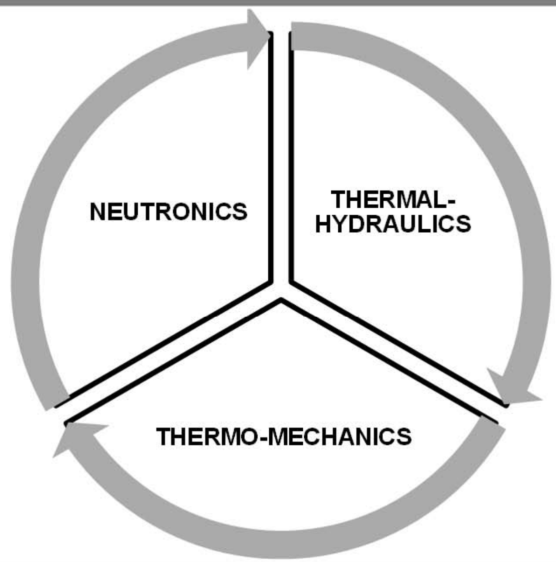
Breeding blanket multi-physics modelling for integrated DEMO design

Gandolfo Alessandro Spagnuolo

25th European Fusion Programme Workshop
27 – 29 November 2017, Dubrovnik (Croatia)

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

INSTITUTE FOR NEUTRON PHYSICS AND REACTOR TECHNOLOGY (INR)
KARLSRUHE INSTITUTE OF TECHNOLOGY (KIT)



Outline

- Motivation
- Coupling procedure
- Developed methodologies
- Analysis & results
  - Neutronics
  - Thermal-hydraulics
  - Mechanics
- Summary
  - Open points
  - Conclusion

Motivation

- Within the framework of the EEG 2015/11 - 10.1 concerning the "Tritium breeding blanket design and analysis", a research campaign dedicated to the development of an integrated simulation-design tool has been launched at Karlsruhe Institute of Technology (KIT);

- the research activity has been devoted:
  - to outline a procedure for the coupling neutronic, thermal-hydraulic and structural mechanical analysis using the well-known commercial software employed in the design of the BB with the great advantage of deploying the same geometry definition for all the analyses involved;
  - to optimise the DEMO BB design;
  - to propose new methodologies for the nuclear fusion components design.

Coupling procedure

Coupling issues:

- Different geometries used for each analysis;
- The changes are not always backwards;

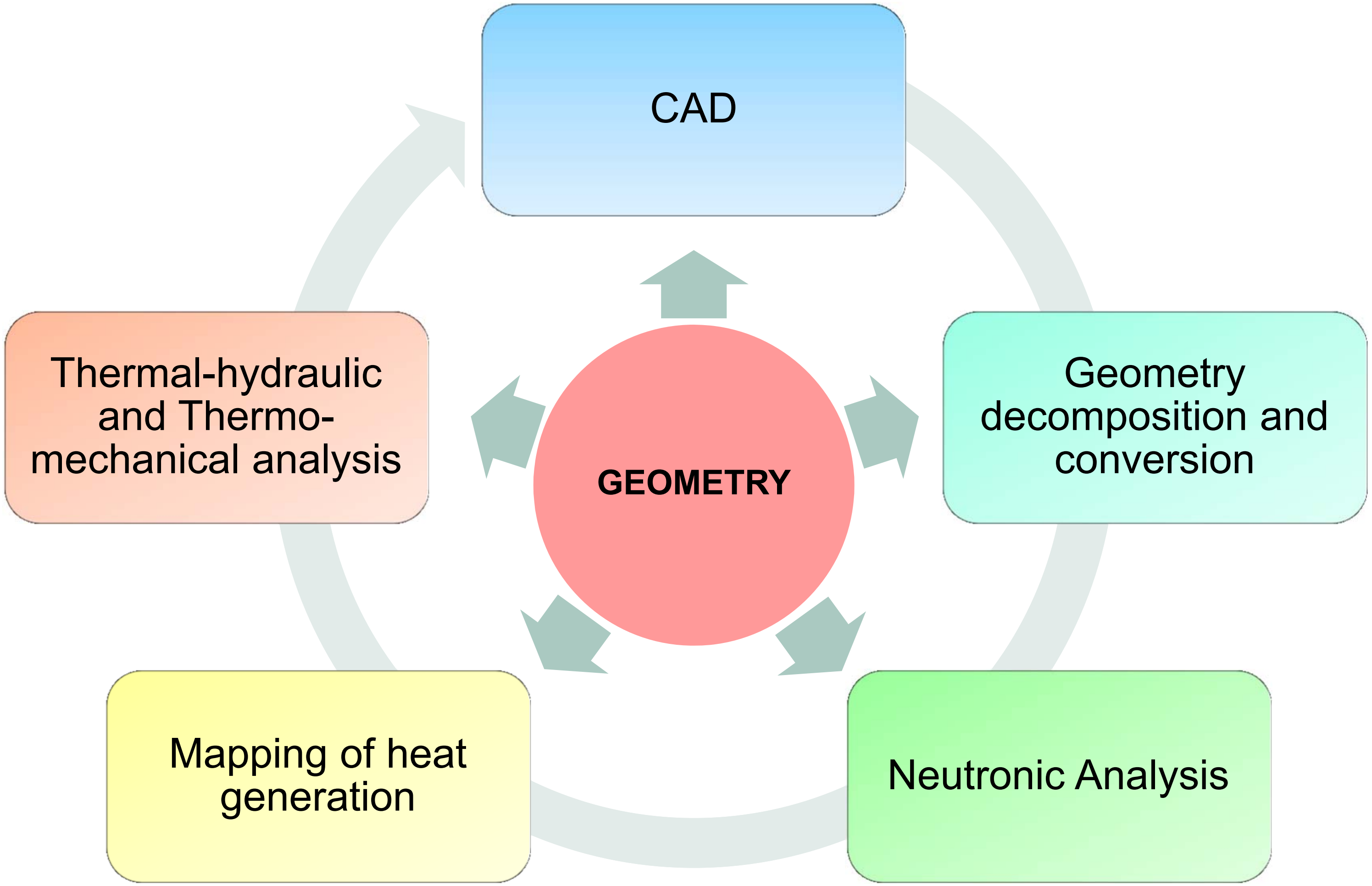
CAD

Neutronic analysis

CFD analysis

Structural analysis

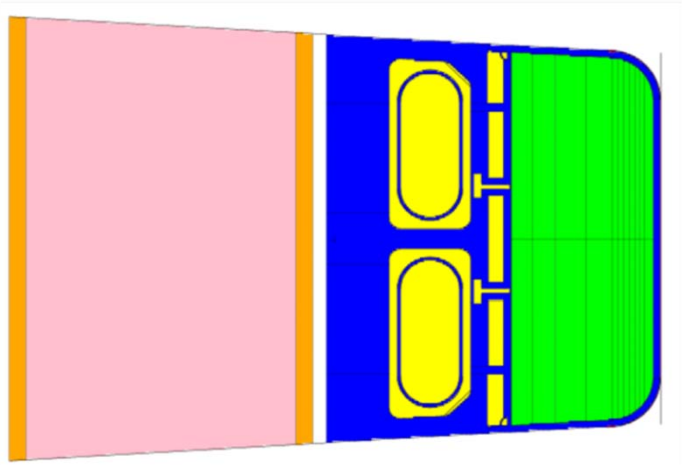
Coupling procedure



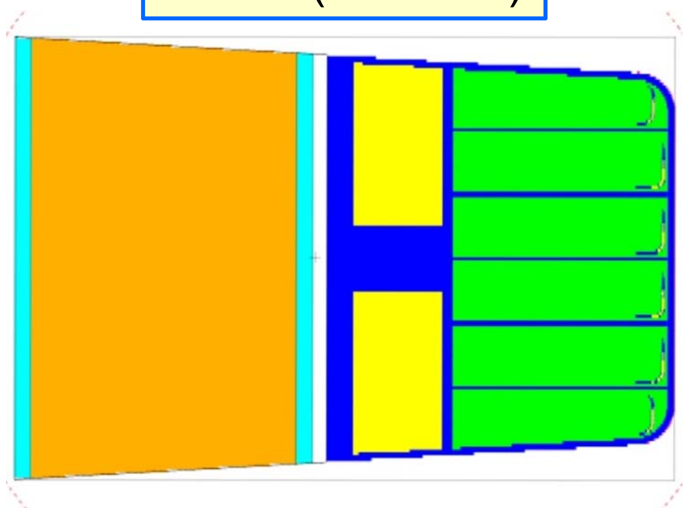
Developed methodologies

- Two different approaches for the creation of the neutronic models have been investigated and applied:
  - Constructive Solid Geometry (CSG) based on one and two-dimensional surfaces representation;
  - HYBRID geometry representation using an Unstructured Mesh (UM) embedded in its legacy CSG.

