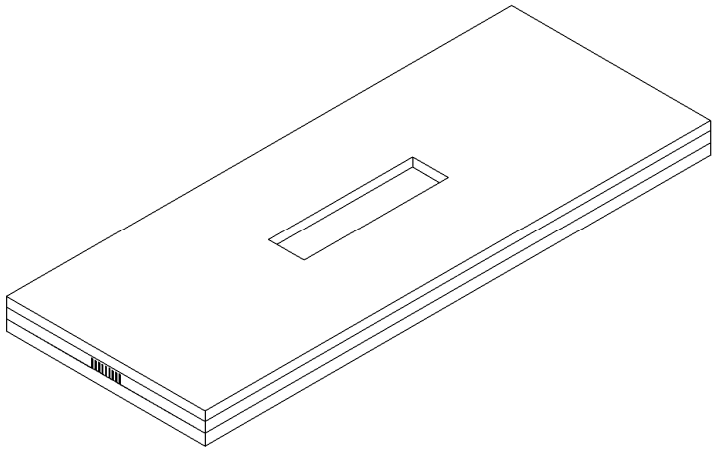




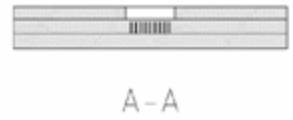
*Suslov, D., Torres, Y., Woschnak, A., Oschwald, M., Vorrichtung und Verfahren zur Erzeugung von Wärmeströmen definierter Wärmestromdichte, September 23, 2004, DLR-Patent, G01N25/18, DE200410042901 20040831

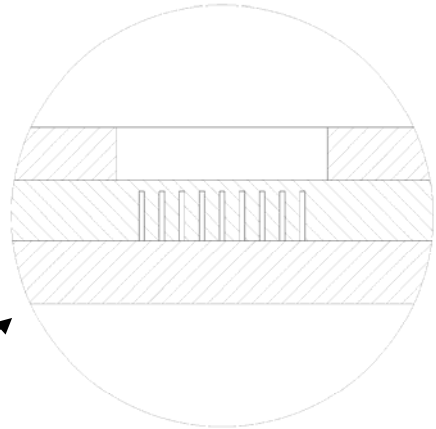
Sandwich part of the TMF panel (Calculation Domain)

