Enhanced quench stress evaluation of W7-X non-planar coil insulation using a SUPERMAGNET thermal-hydraulic model and ANSYS APDL mechanical model

Rafał Ortwein[1], Aleksandra Dembkowska[1,2], Monika Lewandowska[1,2]

Konrad Risse[3], Victor Bykov[3], Mikhail Khokhlov[3]

[1]The Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences, 31-342 Krakow, Poland

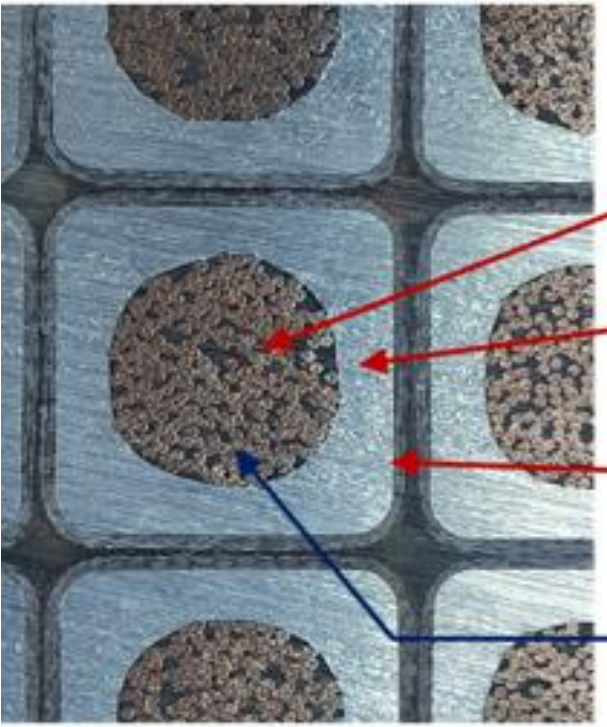
[2]West Pomeranian University of Technology in Szczecin, 70-310 Szczecin, Poland

[3]Max-Planck-Institut für Plasmaphysik, Wendelsteinstraße 1, 17491 Greifswald, Germany

Outline:

1. Motivation
2. Thermo-hydraulic-electric model in THEA (1D)
3. 3D mechanical model
4. Importing temperatures from THEA
5. Solution and results (3D mechanical + 1D)
6. Enhances thermo-hydraulic model (1D+3D)
7. Conclusions/next steps

1. Motivation (1/4)



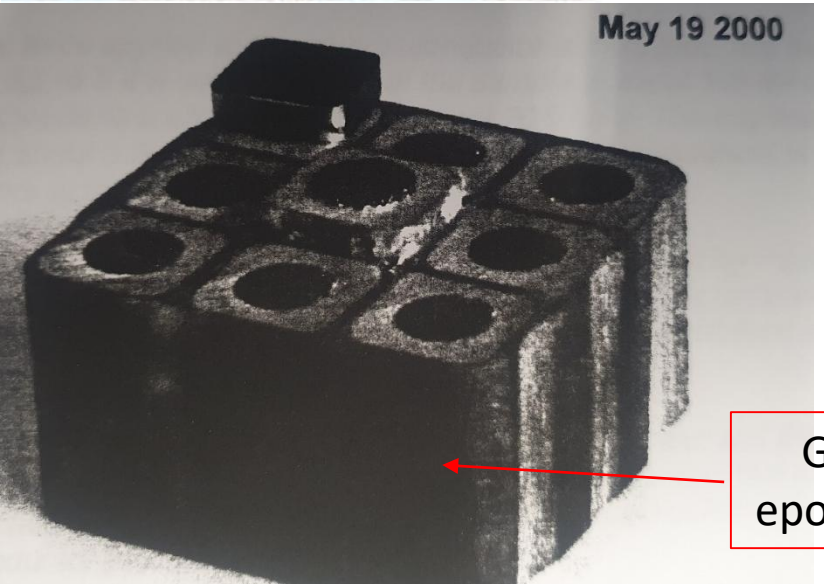
Copper stabilized NbTi strands – Thermal 1

Al jacket – Thermal 2

electrical insulation made of glass epoxy - Thermal 3

37.5 % void fraction for He flow - Hydraulic 1



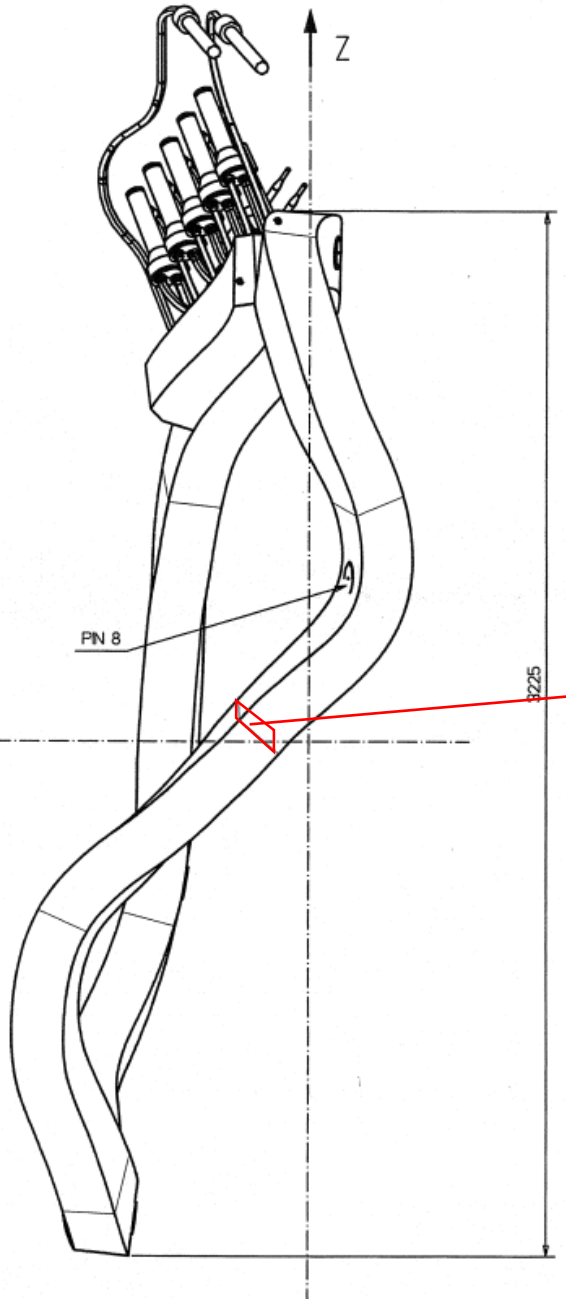


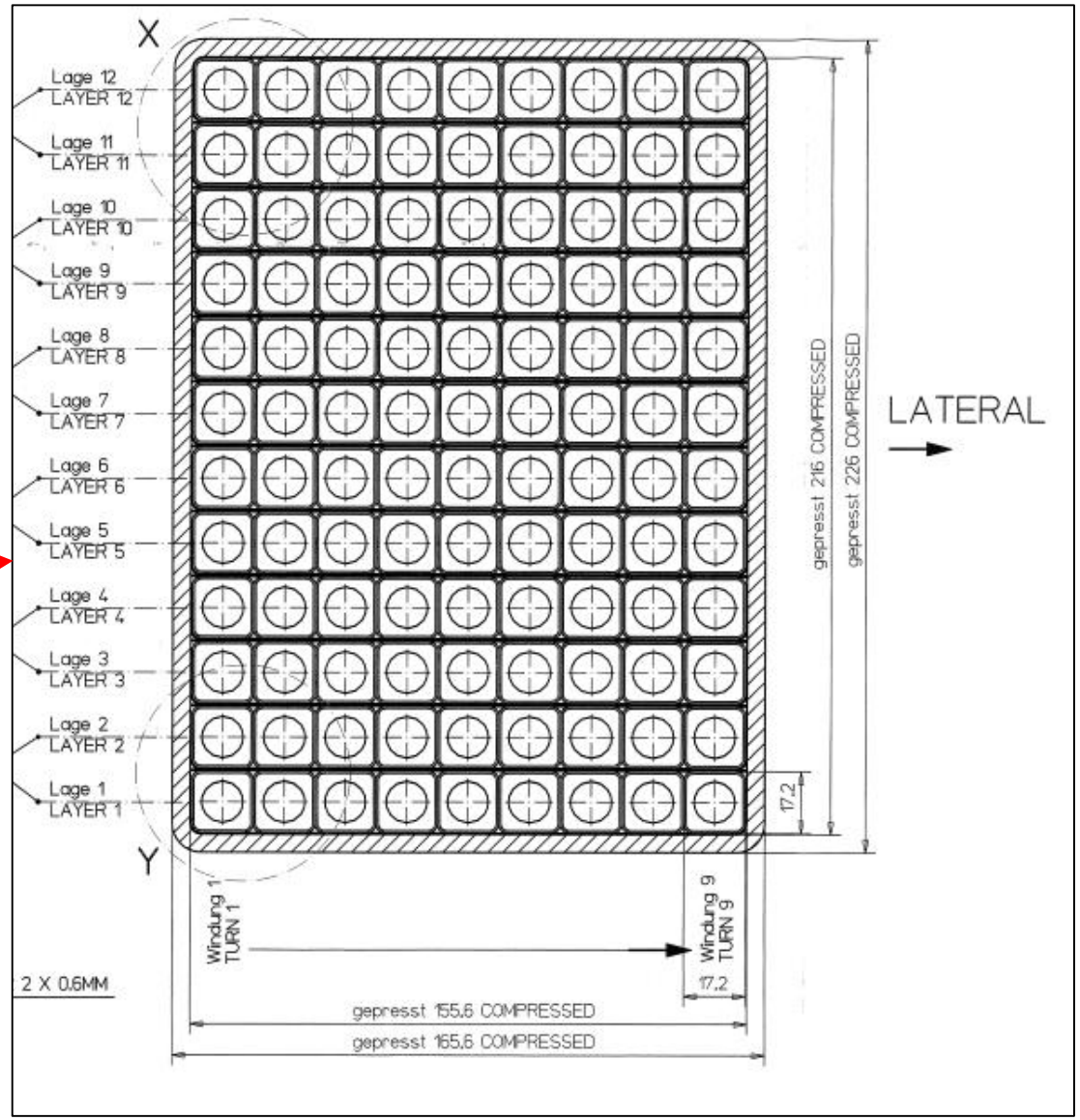
Glass-epoxy (GE)

Min. shear stress value at **4.2 K** for a previously unloaded system is **55 MPa**.

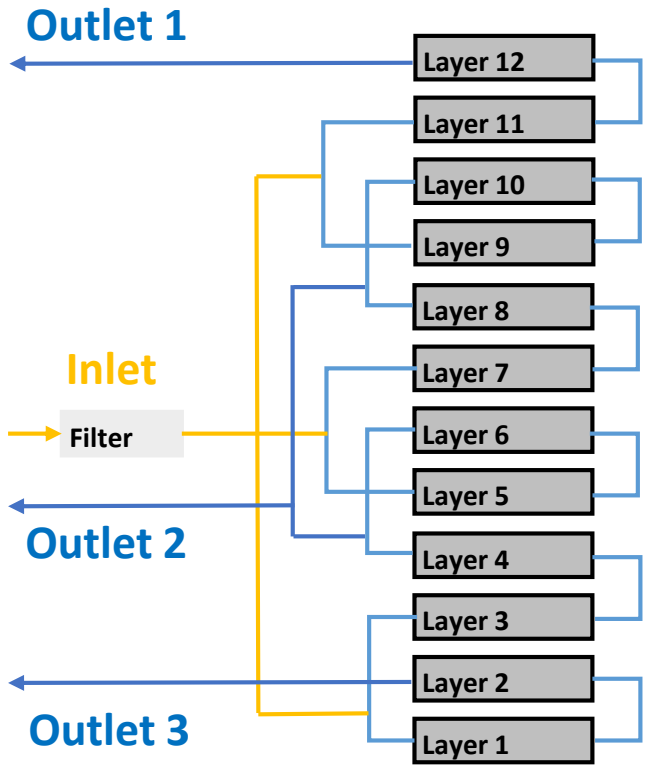
What are the maximum shear stress values in the insulation during quench? Could it lead to a local failure?