HCPB (CSG)

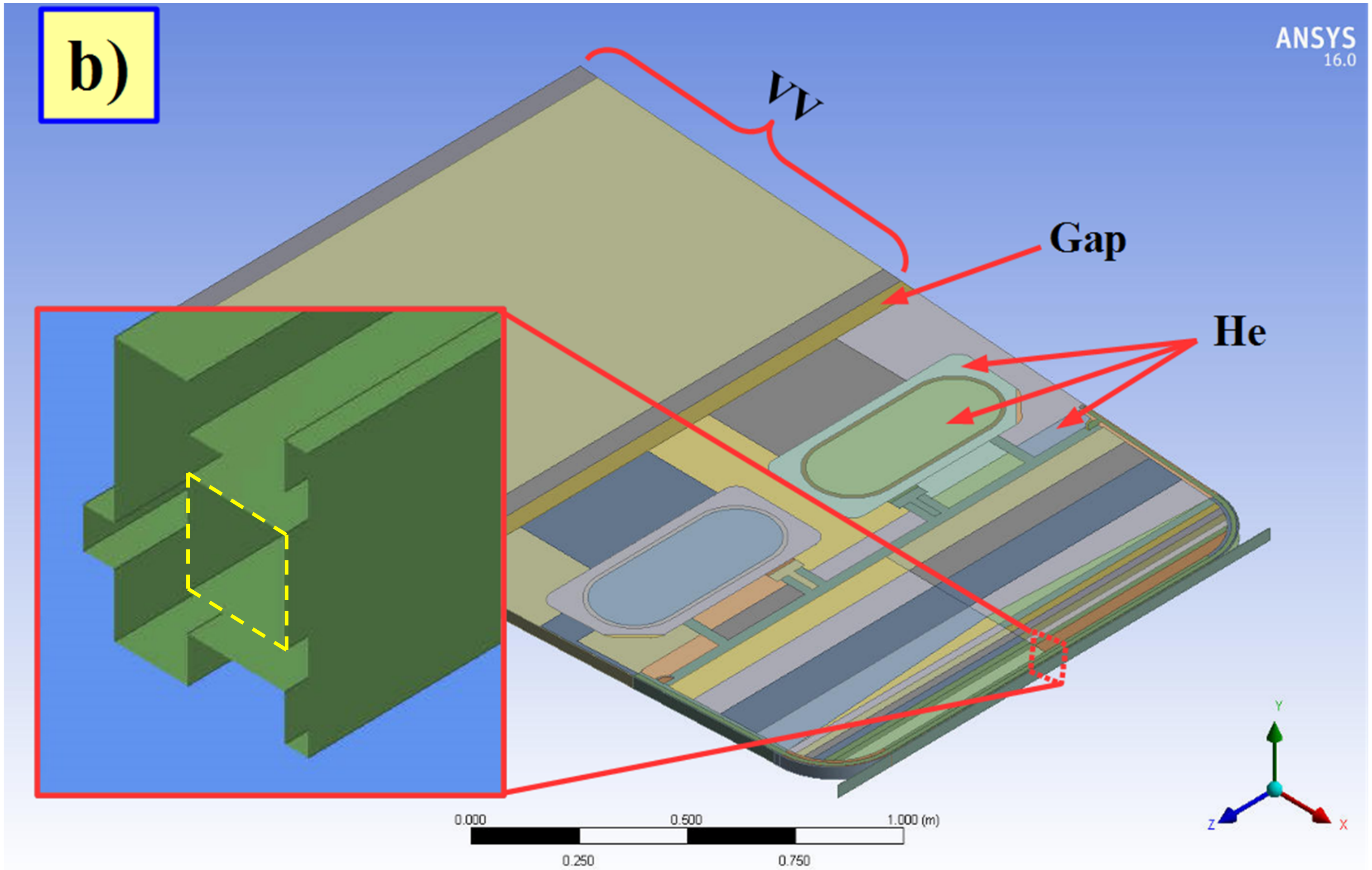


WCLL (HYBRID)



G.A. Spagnuolo et al., Identification of blanket design points using an integrated multi-physics approach, Fusion Eng. Des. 124 (2017) 582-586

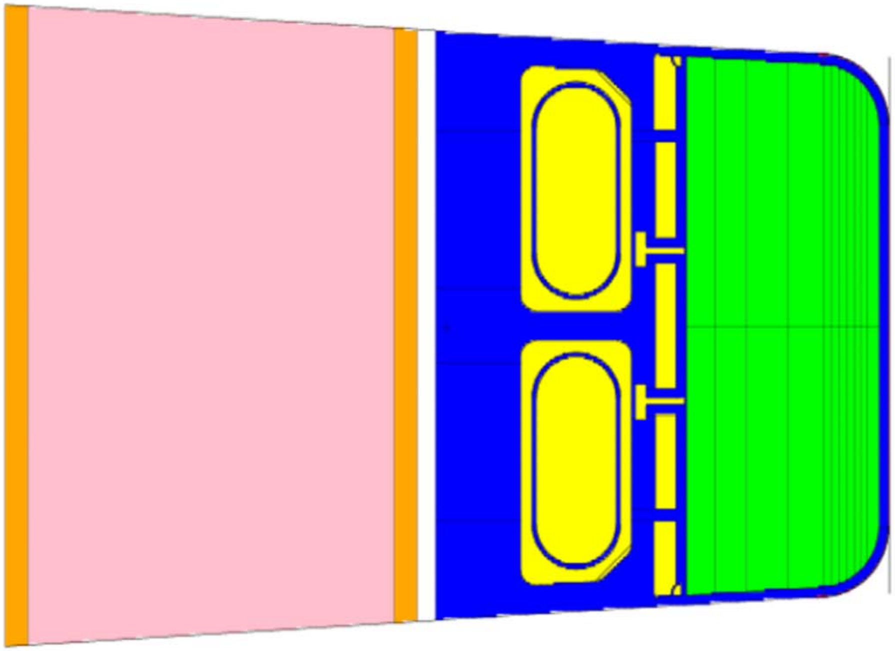
Developed methodologies - CSG

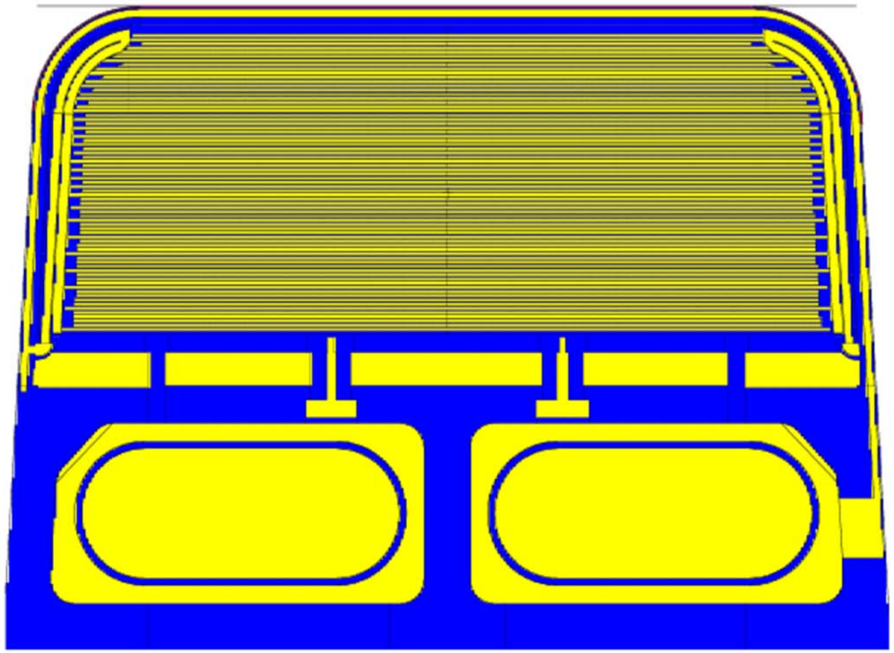


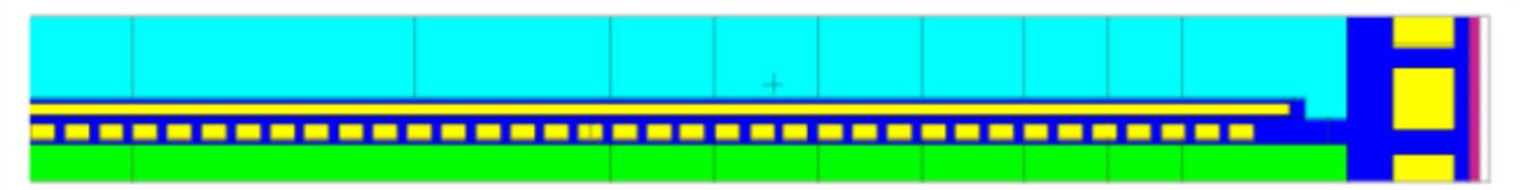
G.A. Spagnuolo et al., Identification of blanket design points using an integrated multi-physics approach, Fusion Eng. Des. 124 (2017) 582-586

Developed methodologies - CSG

- Neutronic model of HCPB slice based on Constructive Solid Geometry (CSG).