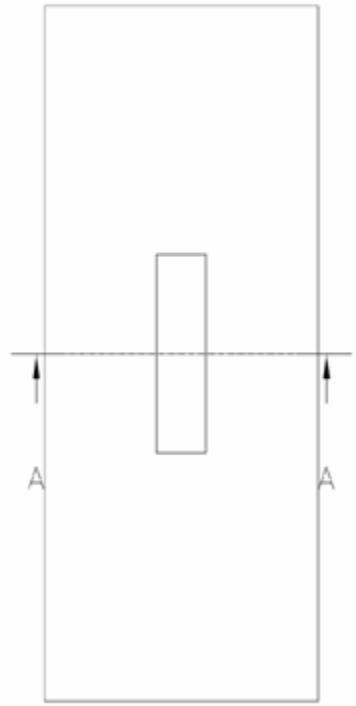
Isometric View of the calculated Volume



cross section in the middle of the Laser loaded area





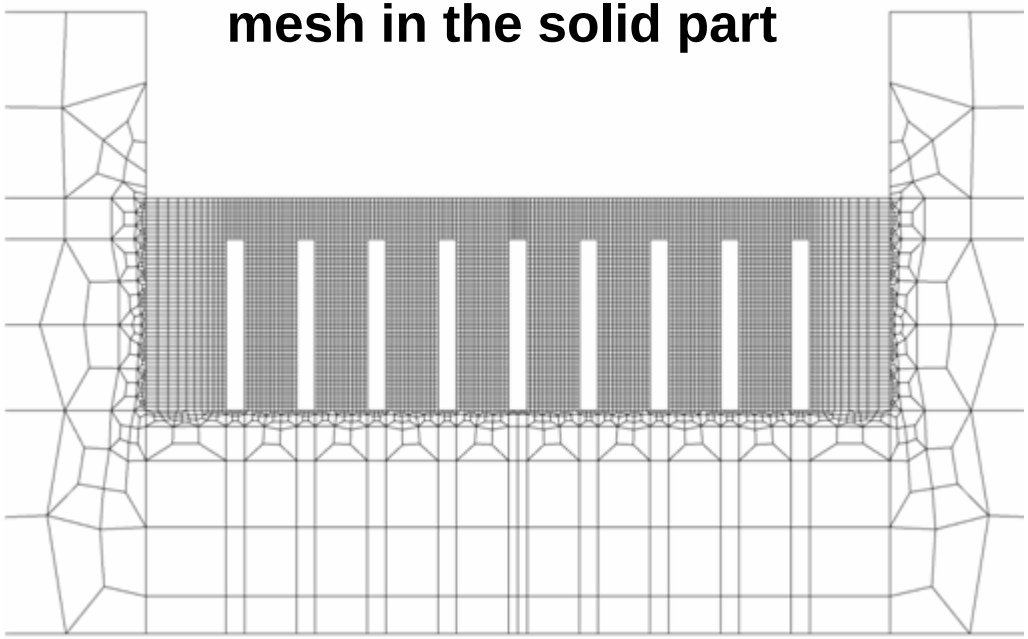


Detail of the cooling channels

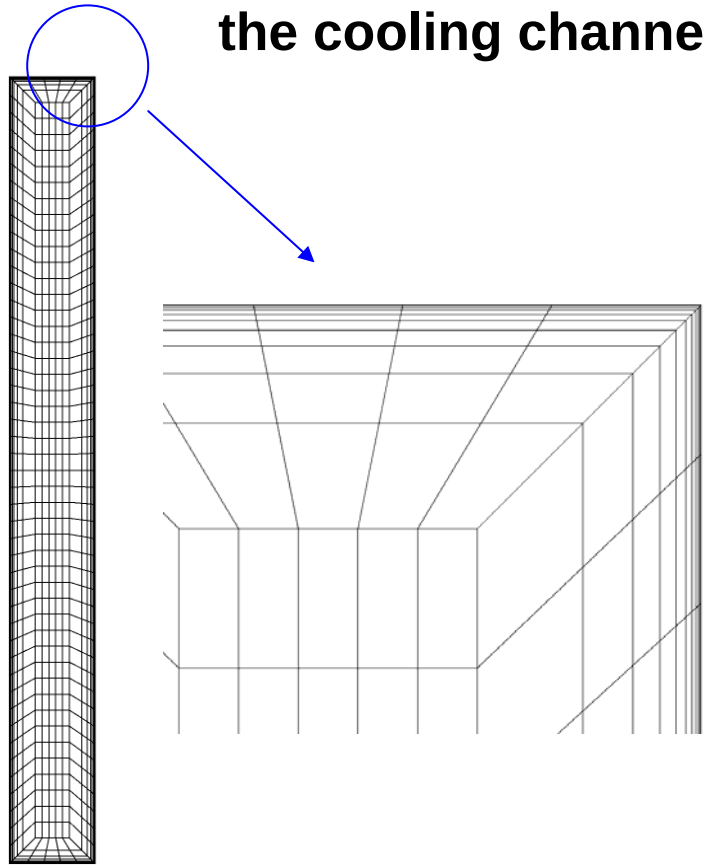
HARCC- dimensions of hot gas wall and cooling channels

CFD analysis of the core part of the TMF panel

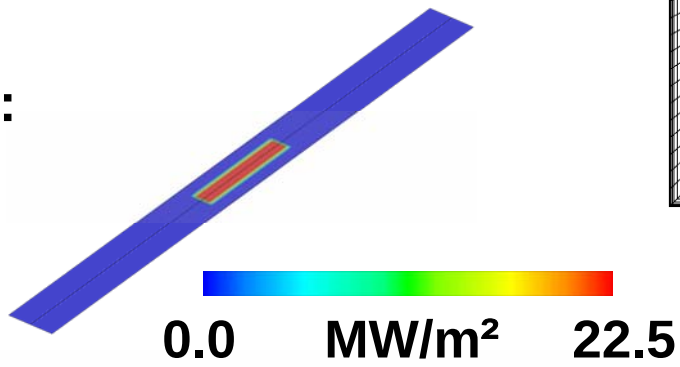
cross section of the CFD mesh in the solid part