1. Motivation (2/4)

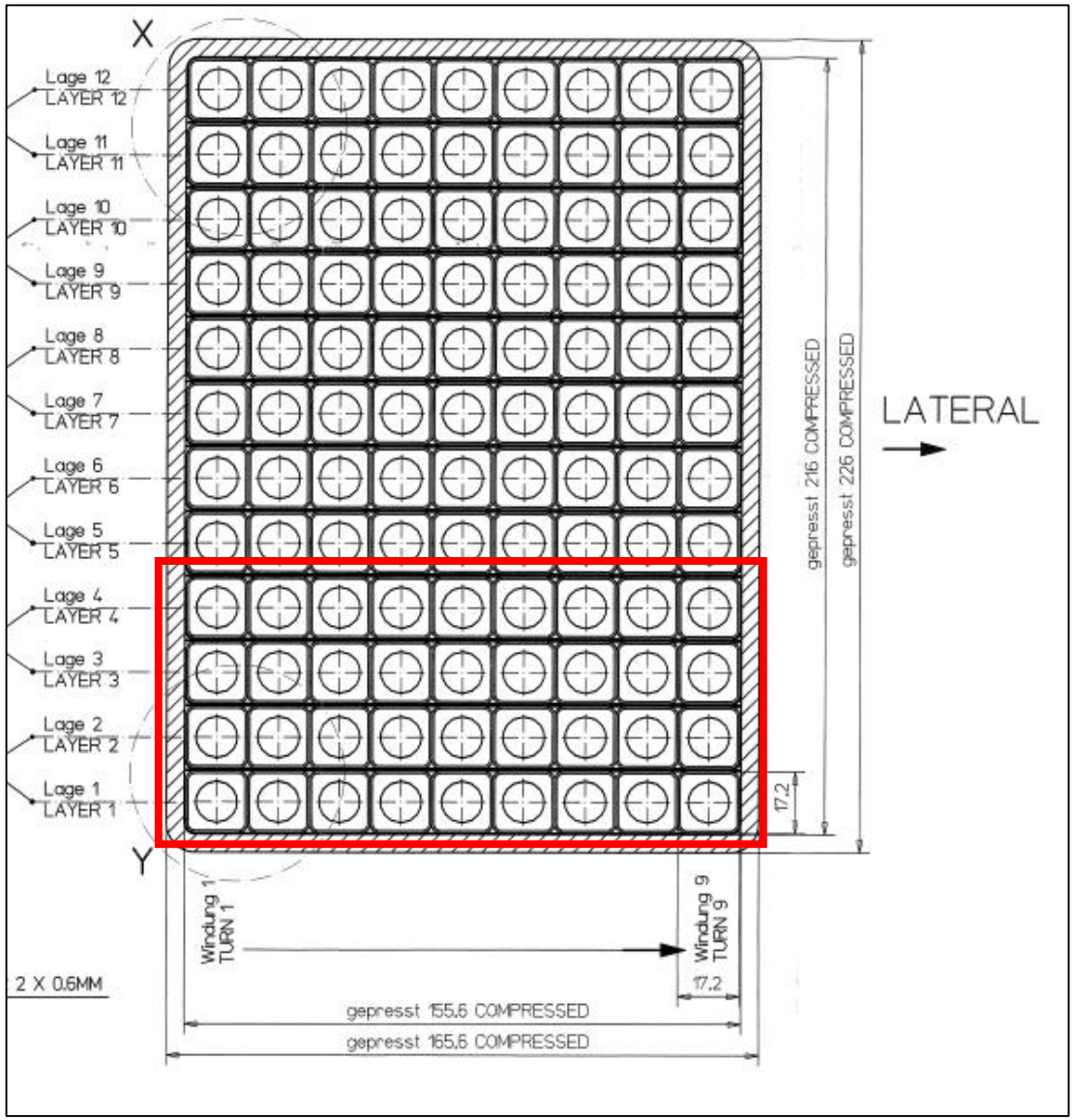






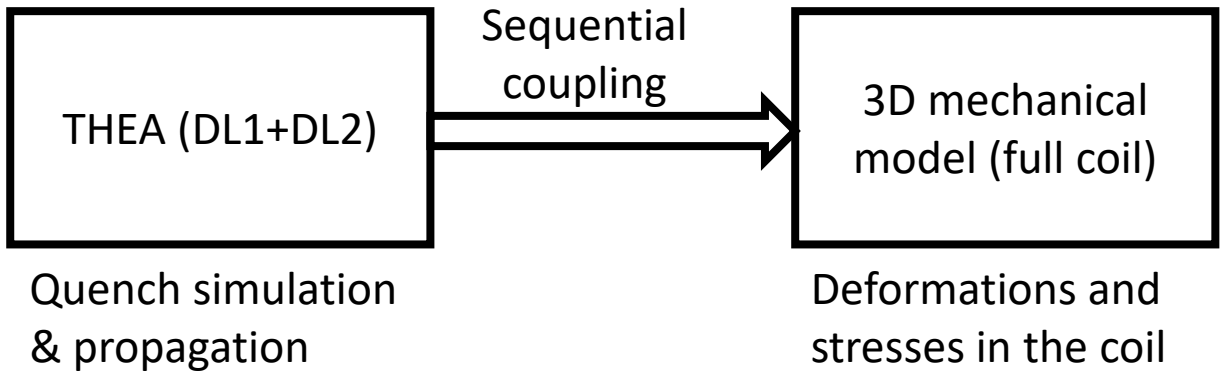


1. Motivation (3/4)

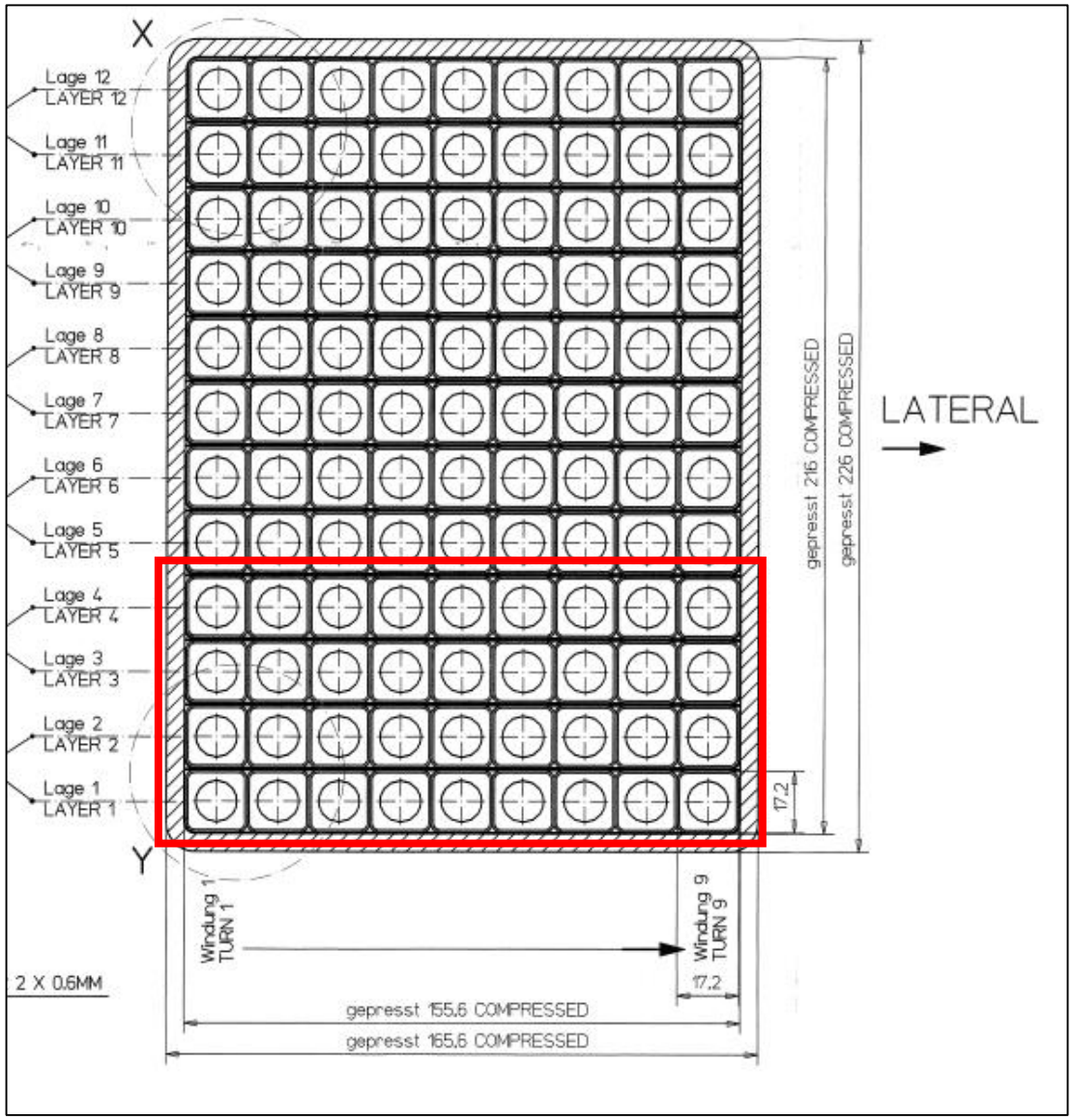


Multiple step approach was assumed, starting from a simplified model, towards full representation of the coil (ongoing work):

1. Considering only the 2 inner double layers (Layer 1-4) for the thermo-hydraulic model.
2. Using THEA code
3. Using a full 3D mechanical model with temperatures of the layers 1-4 computed by THEA, and all the others layers kept at a constant temperature of 4.1 K.