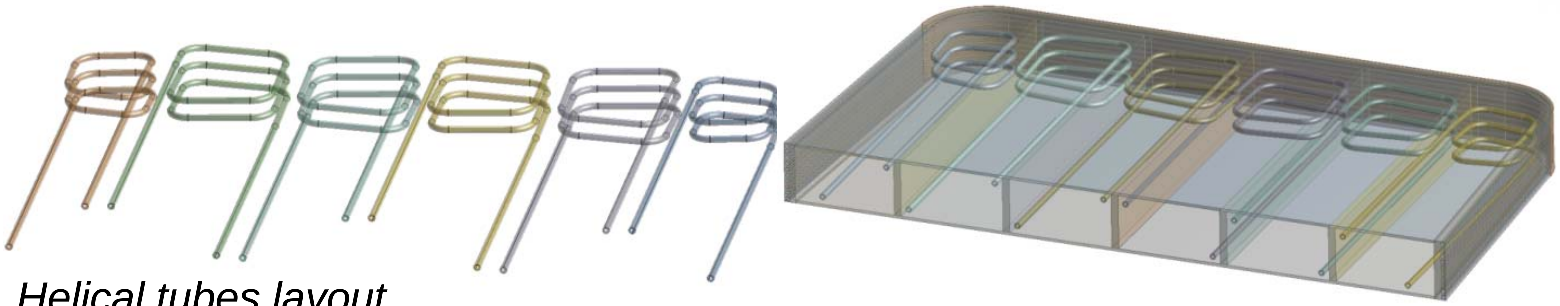




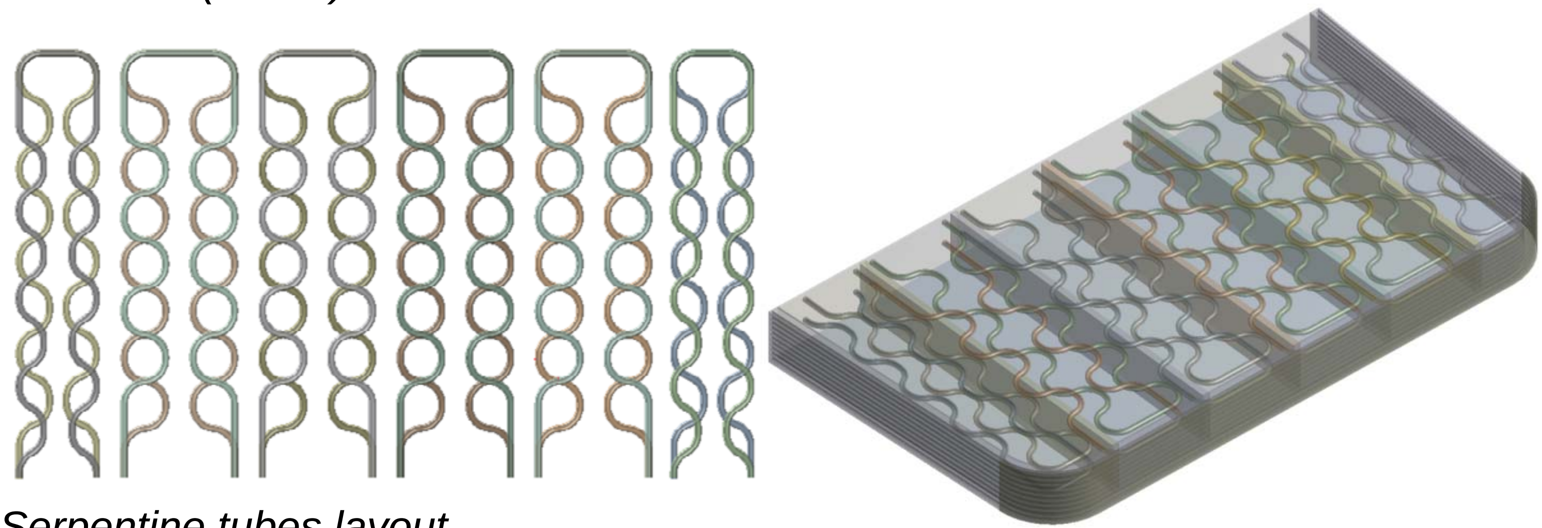


G.A. Spagnuolo et al., Identification of blanket design points using an integrated multi-physics approach, Fusion Eng. Des. 124 (2017) 582-586

Developed methodologies - HYBRID

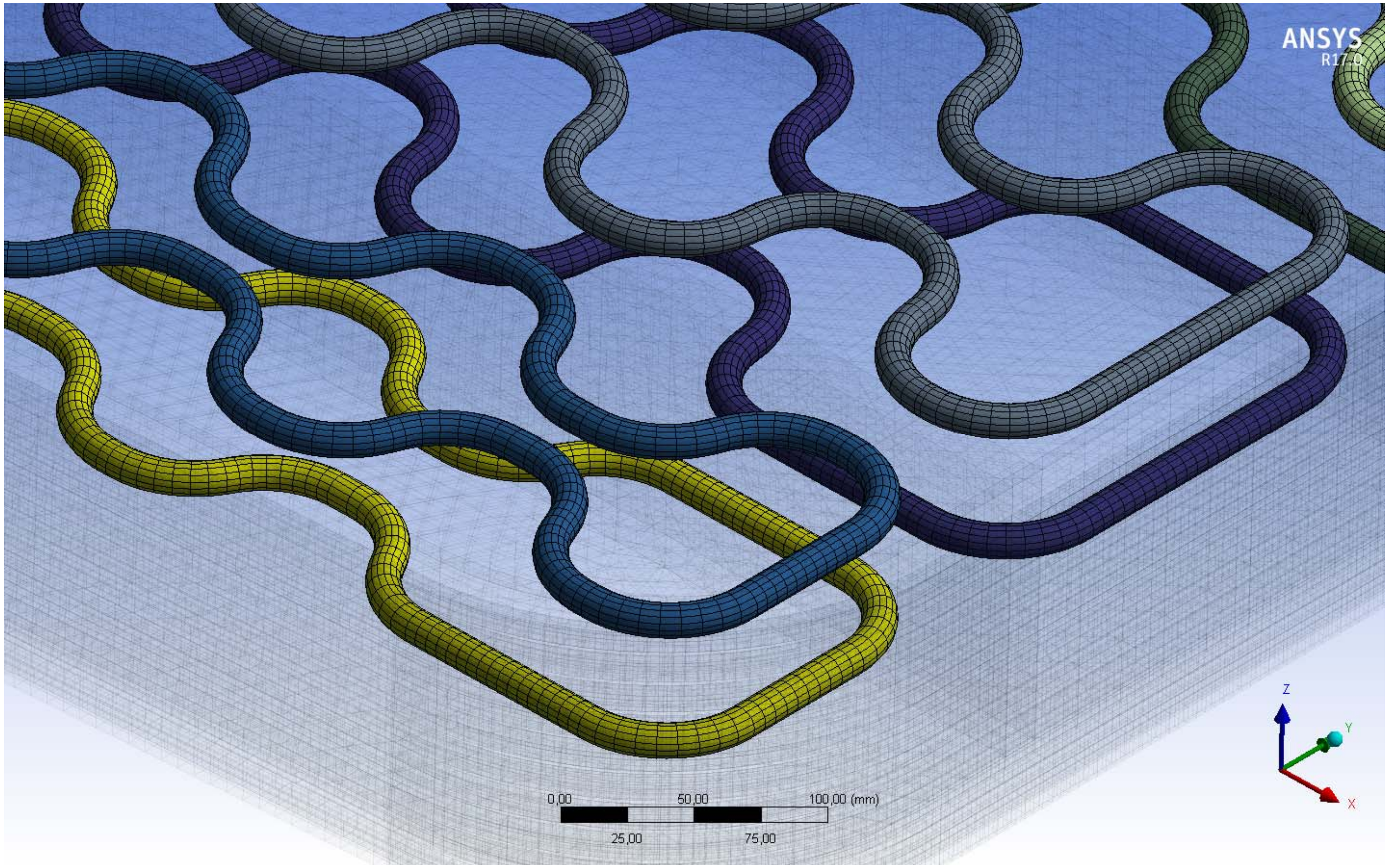


Helical tubes layout,
E. Martelli (ENEA)



Serpentine tubes layout,
G.A. Spagnuolo (KIT)