cross section of the CFD mesh in the cooling channels



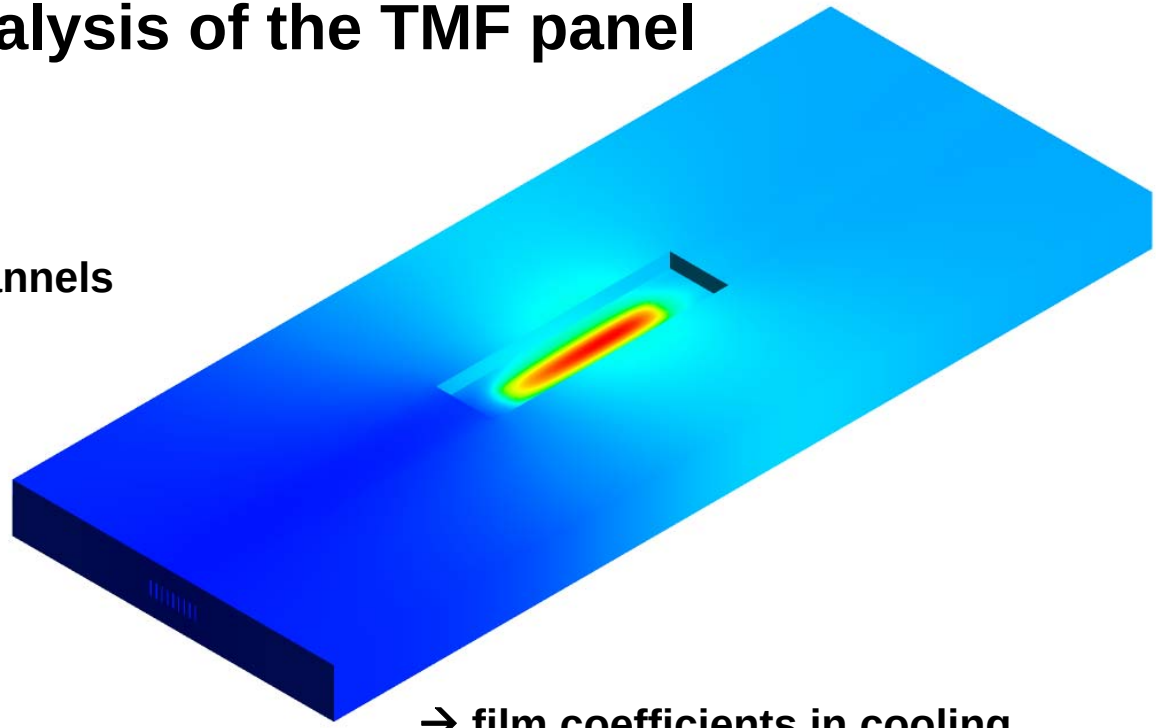
thermal loading: prescribed heat flux on Laser loaded side



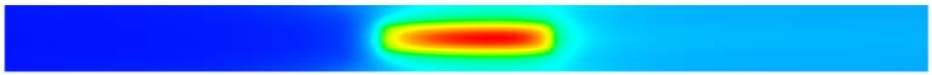
CFD analysis of the TMF panel

CFD model:

- **full 3D model of the cooling channels**
- **solution of the RANS equations**
- **SST turbulence model**
- **compressible flow**
- **real gas behavior**



→ → → Fluid Direction → → →



→ film coefficients in cooling channels taken as input for follow-on thermal and structural Finite Element analyses