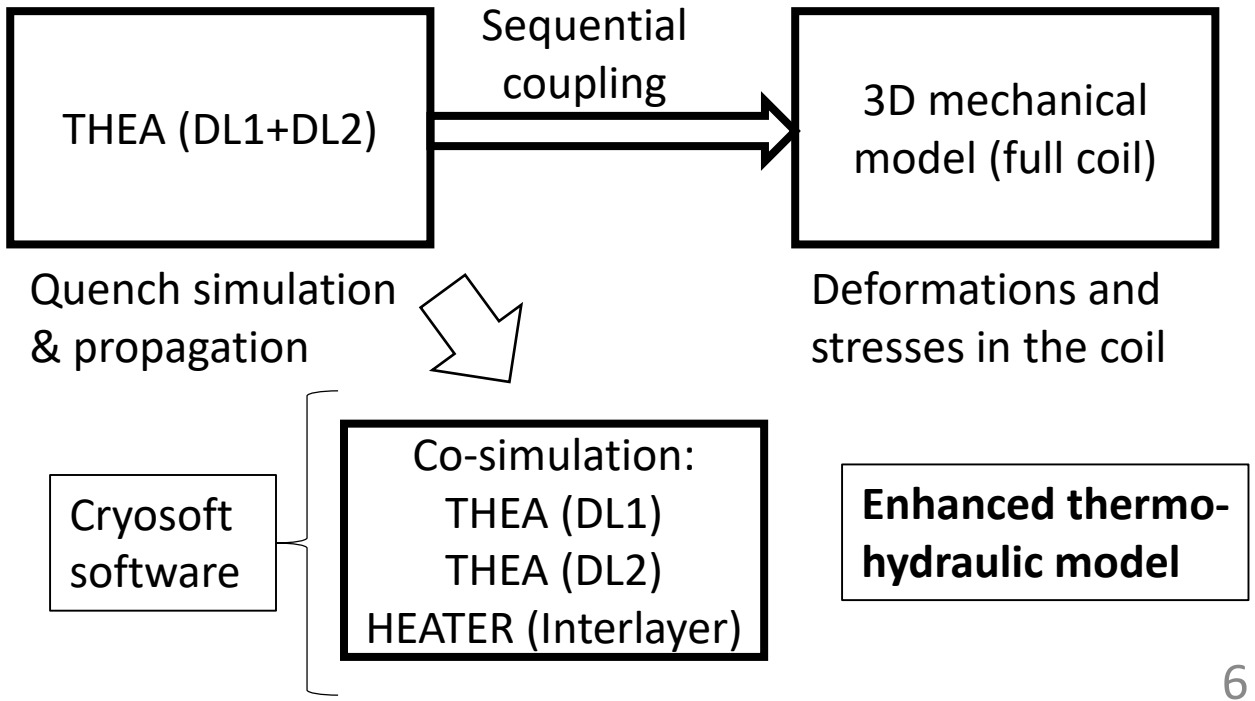


1. Motivation (4/4)

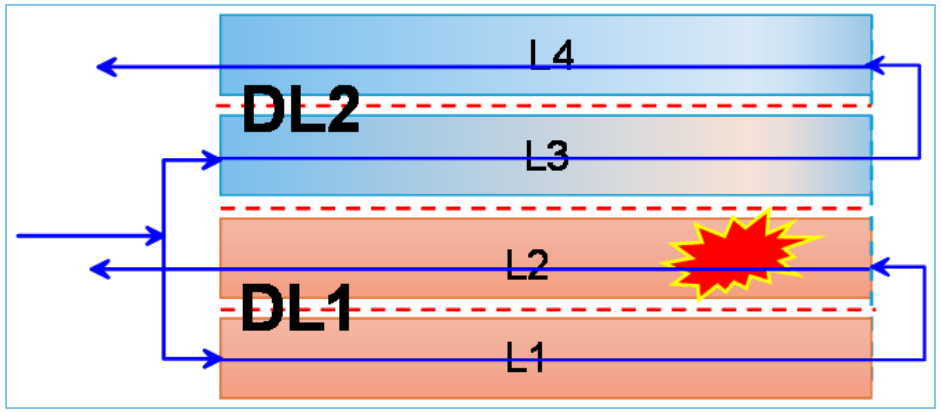


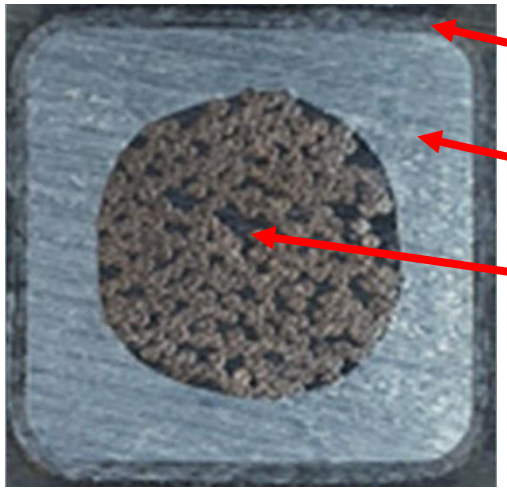
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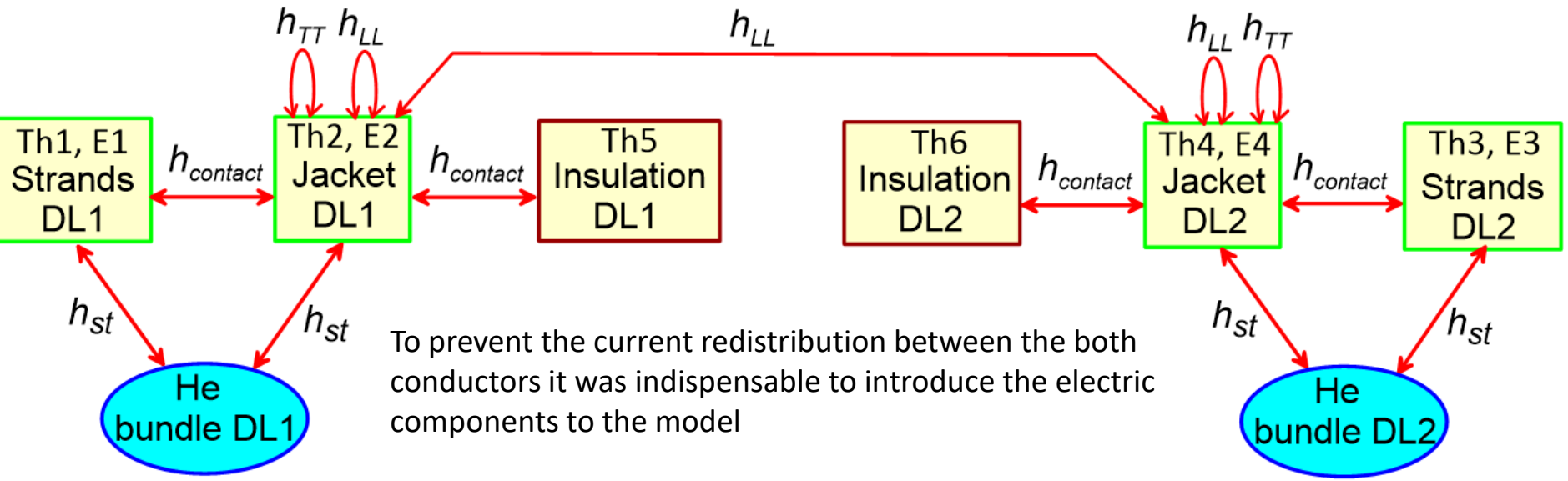
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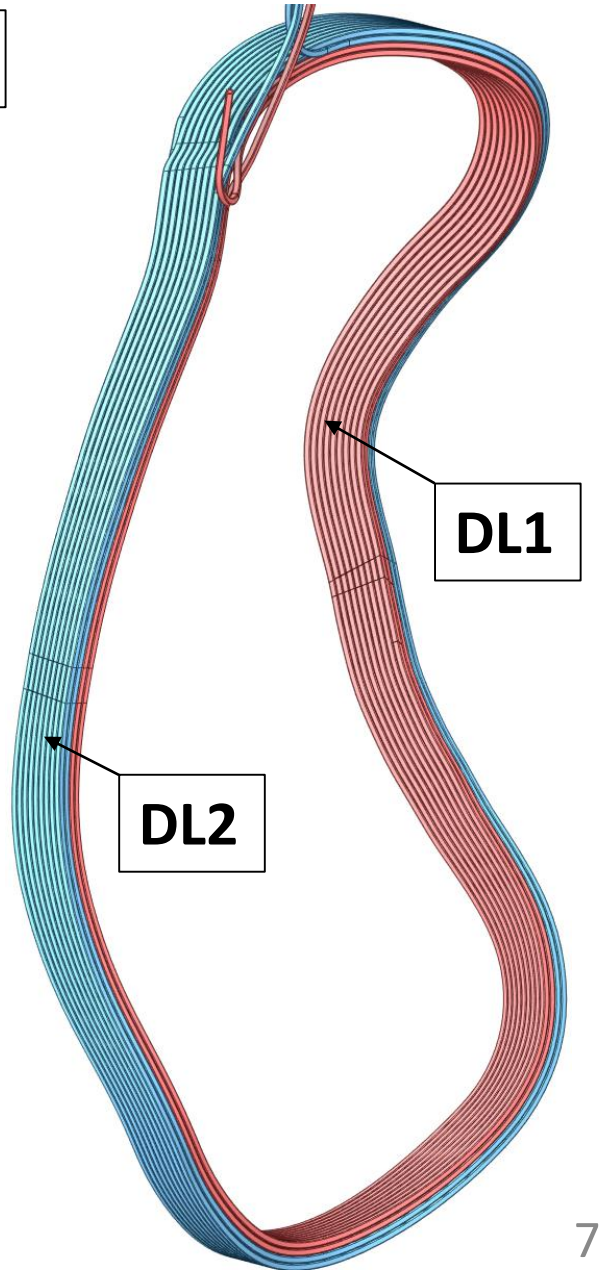