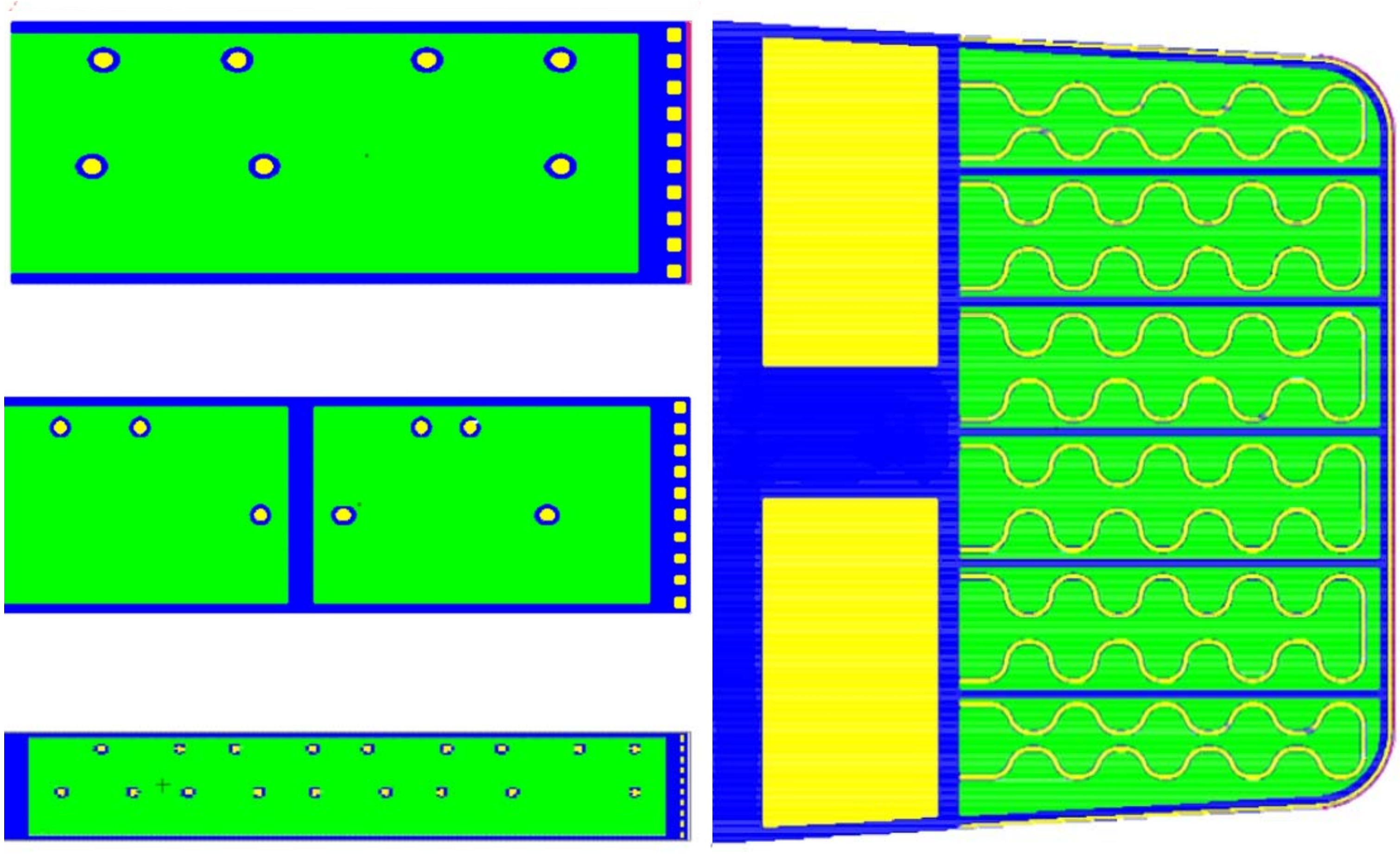
Developed methodologies - HYBRID



Developed methodologies - HYBRID

SERPENTINE TUBES CONFIGURATION	PART NAME	ELEMENT TYPE	NODE NUMBER	ELEMENT NUMBER
1	Armour	C3D8	17712	11118
2	FW	C3D8	63954	46625
3	FW_Coolant	C3D8	65925	29260
4	Plates_North/South	C3D6	39764	39004
5	Vertical_Plates	C3D8	18690	11440
6	BZ_Tubes_1_3	C3D20	365968	66400
7	BZ_Tubes_4_6	C3D20	365968	66400
8	BZ_Coolant_1_2	C3D15	149294	45460
9	BZ_Coolant_3_4	C3D15	156356	47104
10	BZ_Coolant_5_6	C3D15	145866	44092
11	PbLi_1	C3D10	141367	71034
12	PbLi_2	C3D10	161870	81215
13	PbLi_3	C3D10	161314	80773
14	PbLi_4	C3D10	161236	80694
15	PbLi_5	C3D10	161433	80825
16	PbLi_6	C3D10	141647	71231
17	BSS	C3D8	57270	47866
18	BSS_Coolant	C3D8	9504	7616
TOTAL			**2385138**	**928157**

Developed methodologies - HYBRID



Analysis - Neutronics

- The correct definition of the cells and the conservation of the volumes has been checked by means of the stochastic volume estimation based on the ray tracing technique in order to demonstrate that the neutronic models represent faithfully the real geometry;

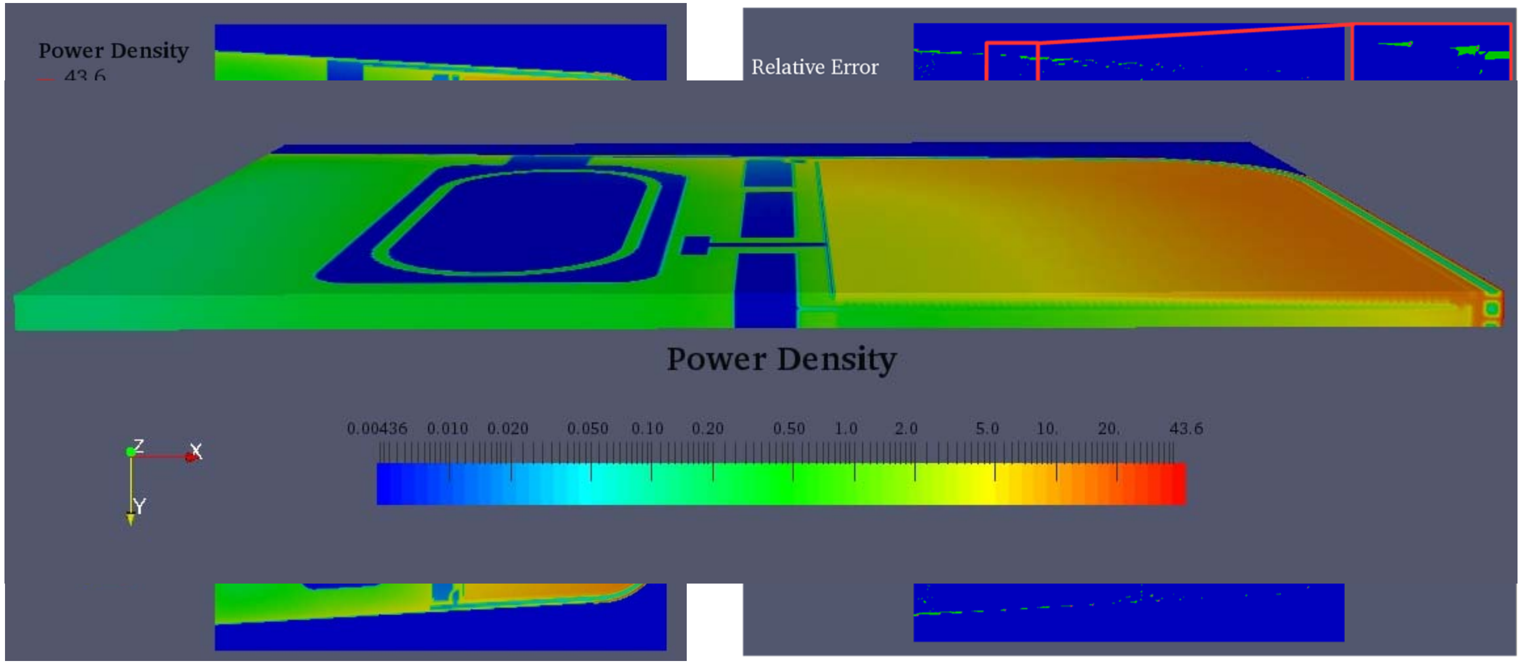
	CSG	HYBRID	
Overall Error [%]	0.01%	Helical	-0.0035%
		Serpentine	-0.0005%

- reflecting boundary conditions have been imposed in the poloidal and toroidal direction, while, for the radial direction, the VV has been included;

- a dedicated global neutron source model has been developed to simulate the actual neutron volumetric source of a fusion reactor. It has been identified the surface corresponding to the outboard equatorial module where the neutrons are biased in cosine and energy. The cosine distribution has been ranged in 10 subdivisions while:
  - the neutron energy has been sampled from 0.111 MeV to 14.2 MeV subdivided in 98 energy bins;
  - the photon energy has been sampled from 0.001 MeV to 50.0 MeV subdivided in 43 energy bins.

Results – Neutronics (CSG)

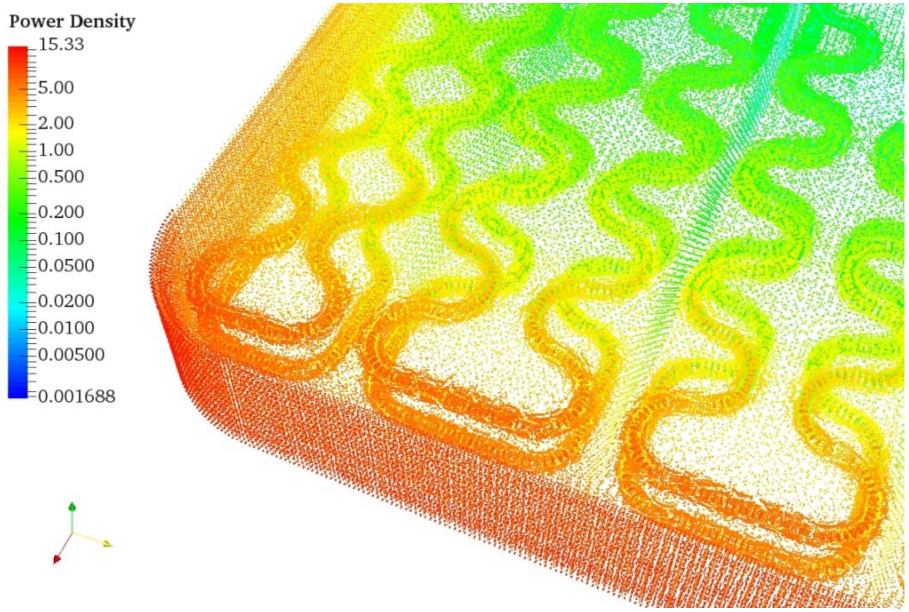
- The neutronic Monte Carlo calculation has been performed with the MCNP5 code running a statistically-relevant number particle histories (e.g. 1E+08). Run time ~ 20h;
- the power density deposition has been calculated on a superimposed mesh of 1.88E+06 voxel with a resolution lower than 3 mm in x, y and z direction;
- the 99.13% of the 1.88E + 06 mesh elements have a relative error lower than 5%, 0.82% between 5 and 10%, and only 0.05% greater than the 10%.