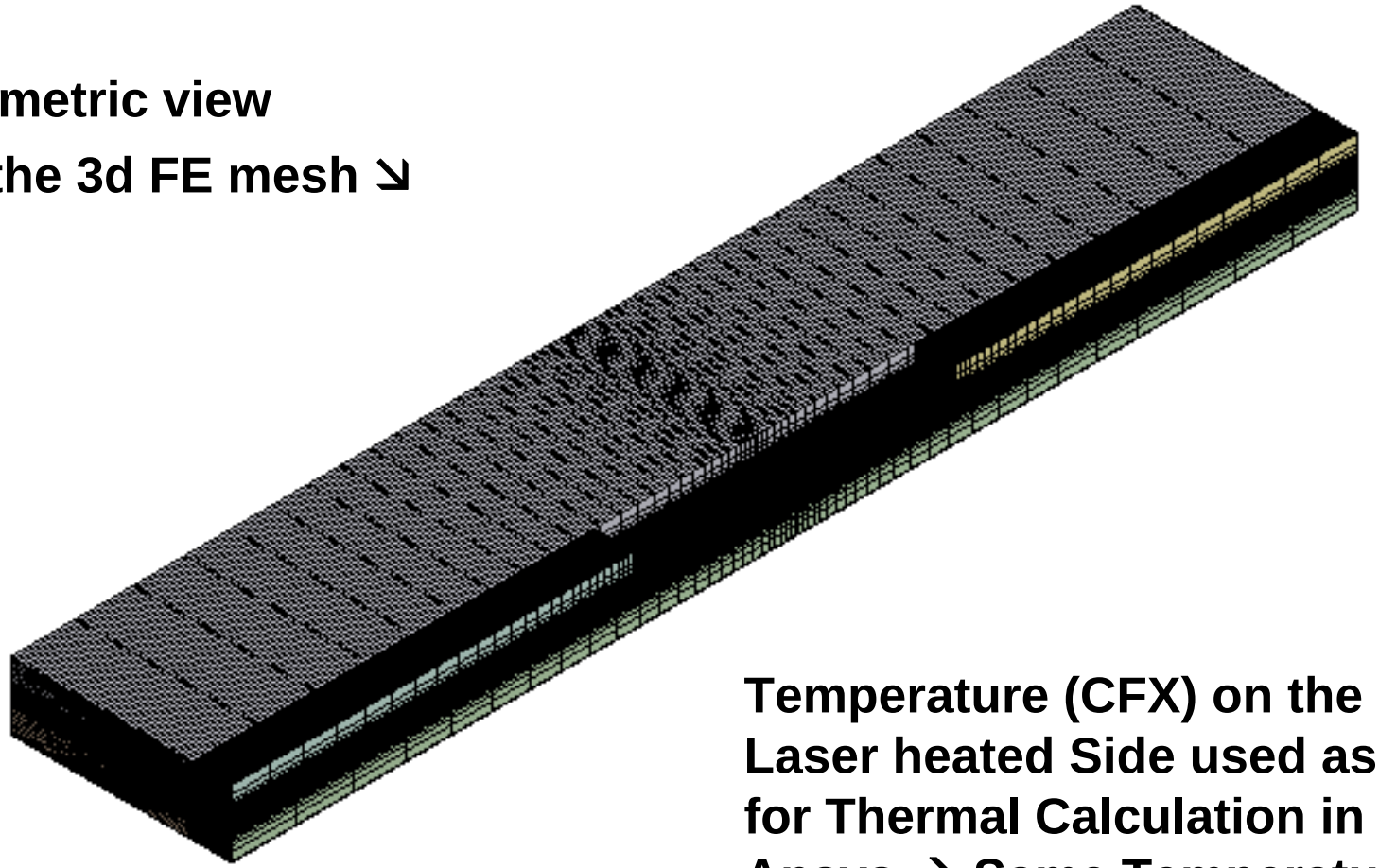
160 K **440 K** **720 K**

surface temperature on the Laser loaded panel

Finite Element mesh and result of the thermal analysis

isometric view

of the 3d FE mesh ↘

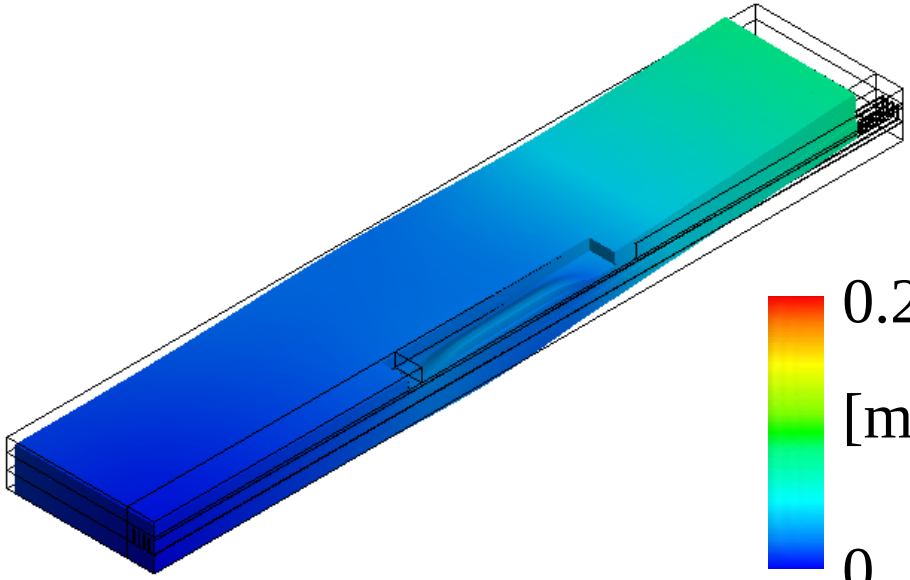


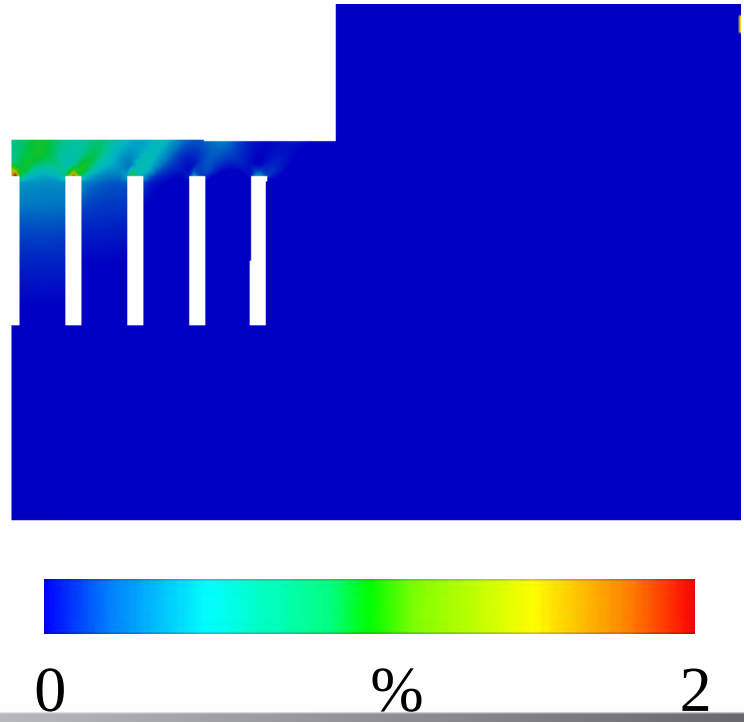
Temperature (CFX) on the Laser heated Side used as Input for Thermal Calculation in Ansys → Same Temperature field

Structural Finite Element analysis: model and results

- multilinear elasto-plastic material behavior with the von Mises yield function
- geometric nonlinearity
- temperature dependent material properties

exemplary result: Deformation (x100) ↓ Plastic Strain in x-Direction





Conclusion and outlook

TMF Tests of HARCC-Geometry offers

- → **Measuring of the fluid flow inside a straight cooling channel**
- → **Measurement of the deformation of the whole channel**

With respect to the other Test benches

- → **Measurement of the heat Transfer of the cooling channel geometry with respect to curving and deformation**
- → **Measurement of Deformation to compare with structural deformation codes**

Outlook

- → **Change the design to be able to feed each line separately**
  - → **The heat flux perpendicular to the fluid flow can be minimized**
  - → **Temperature on the Laser loaded side is more similar to the one of the combustion chamber**
  - → **Measurement of each fluid mass flow**