2. Thermo-hydraulic-electric model in THEA (1D) (1/11)

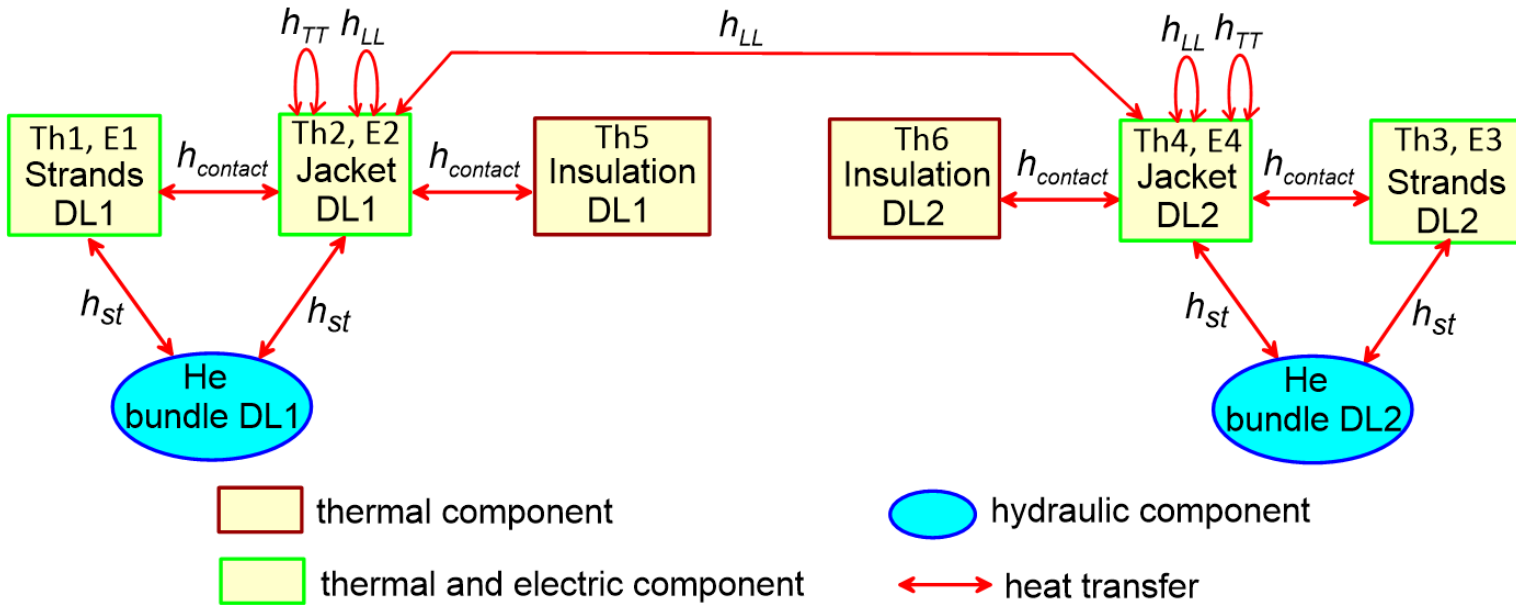


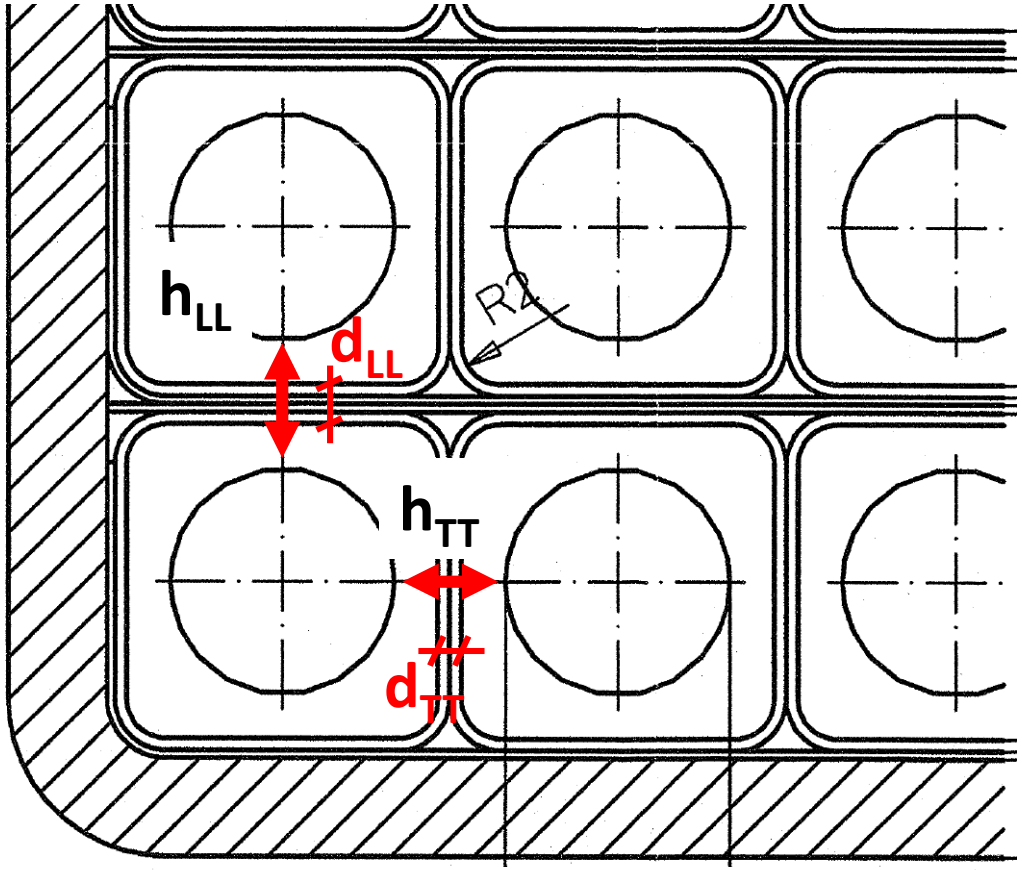




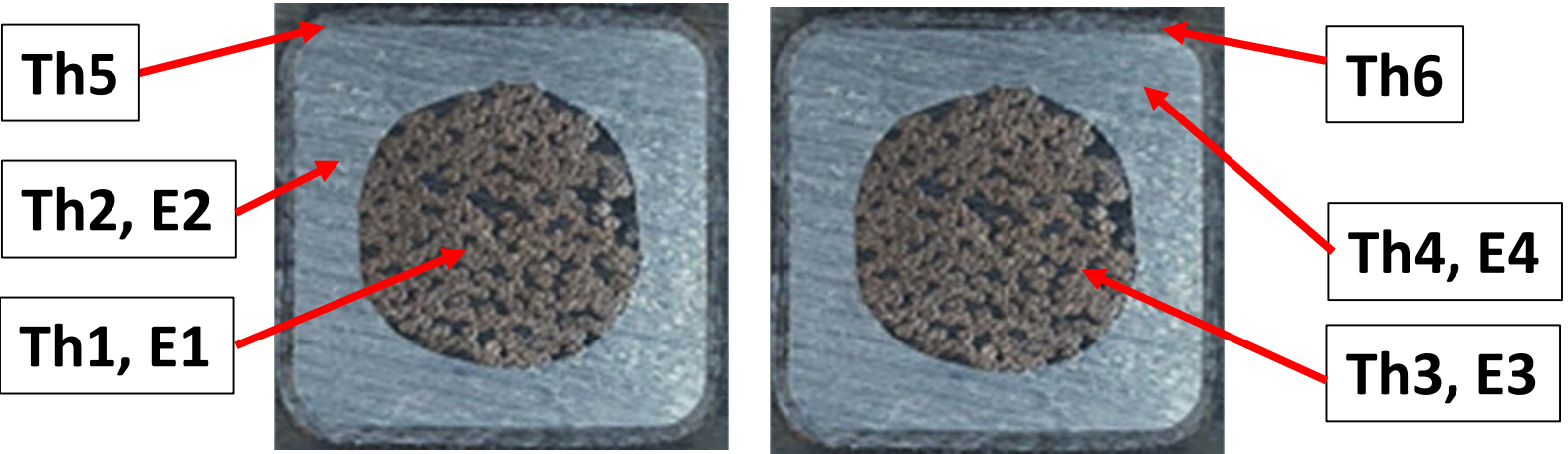


2. Thermo-hydraulic-electric model in THEA (1D) (2/11)





h_{st} – smooth tube correlation

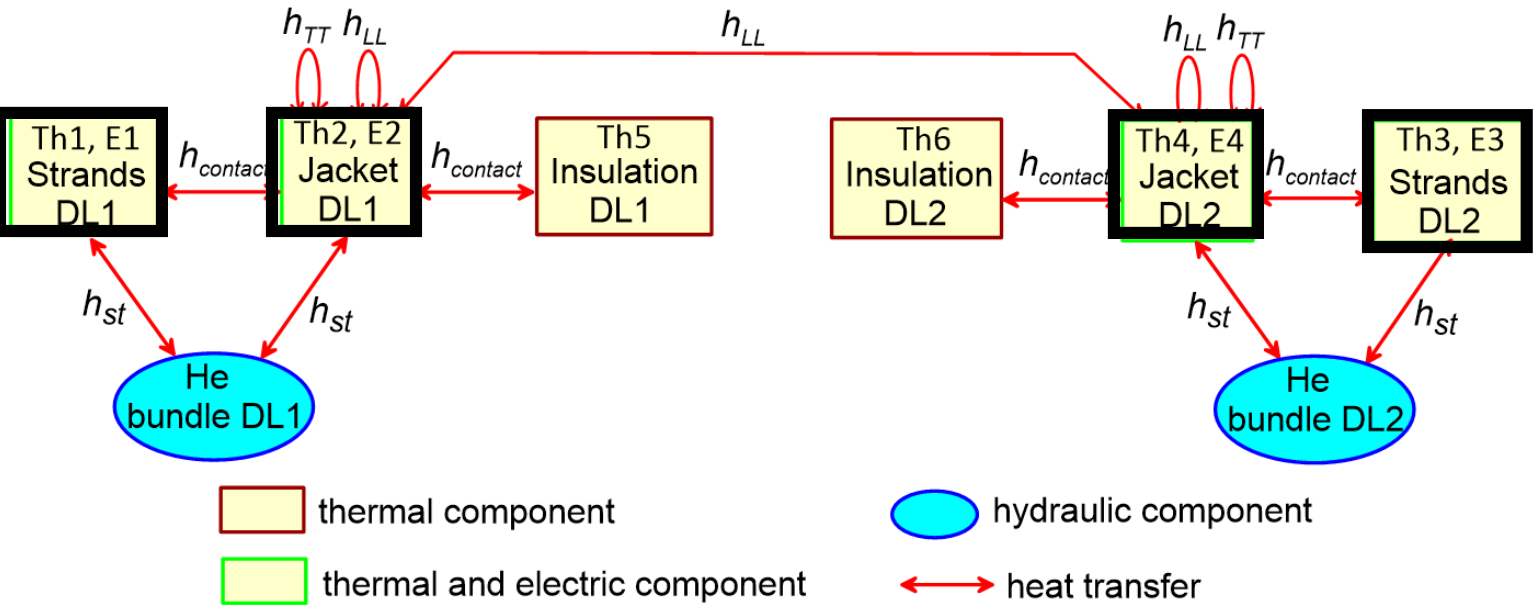


h_{TT} – turn to turn HT

h_{LL} – layer to layer HT

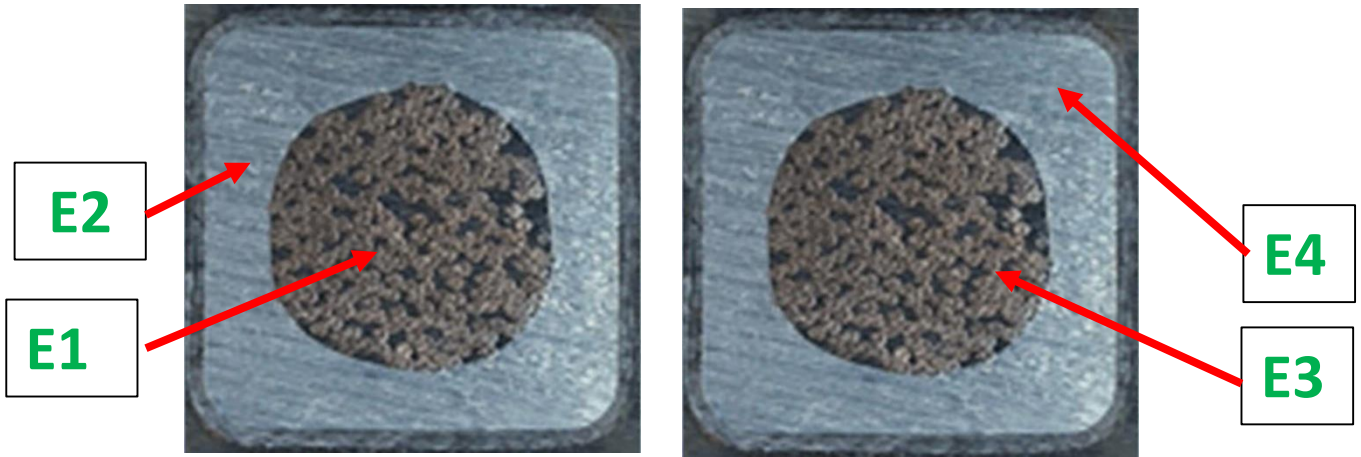
$$h_{LL} = \frac{k_{GE}(T_{av})}{d_{LL}} \qquad h_{TT} = \frac{k_{GE}(T_{av})}{d_{TT}}$$

2. Thermo-hydraulic-electric model in THEA (1D) (3/11)

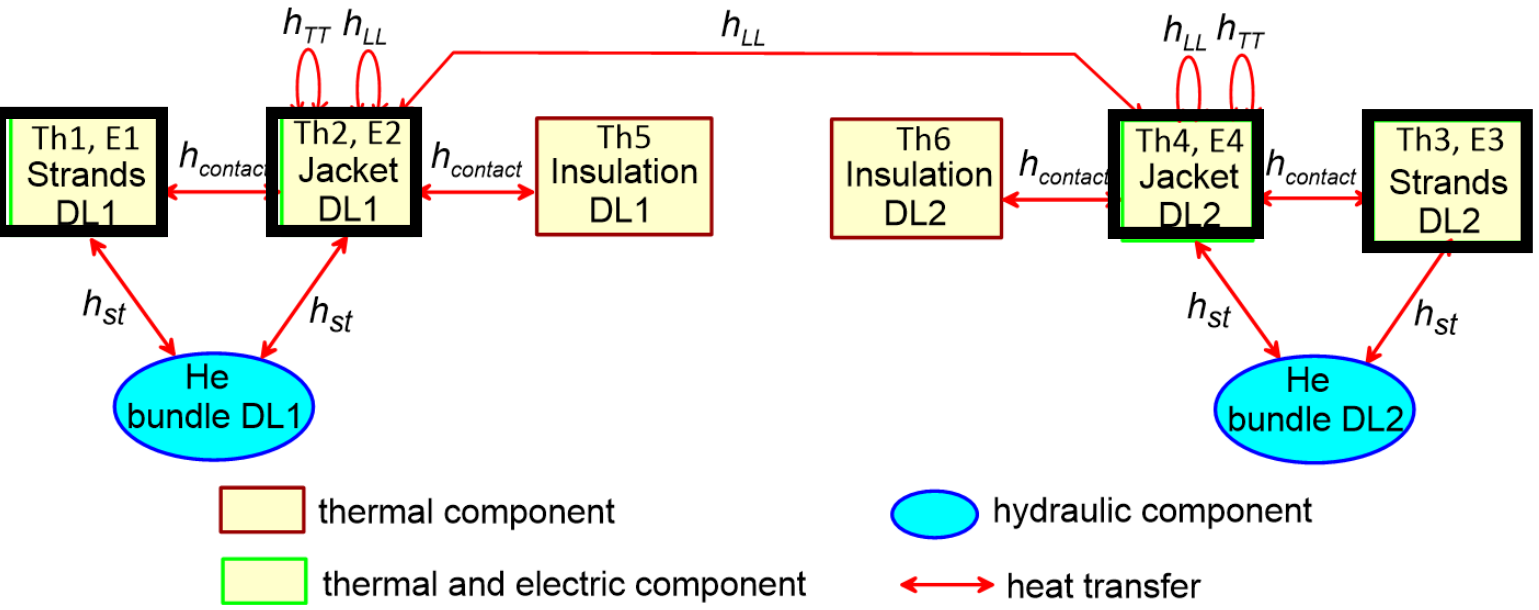


Electrical elements require additional parameters to be specified:

- Inductance matrix
- Electrical conductivity matrix



2. Thermo-hydraulic-electric model in THEA (1D) (4/11)



Electrical elements require additional parameters to be specified:

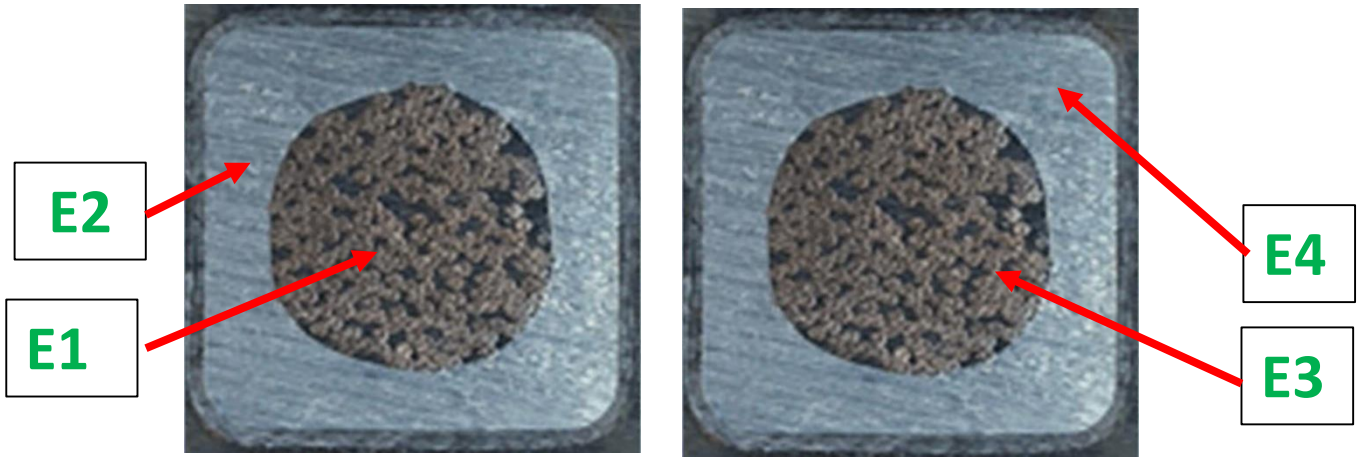
- Inductance matrix
- Electrical conductivity matrix

Inductance matrix

$E1-E1$	$E1-E2$	$E1-E3$	$E1-E4$
$E1-E2$	$E2-E2$	$E2-E3$	$E2-E4$
$E1-E3$	$E2-E3$	$E3-E3$	$E3-E4$
$E1-E4$	$E2-E4$	$E3-E4$	$E4-E4$

Electrical conductance matrix

$E1-E2$	$E1-E3$	$E1-E4$
$E1-E3$	$E2-E3$	$E2-E4$
$E1-E4$	$E2-E4$	$E3-E4$



2. Thermo-hydraulic-electric model in THEA (1D) (5/11)

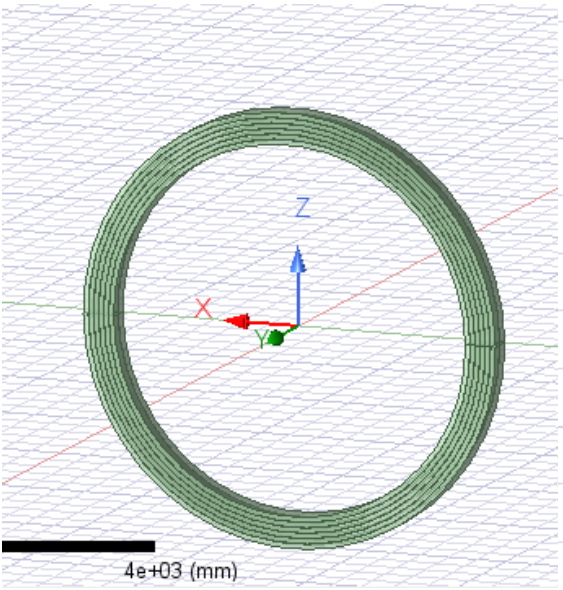
2D axisymmetric model [mH]

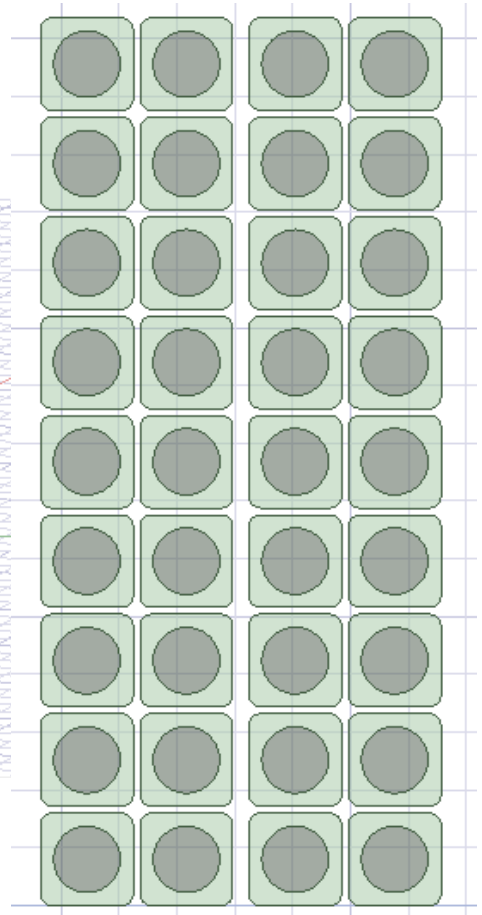
1.6260	1.6058	1.4669	1.4668
sym	1.6038	1.4669	1.449
sym	*sym*	1.6909	1.6701
sym	*sym*	*sym*	1.6680

Models used to compute inductance matrix

3D model (real shape) – coarse mesh [mH]

1.8678	1.8047	1.4954	1.4935
sym	1.7743	1.4934	1.4973
sym	*sym*	1.9562	1.8897
sym	*sym*	*sym*	1.8576