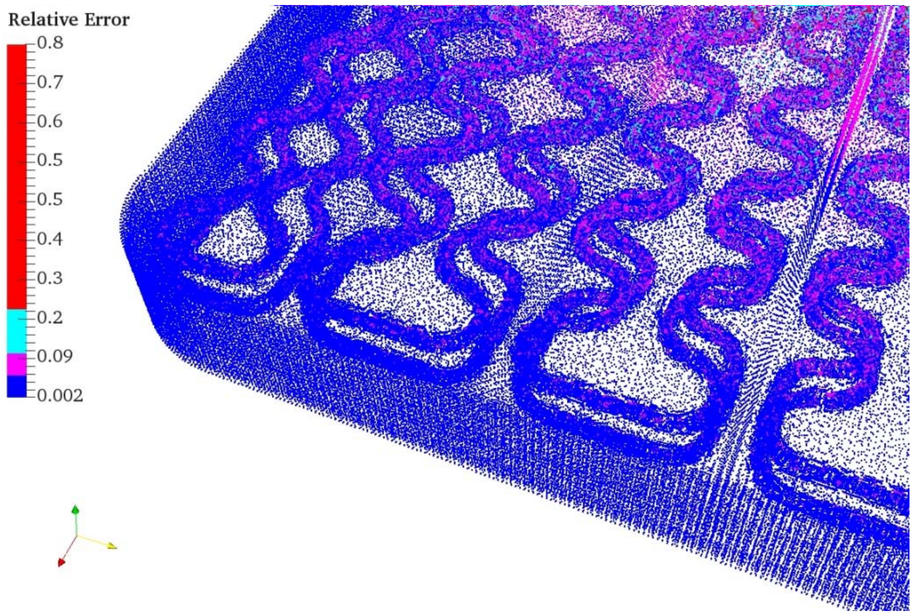
Results – Neutronics (HYBRID)

- The neutronic Monte Carlo calculation has been performed with the MCNP6 code running a statistically-relevant number particle histories (e.g. 1E+08). Run time ~ 11h;
- between the 86.9% and the 89.42% of the mesh elements have a relative error lower than 10%, 8.03-10.33% between 10 and 20%, and 2.56-2.78% with an error greater than 10%;
- for these preliminary analyses, no variance reduction technique has been used.

3D power density profile – Serpentine tube configuration

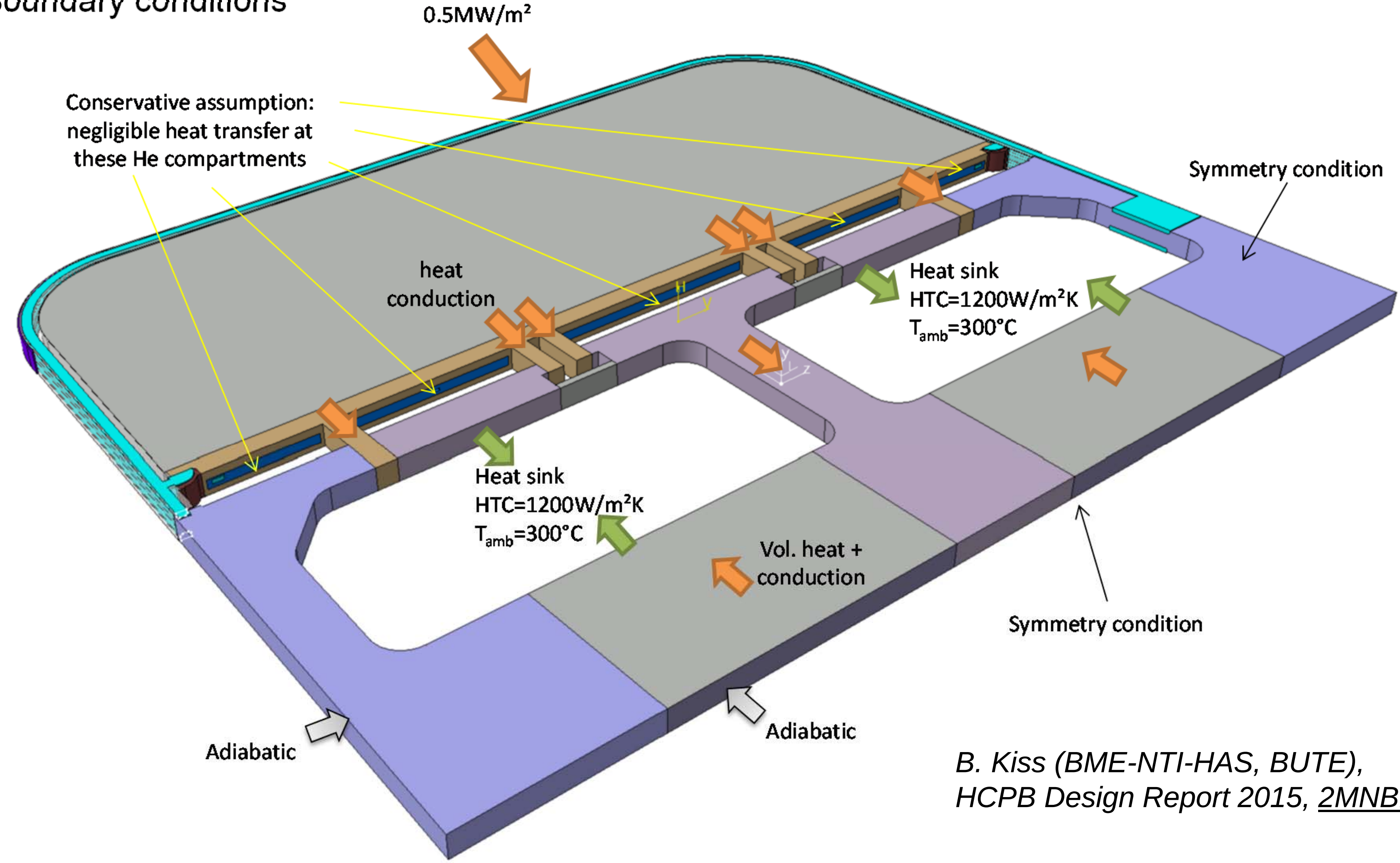


3D relative error profile – Serpentine tube configuration



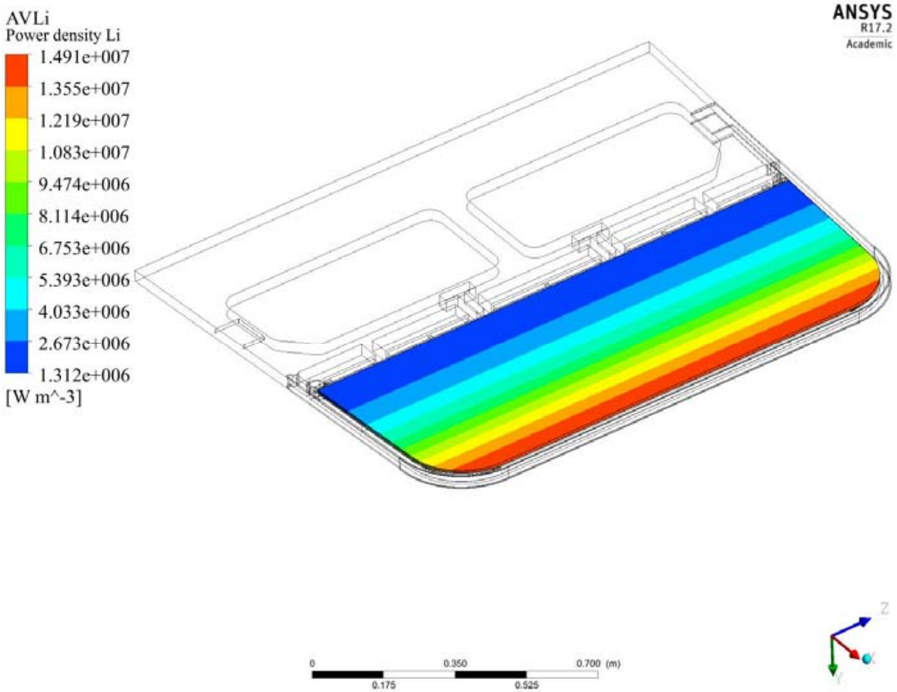
Analysis – Thermal-hydraulics (CSG)

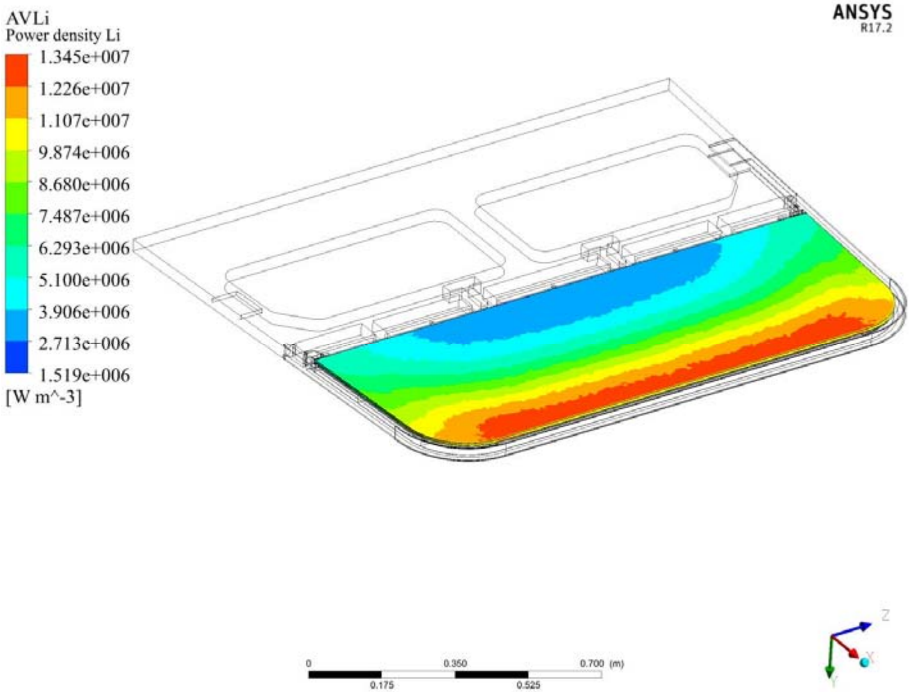
- Boundary conditions



B. Kiss (BME-NTI-HAS, BUTE), HCPB Design Report 2015, 2MNBH9

Analysis – Thermal-hydraulics (CSG)