2. Thermo-hydraulic-electric model in THEA (1D) (6/11)

2D axisymmetric model [mH]

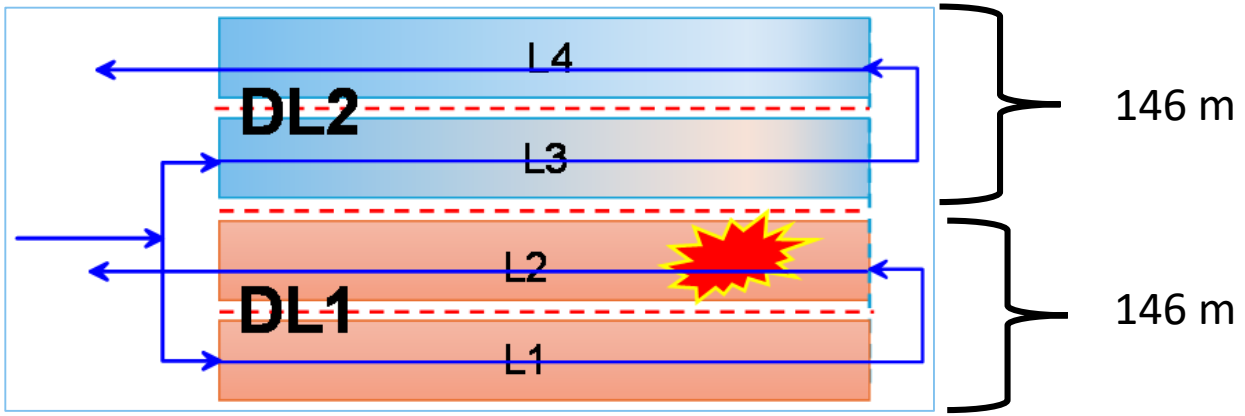
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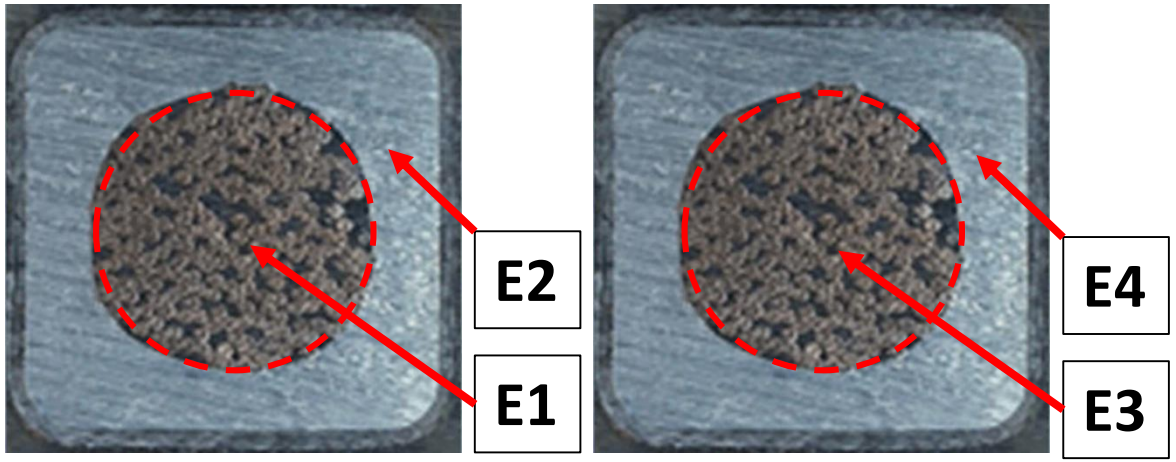
1.8678	1.8047	1.4954	1.4935
sym	1.7743	1.4934	1.4973
sym	*sym*	1.9562	1.8897
sym	*sym*	*sym*	1.8576

Dividing by the length of the cable (146 m) [H/m]

$1.114e-5$	$1.100e-5$	$1.005e-5$	$1.005e-5$
sym	$1.100e-5$	$1.100e-5$	$1.005e-5$
sym	*sym*	$1.158e-5$	$1.144e-5$
sym	*sym*	*sym*	$1.142e-5$



2. Thermo-hydraulic-electric model in THEA (1D) (7/11)



Electrical conductance (per unit length) matrix [S]

$\boldsymbol{E1-E2}$	$E1-E3$	$E1-E4$
sym	$E2-E3$	$E2-E4$
sym	sym	$\boldsymbol{E3-E4}$

$\boldsymbol{E1-E2}$	0.1	0.1
sym	0.1	0.1
sym	sym	$\boldsymbol{E3-E4}$

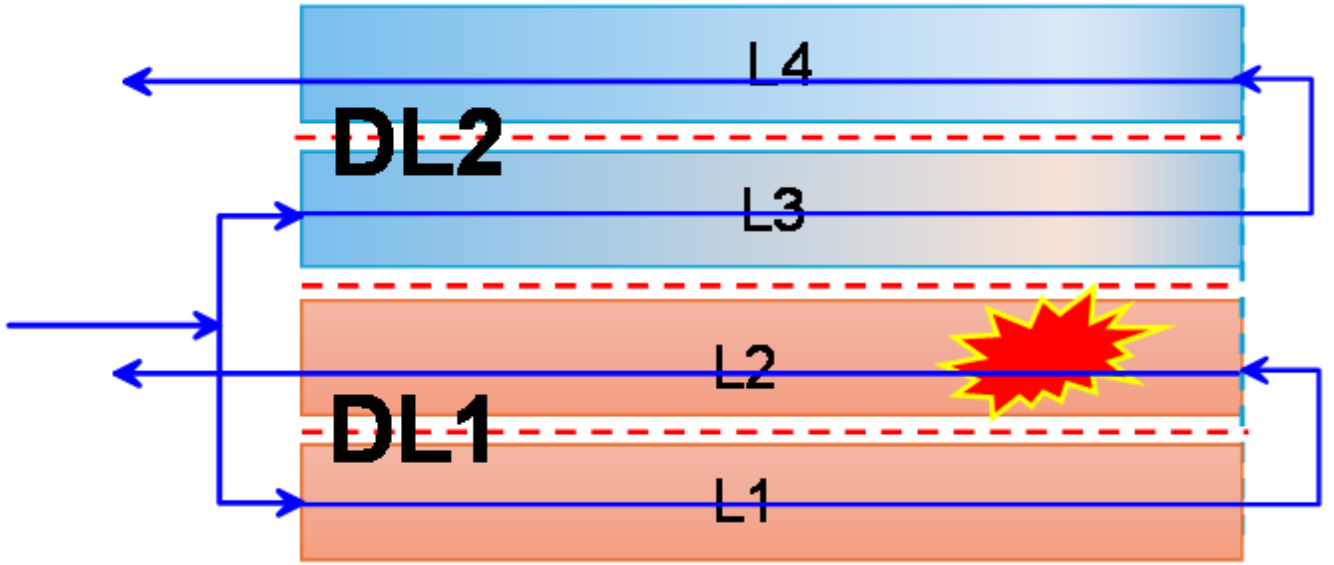
0.1 S - smallest value accepted by THEA

The electrical conductance per unit length was varied parametrically

Case	E1-E2 =E3-E4 (S)	$T_{max\ strands\ DL1}$ (K)	$T_{max\ jacket\ DL1}$ (K)	$T_{max\ strands\ DL2}$ (K)	$T_{max\ jacket\ DL2}$ (K)
1	100 000	112.81	88.39	107.77	87.73
2	10 000	122.68	84.19	114.69	84.71
3	1000	149.02	86.13	130.23	86.99
4	120	185.73	105.00	153.38	102.47

2. Thermo-hydraulic-electric model in THEA (1D) (8/11)

- Constant mesh size = 0.01 m
- Time step adaption method (*StepEstimate*) based on smoot decrease/increase, performed depending on the comparisor of the estimated integration error and the desired tolerance (set equal to 0.03)



The simulation was done in two steps:

1. To obtain the steady state

T_{ini} = 4.1 K, p_{ini} = 3.62 bar, $\dot{m}_{ini}$ = 0.59 g/s

T_{out} = 4.14 K, p_{out} = 3.26 bar

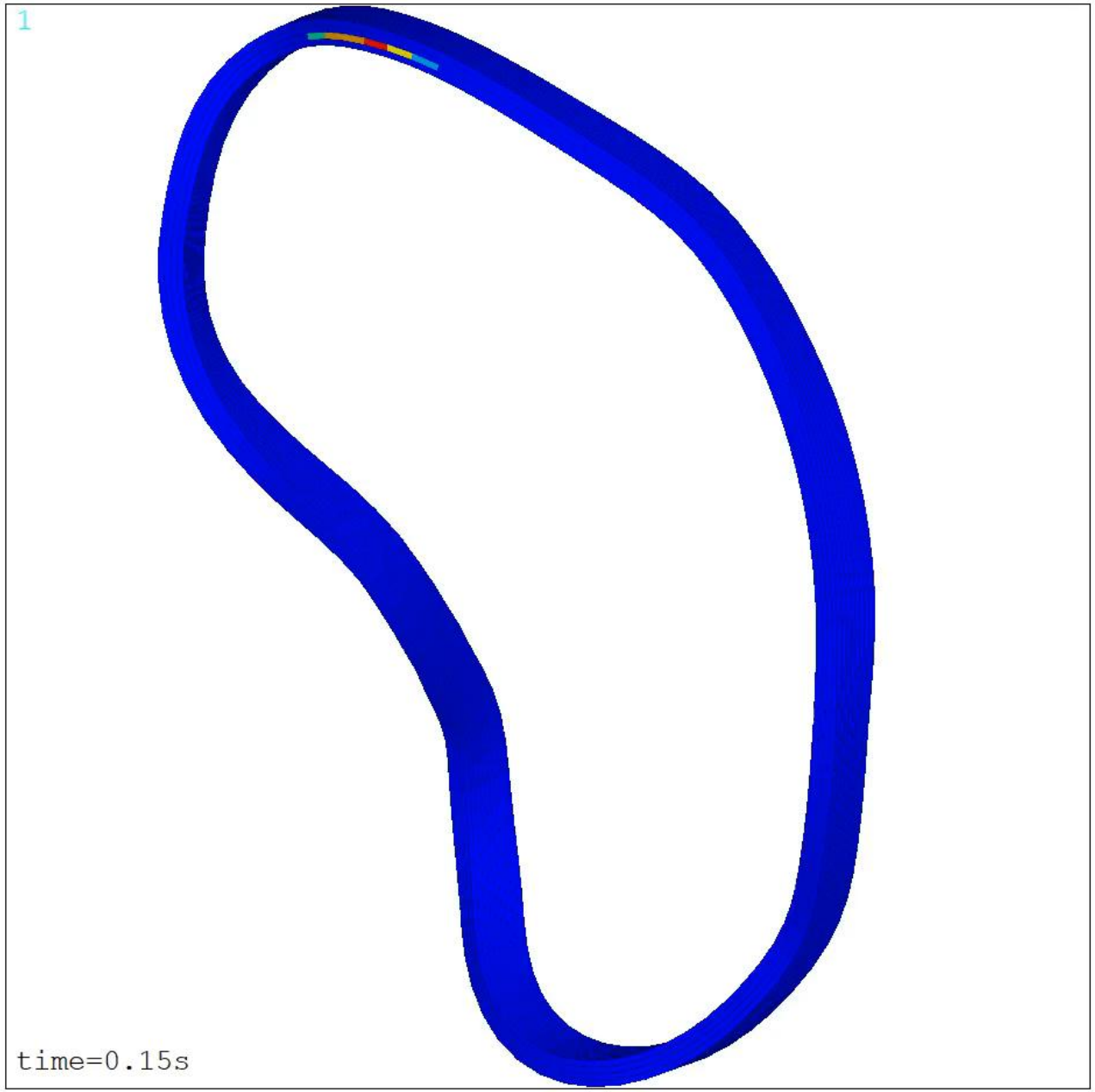
E1 (DL1 strands): 0.999 · Current,
E2 (DL1 jacket): 0.001 · Current,
E3 (DL2 strands): 0.999 · Current,
E4 (DL2 jacket): free

2. Quench was initiated by a heat pulse of 200 W/m lasting 100 ms, imposed in the section 80.0 m – 80.1 m, located in the layer L2 close to the middle of the DL1 conductor

for $t \geq t_{delay}$ (0.715 s)

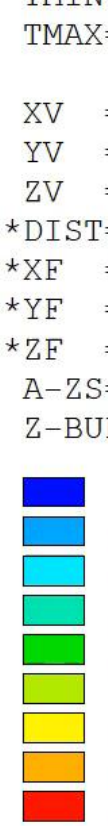
E1 (DL1 strands): 0.9334 · Current,
E2 (DL1 jacket): 0.0667 · Current,
E3 (DL2 strands): E_Current (strand 2, node 35 at 0.35 m distance) (adaptive current sharing)
E4 (DL2 jacket): free

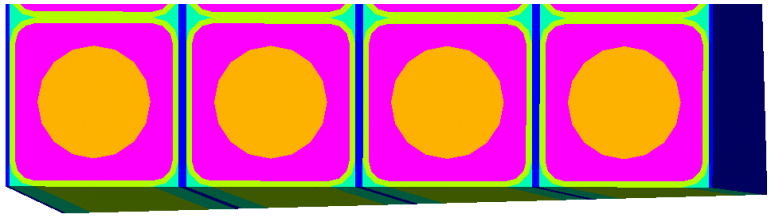
2. Thermo-hydraulic-electric model in THEA (1D) (9/11)



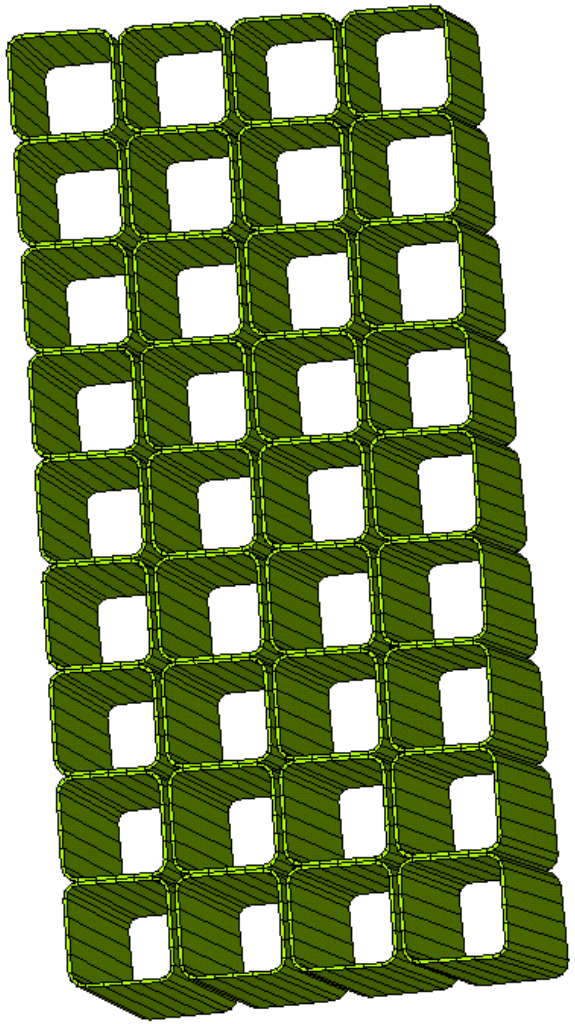
ANSYS 2025 R2.02
Build 25.2
DEC 2 2025
11:56:53
ELEMENTS
TEMPERATURES
TMIN=4.104
TMAX=9.16145

XV =.634376
YV =-.758419
ZV =.149559
*DIST=1.42214
*XF =5.90149
*YF =.302781
*ZF =.042299
A-ZS=-76.7447
Z-BUFFER

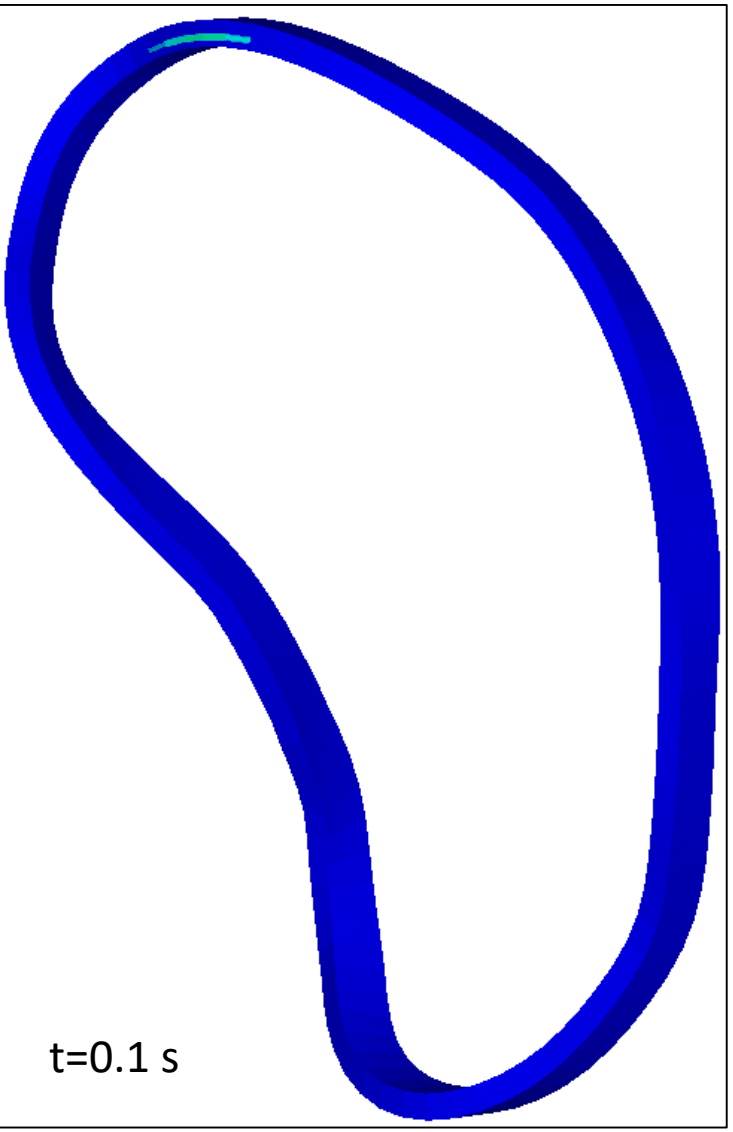


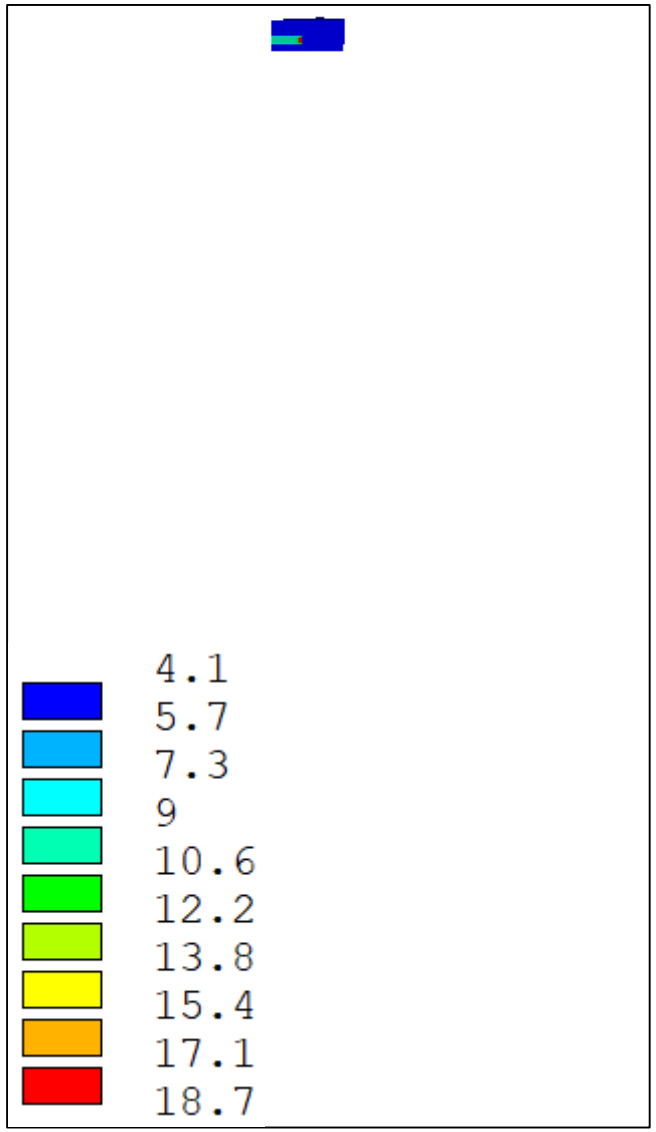


Only turn insulations

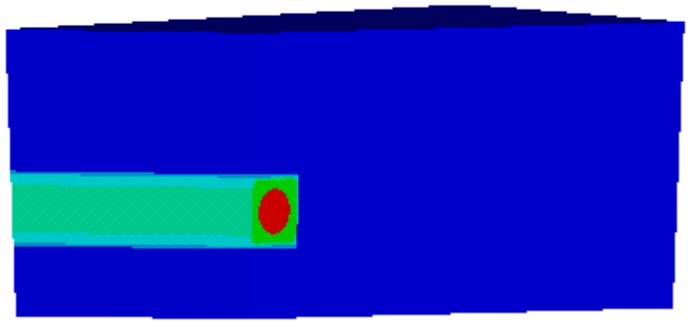


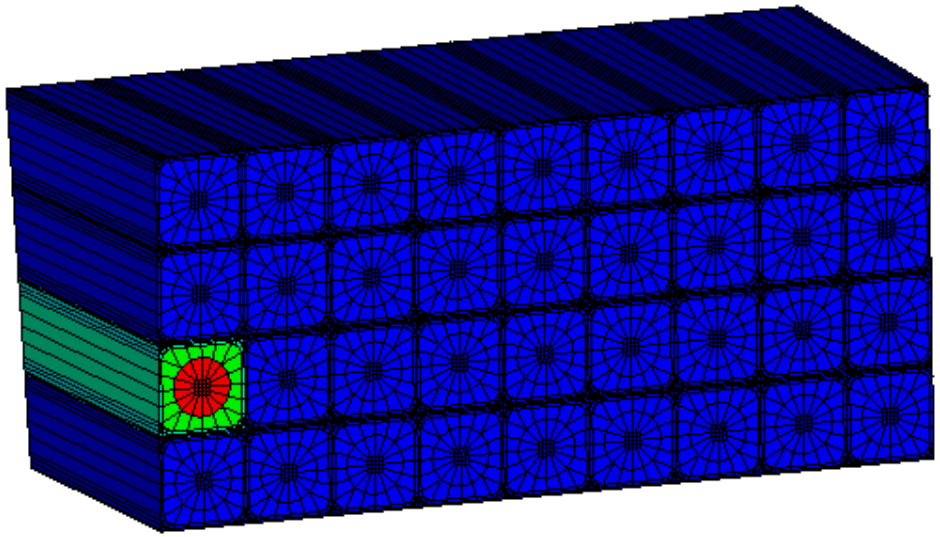
2. Thermo-hydraulic-electric model in THEA (1D) (10/11)