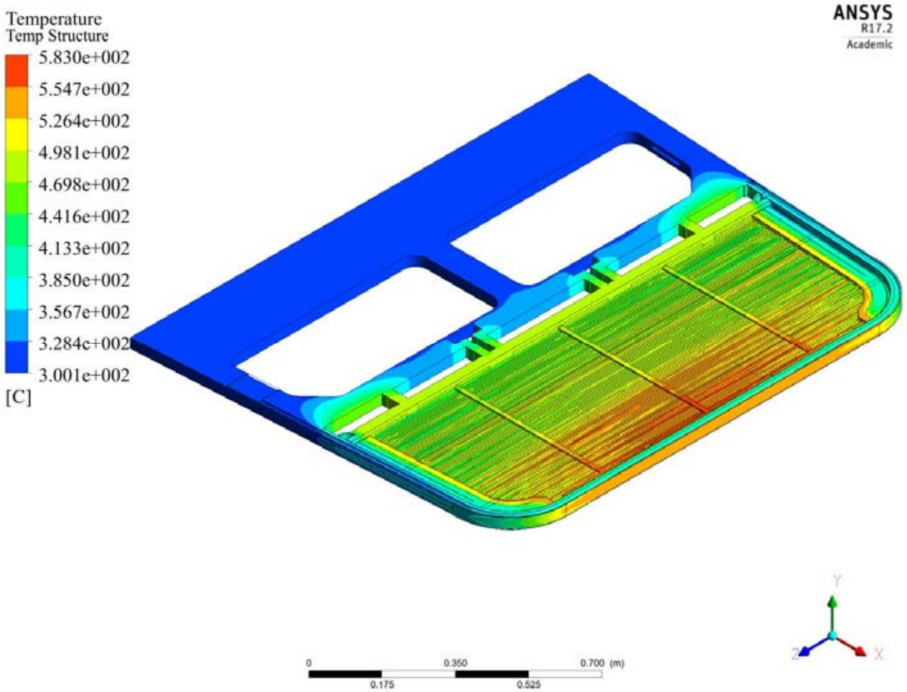




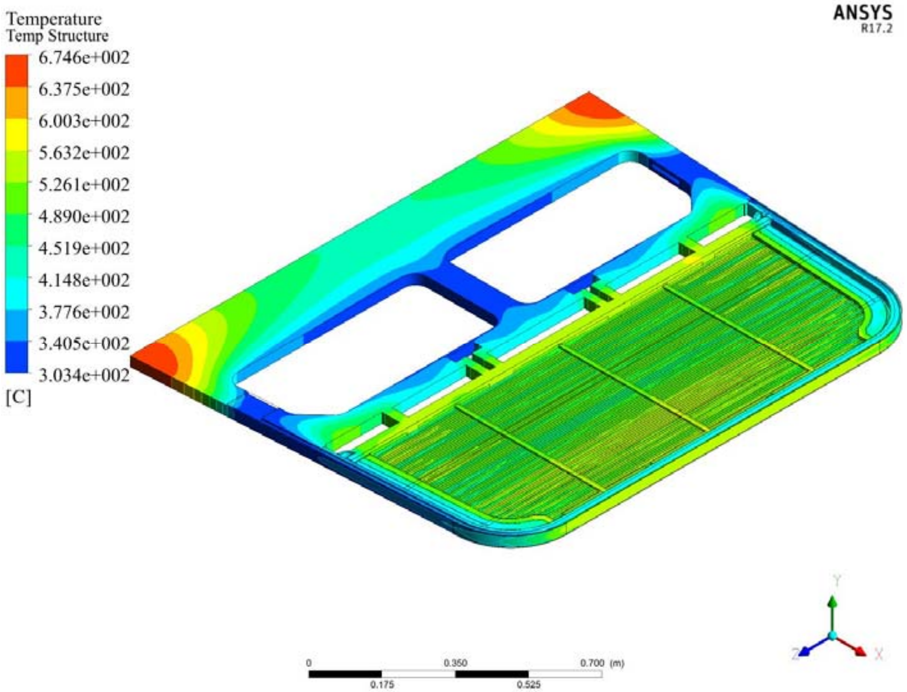
B. Kiss (BME-NTI-HAS, BUTE), HCPB Design Report 2015, 2MNBH9

G.A. Spagnuolo (KIT), 3D power density profile

Results – Thermal-hydraulics (CSG)



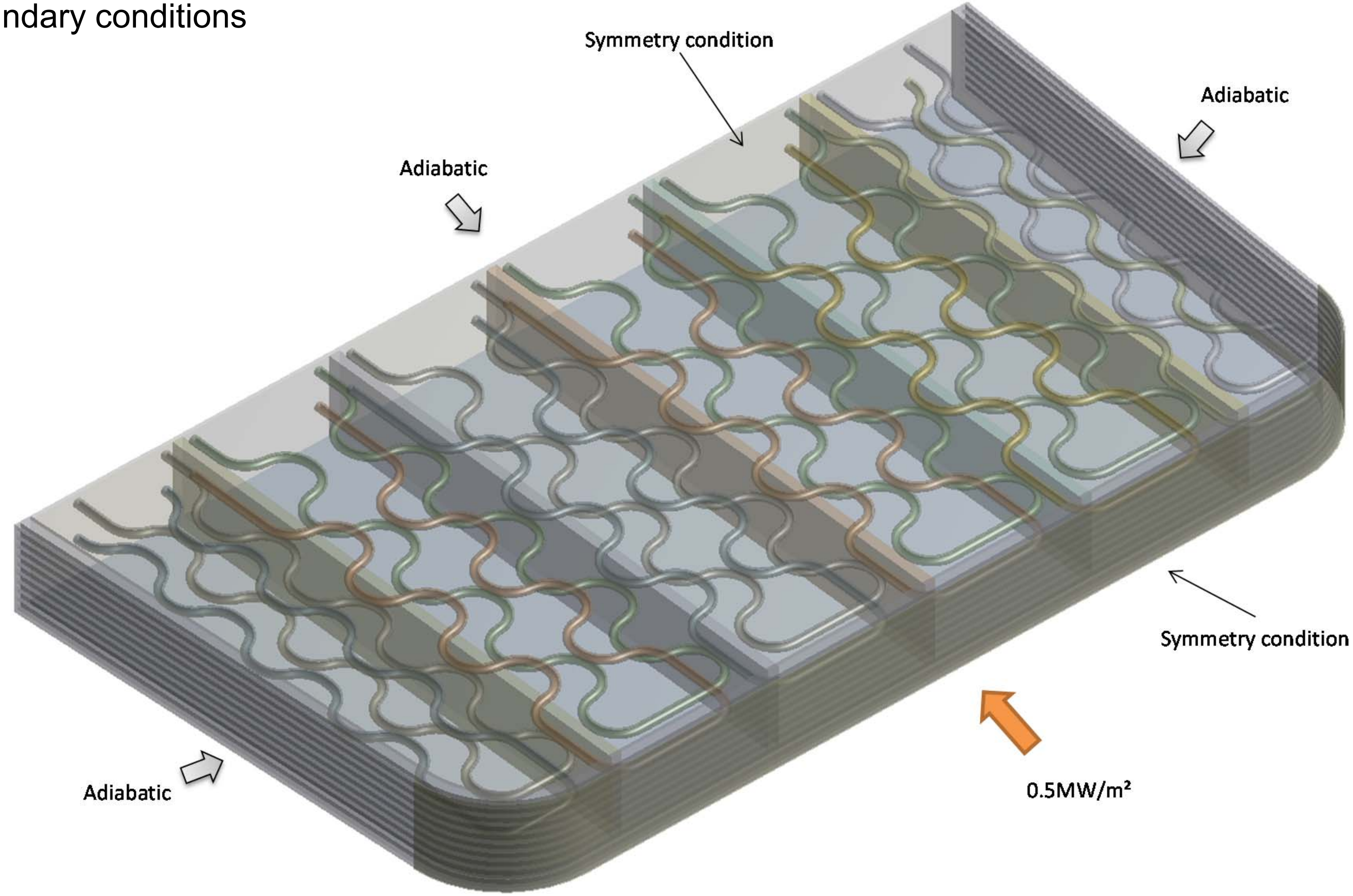
B. Kiss (BME-NTI-HAS, BUTE),
HCPB Design Report 2015, 2MNBH9



G.A. Spagnuolo (KIT),
3D power density profile

Analysis – Thermal-hydraulics (HYBRID)