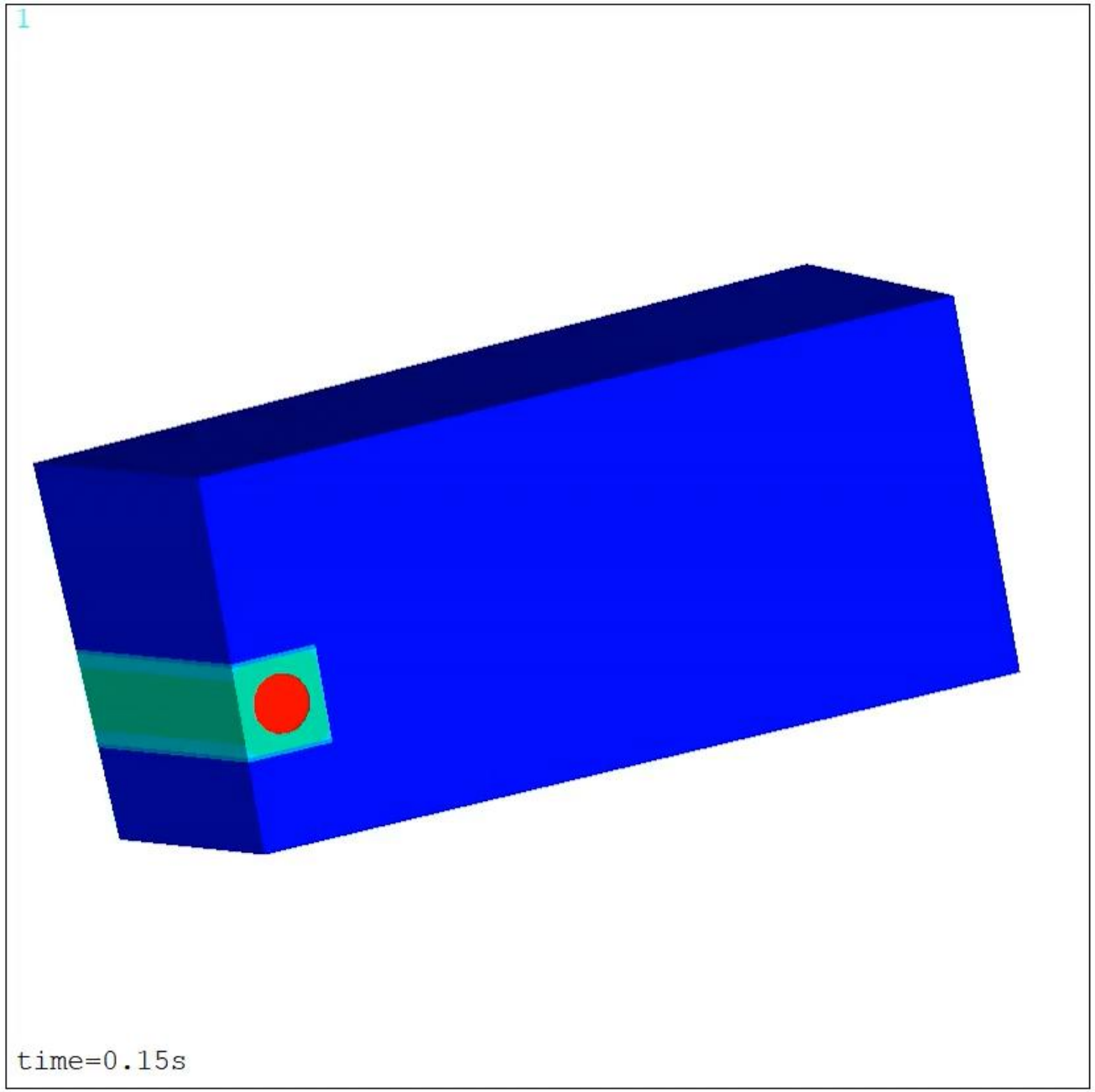


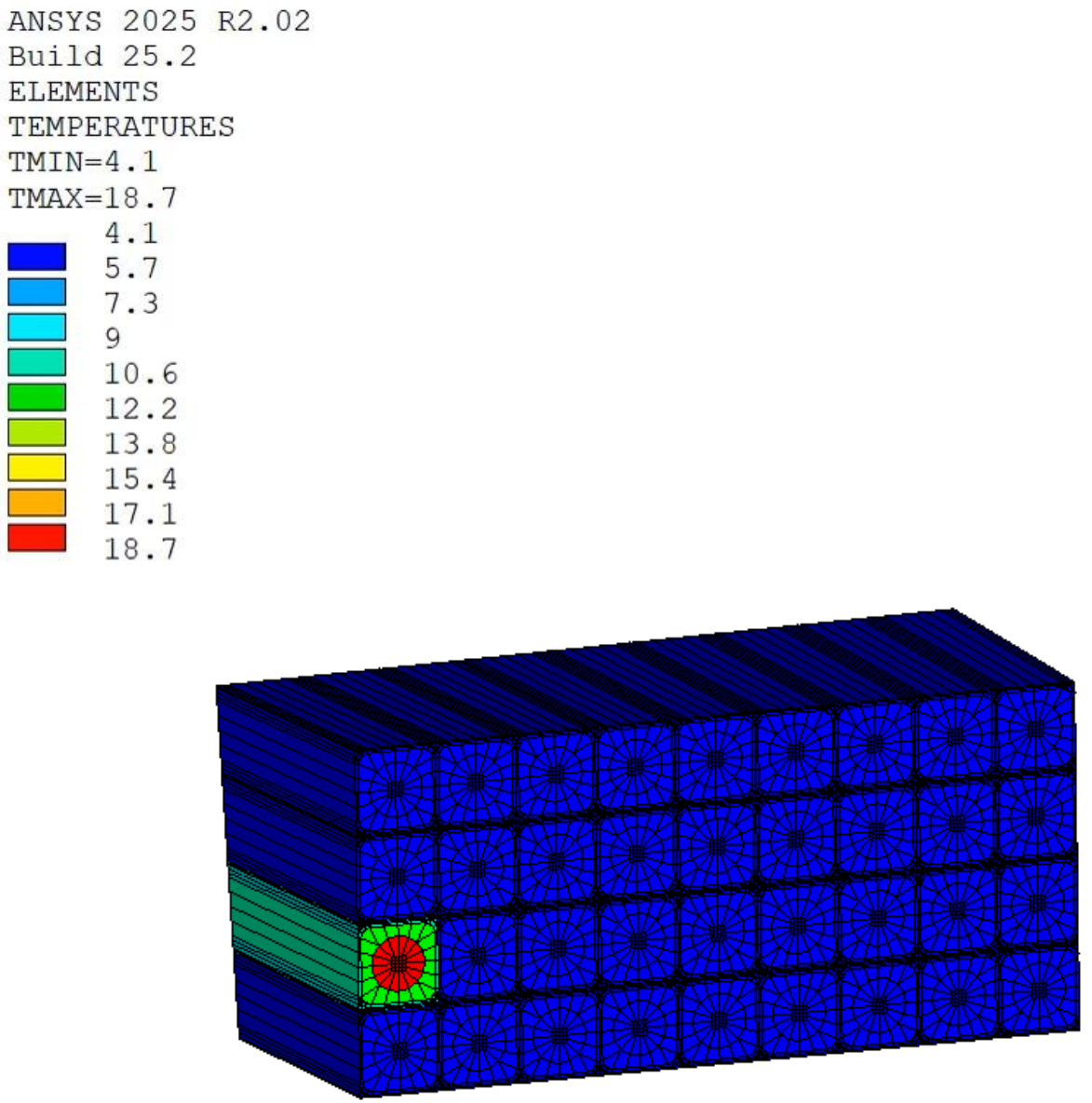
x=0.808 m



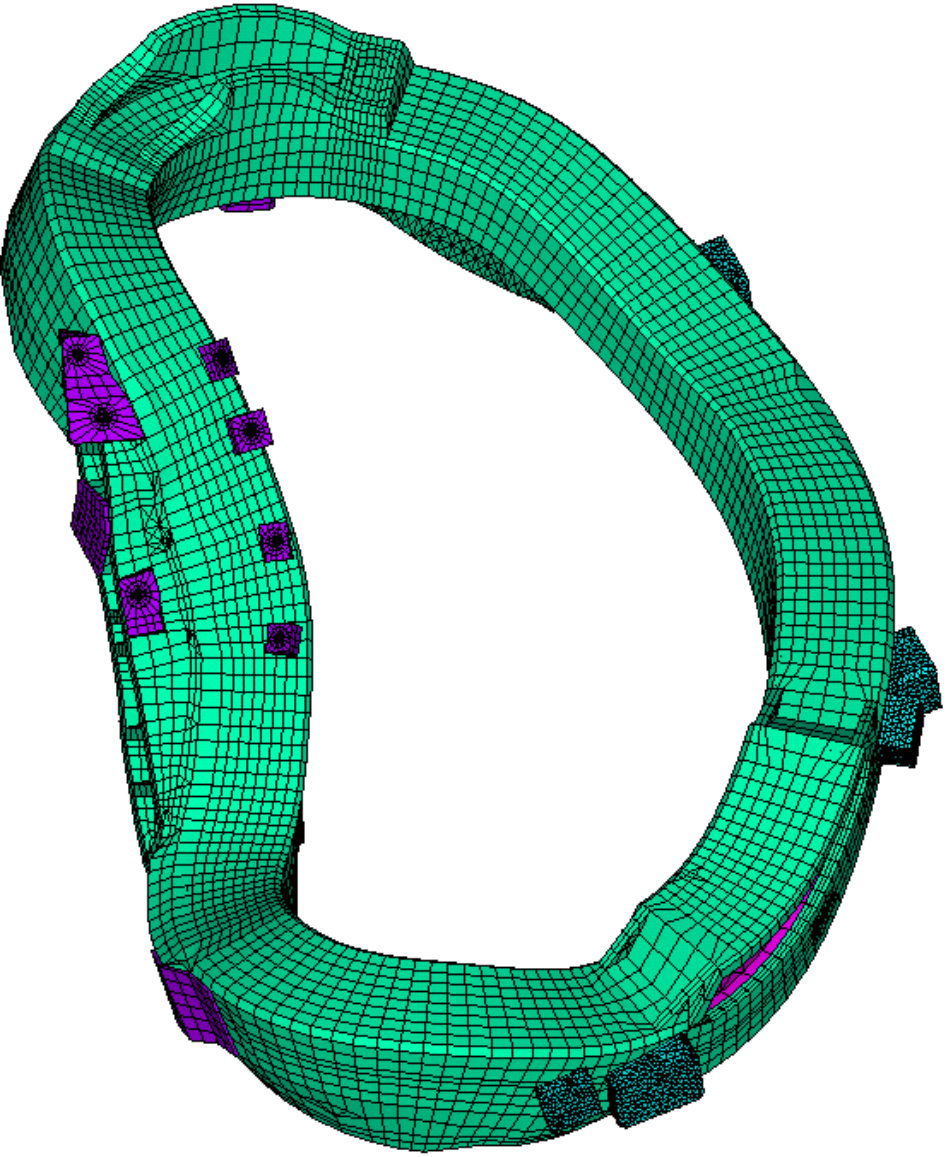


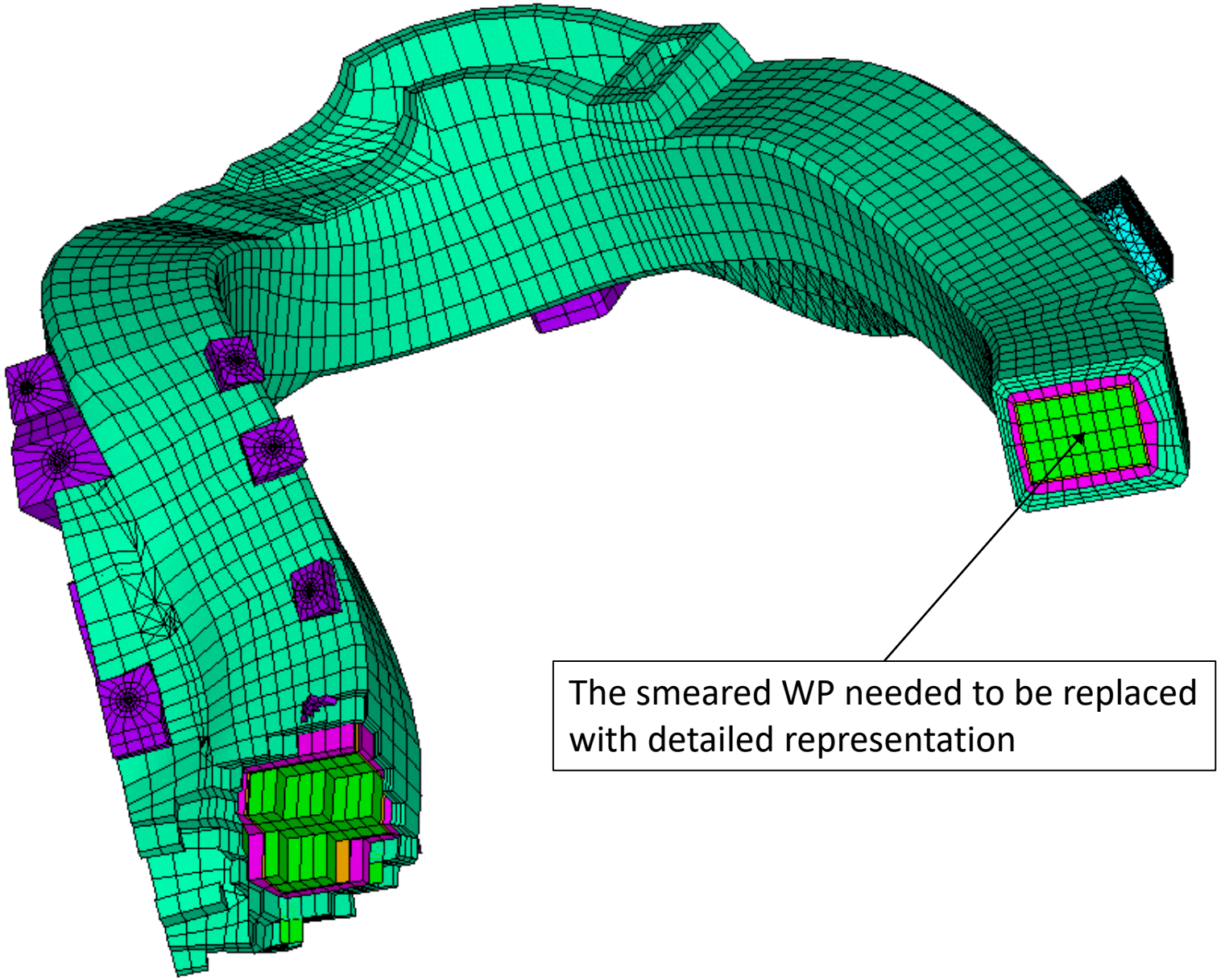
2. Thermo-hydraulic-electric model in THEA (1D) (11/11)





3. Mechanical model (1/21)





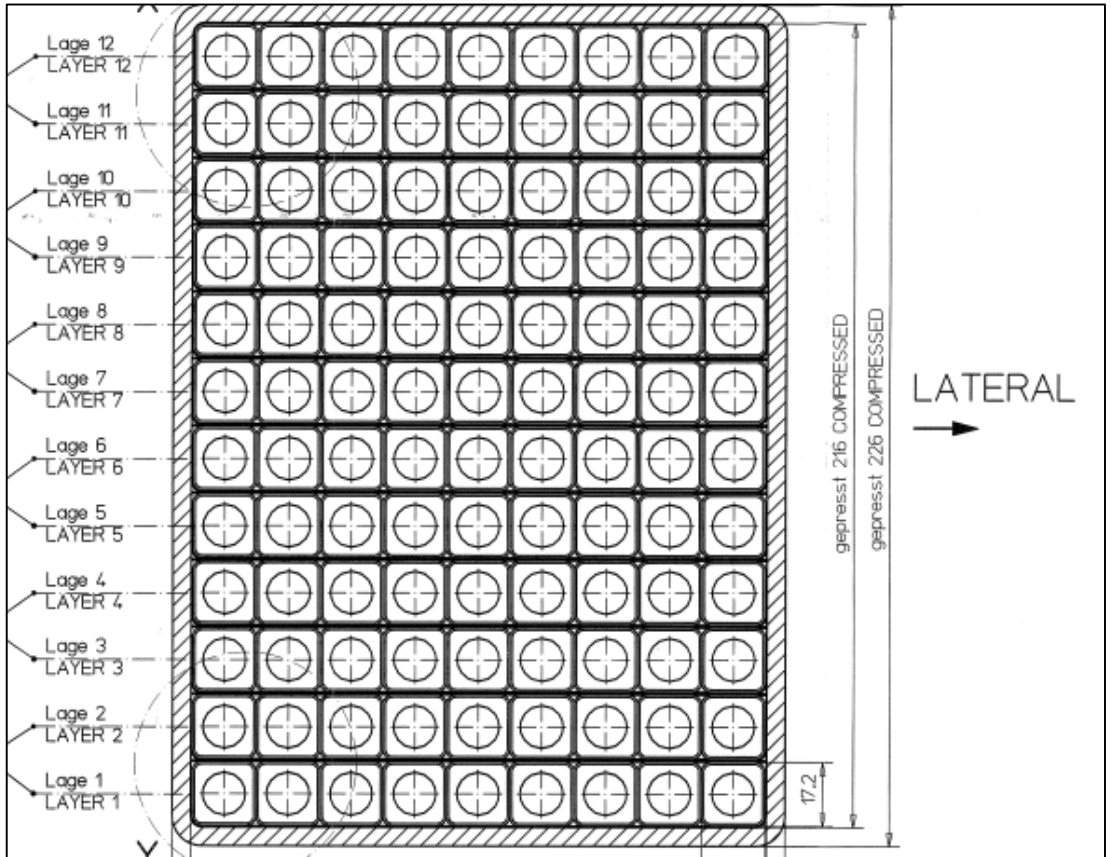
The smeared WP needed to be replaced with detailed representation