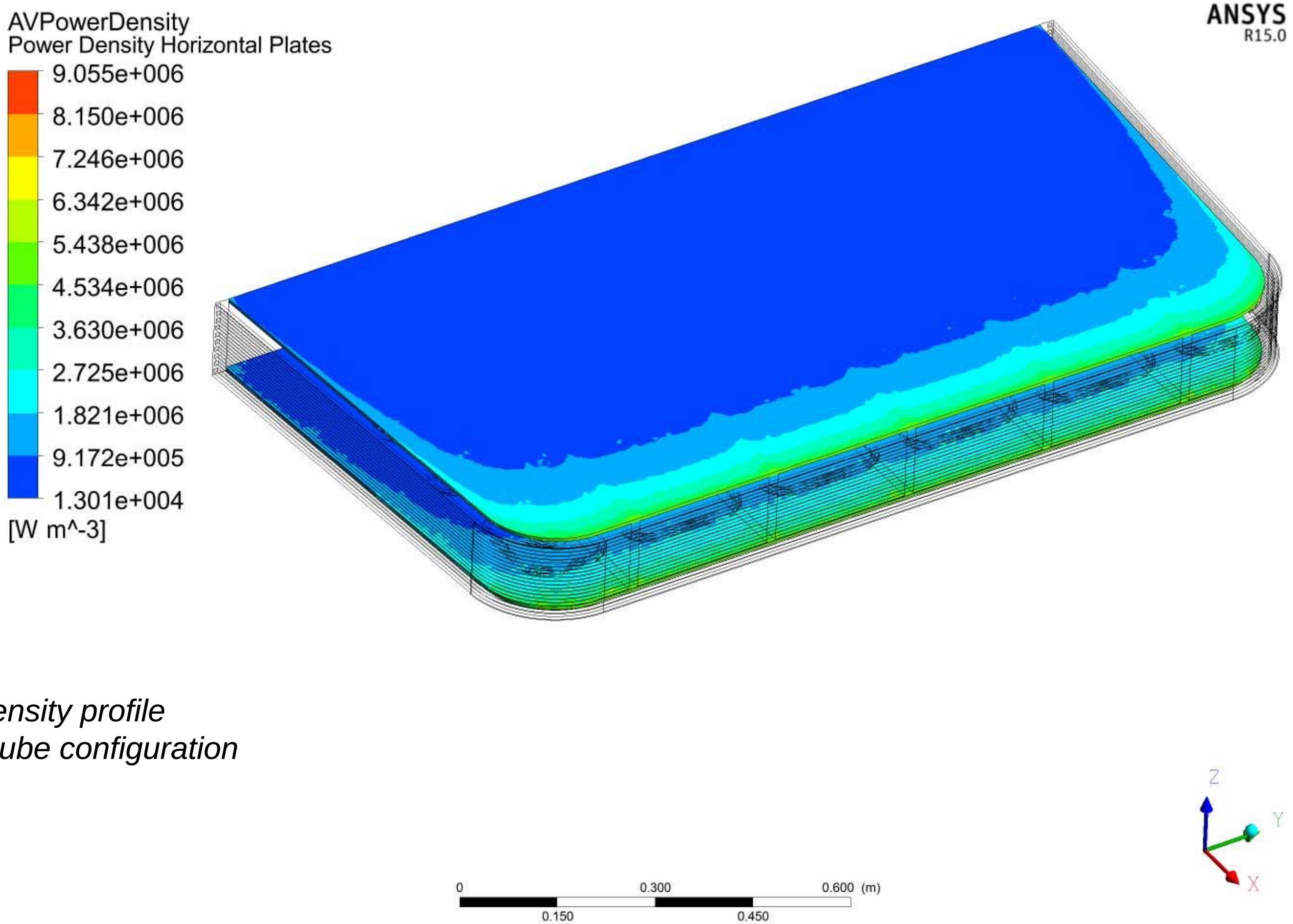
- Boundary conditions



Motivation › **Coupling** › **Methodologies** › **Analyses & results** › Summary

Analysis – Thermal-hydraulics (HYBRID)

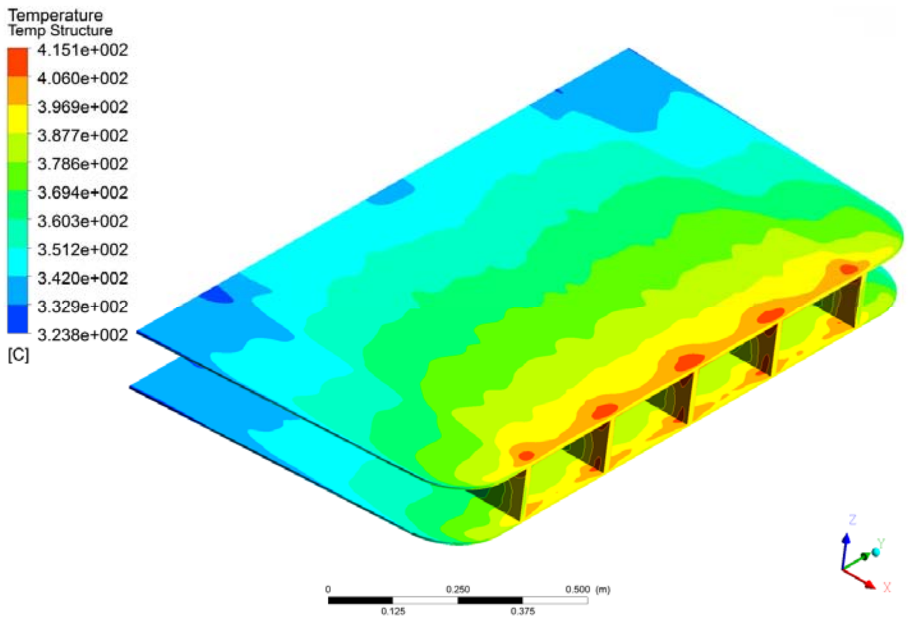
Karlsruhe Institute of Technology



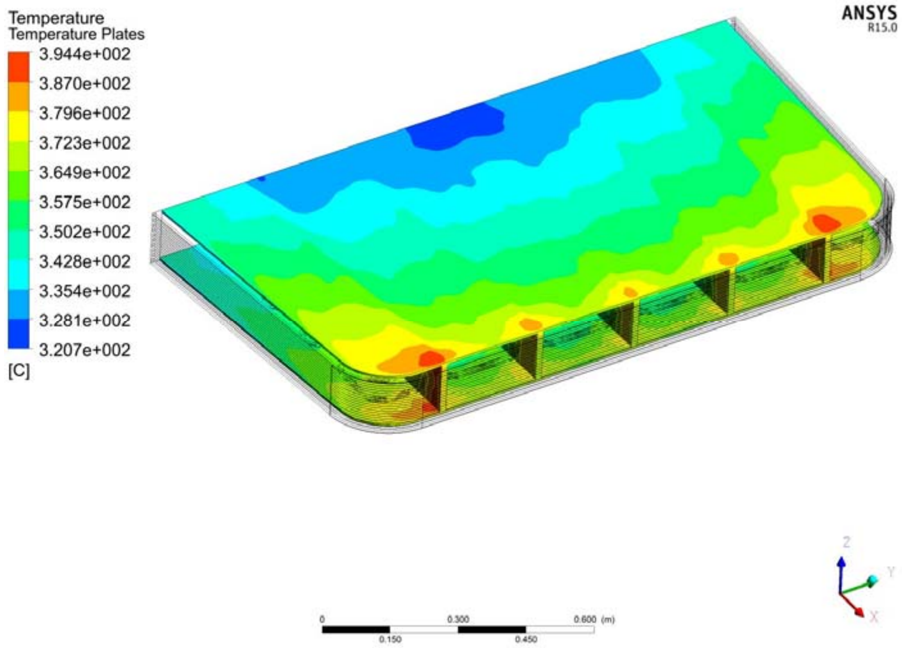
3D power density profile
Serpentine tube configuration

Motivation » **Coupling** » **Methodologies** » **Analyses & results** » Summary

Results – Thermal-hydraulics (HYBRID)



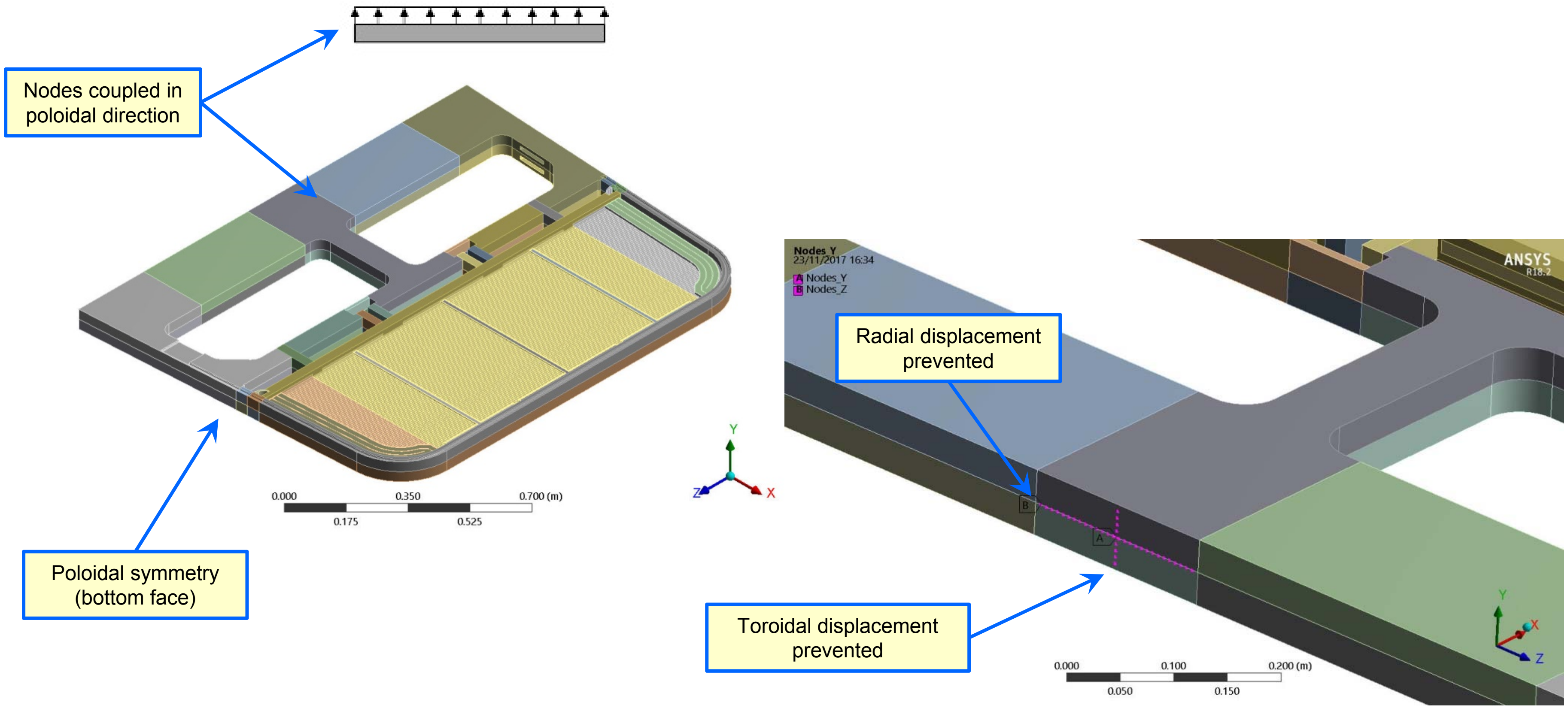
Temperature calculated using a power density radial profile



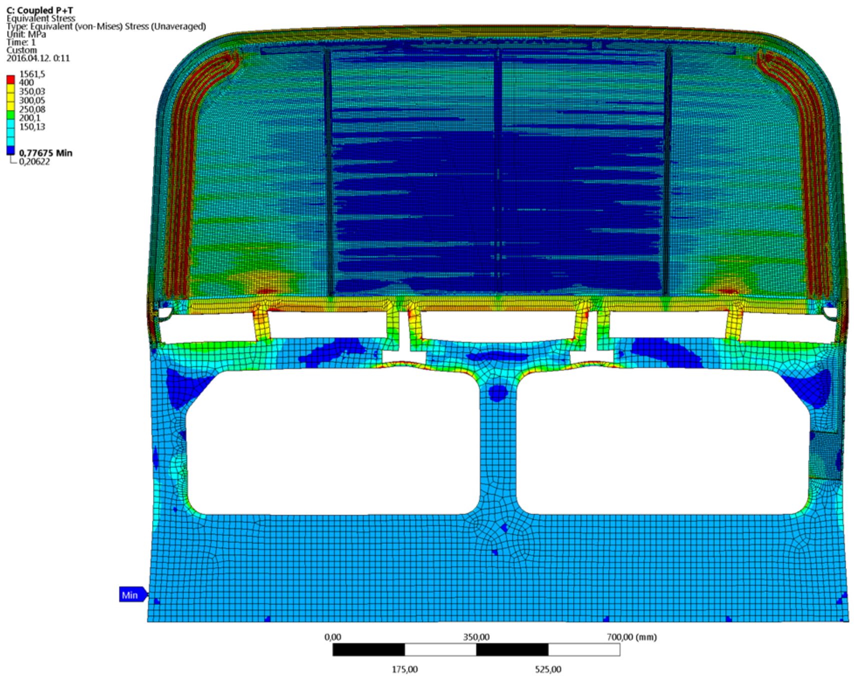
Temperature calculated using a 3D power density profile

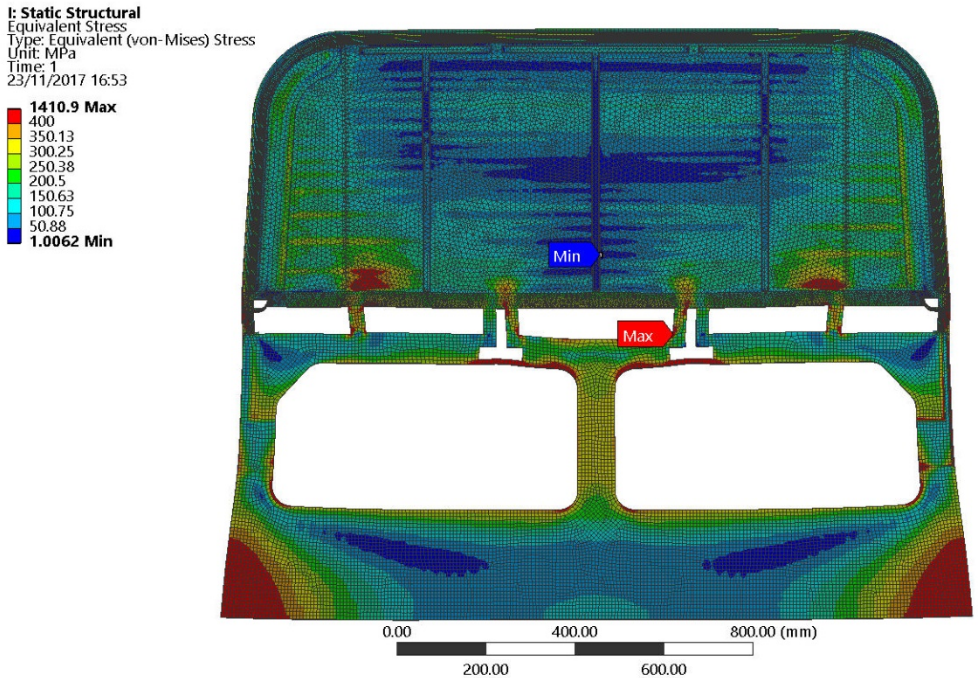
Analysis – Mechanics (CSG)

- Boundary conditions in normal operation (static)
  - The following set of mechanical boundary conditions along radial (x), toroidal (z) and poloidal (y) directions has been imposed to simulate the presence of the rest of the module as well as the attachment mechanical action.



Results – Mechanics (CSG)



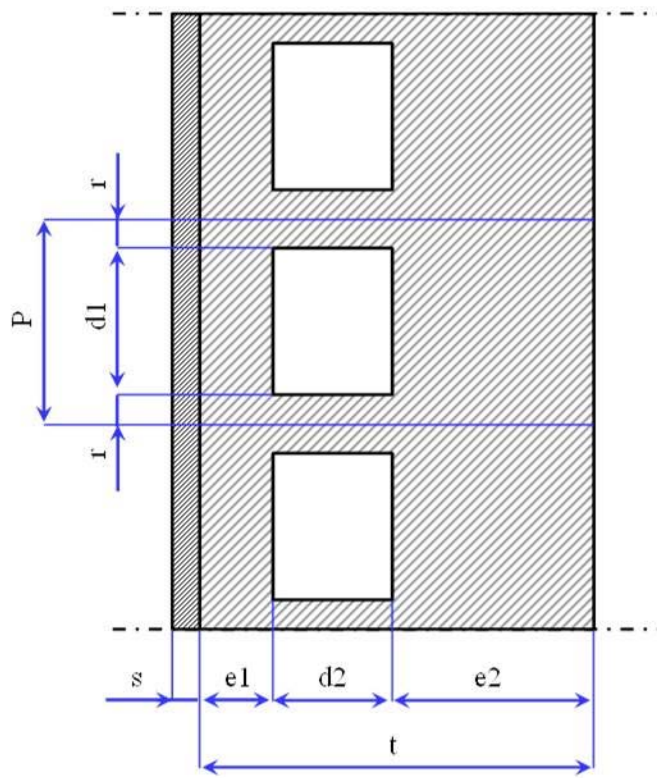


G. Nádasi (Wigner RCP),
HCPB Design Report 2015, 2MNBH9

G.A. Spagnuolo (KIT),
3D power density profile

Summary – Open Points

- A research campaign is currently on going for the verification and validation of the neutron source and boundary conditions used for the neutronic analysis;
  - the integration of HCPB slice as well as the nodalisation of the HCPB CAP has been already completed and integrated in the neutronic model ‘‘2015DEMO_HCPB_MCNP‘‘ using the CSG methodology.
- geometry parametrisation for multi-physics scoping analysis in order to analyse quickly the impact of geometry and/or material modifications;
- study of possible connection with system code for updating BB input parameters;
- ...



G.A. Spagnuolo et al., Development of HCLL DEMO First Wall design for SYCOMORE System Code, presented at ISFNT-13, 2017

Conclusion

Karlsruhe Institute of Technology

- The capability of ANSYS to generate inputs based on CSG and UM representations suitable for neutronic analysis has been demonstrated;
- the coupling procedure between neutronic, thermal-hydraulic and structural calculations has been carried out and developed;
- the versatility of the coupling methodology has been investigated and demonstrated;
- the developed methodologies allow an extremely precise estimation of the power density profile providing important inputs to be used for the BB design.

THANKS FOR YOUR ATTENTION!

Breeding blanket multi-physics modelling for integrated DEMO design

Gandolfo Alessandro Spagnuolo

25th European Fusion Programme Workshop
27 – 29 November 2017, Dubrovnik (Croatia)

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

INSTITUTE FOR NEUTRON PHYSICS AND REACTOR TECHNOLOGY (INR)
KARLSRUHE INSTITUTE OF TECHNOLOGY (KIT)