3. Mechanical model (2/21)

Methodology -> Creating a **structured mesh** from the **bottom up**

Control over the mesh

Speed of mesh creation



Methodology developed in:

R. Ortwein and Glyn Kirby Parametric FEM modeling of multilayer castellated canted cosine theta (CCT) magnets (2021) *Supercond. Sci. Technol.* **34** 055008

R. Ortwein, F. Nunio. Mechanical analysis of the DEMO TF with 2D and 3D models: homogenized and fully detailed – comparison of accuracy. Fusion Engineering and Design (2025), 115156 117

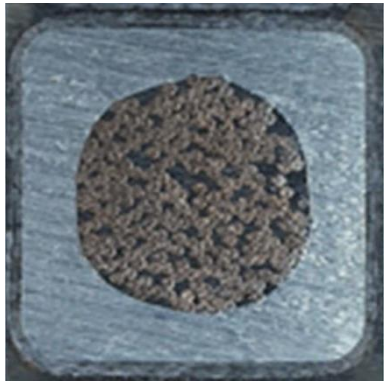
R. Ortwein, X. Sarasola, F. Dematte. 3D modelling of the R&W TF coil design for EU-DEMO including the winding pack and frictional effects. Cryogenics 104180 151 (2025)

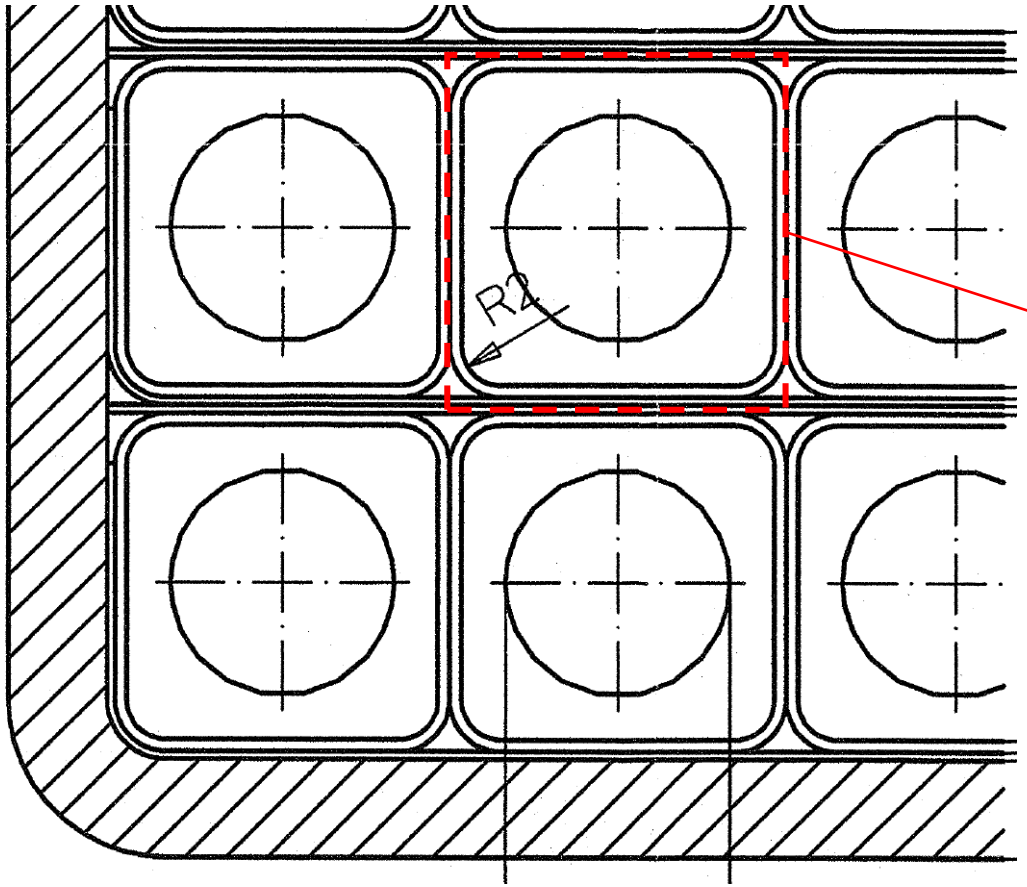
3. Mechanical model (3/21)

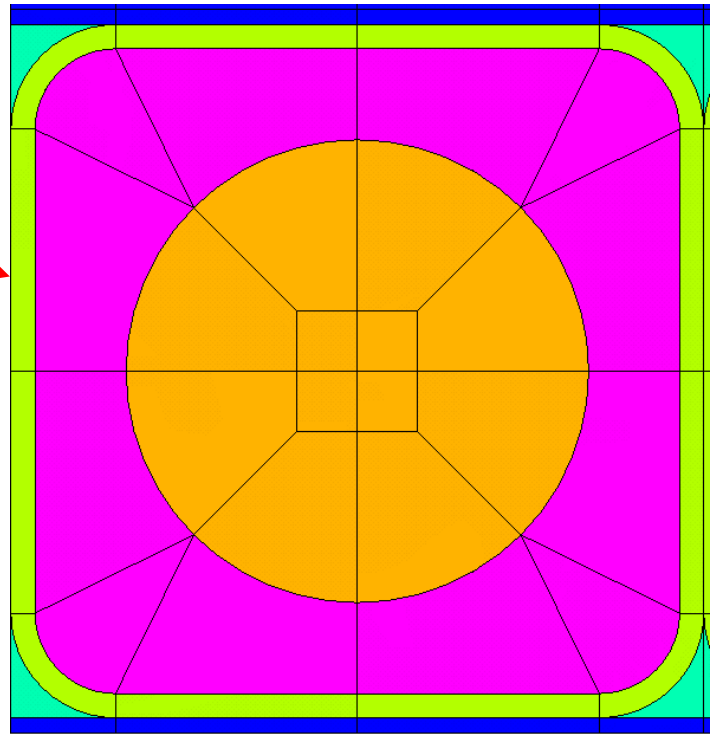
Methodology -> Creating a **structured mesh** from the **bottom up**

Control over

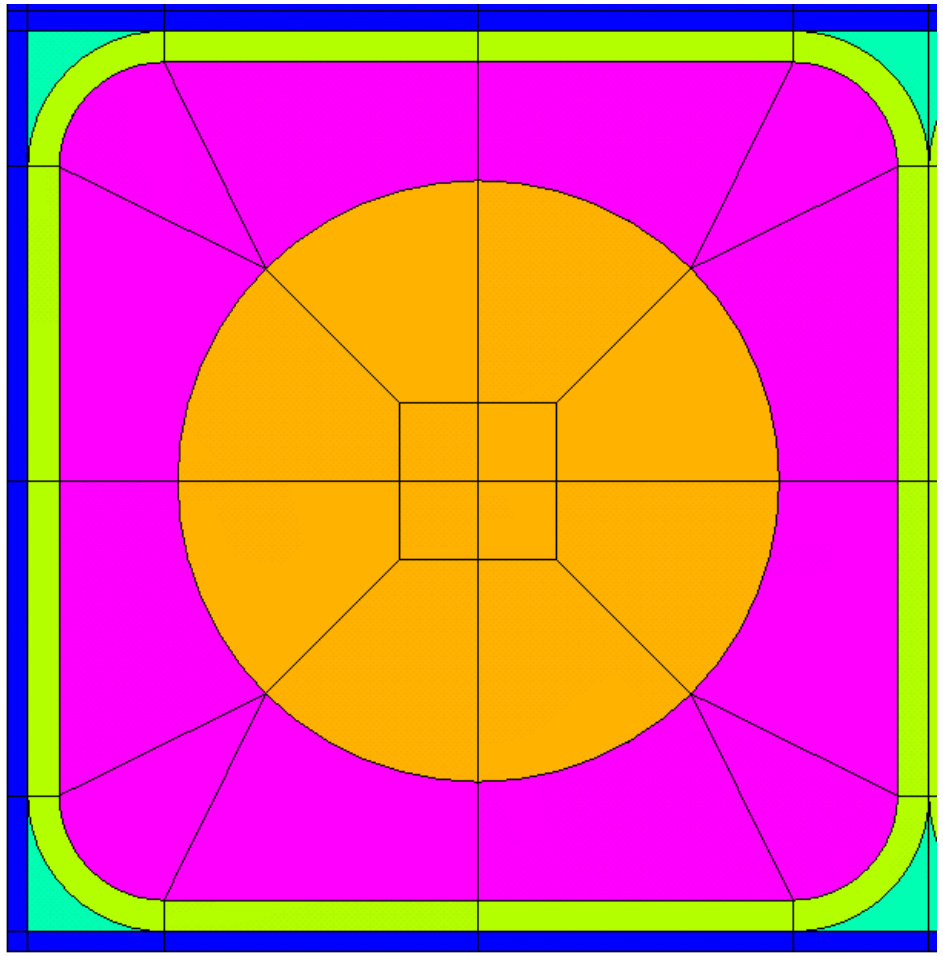
Speed of mesh creation

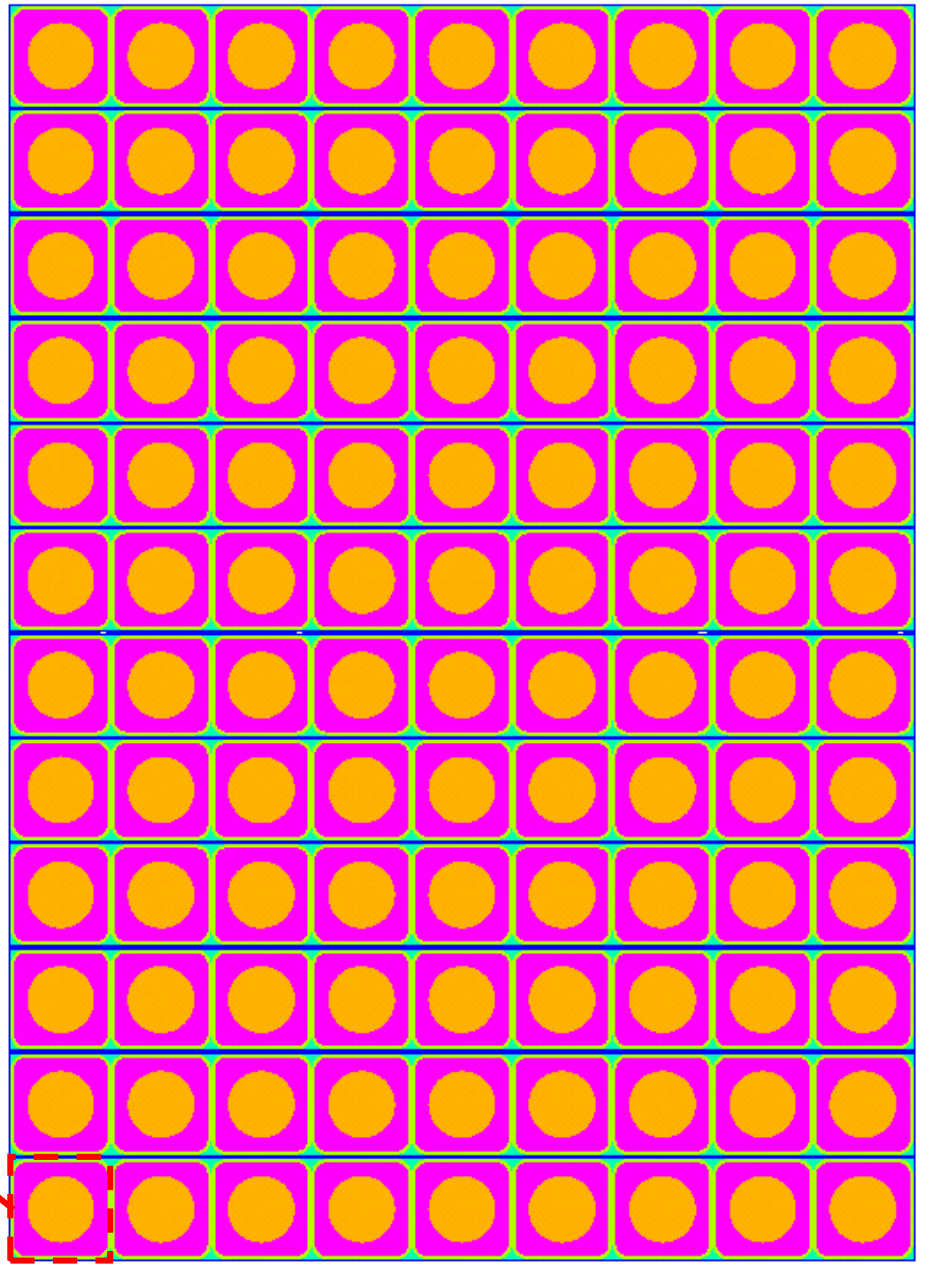




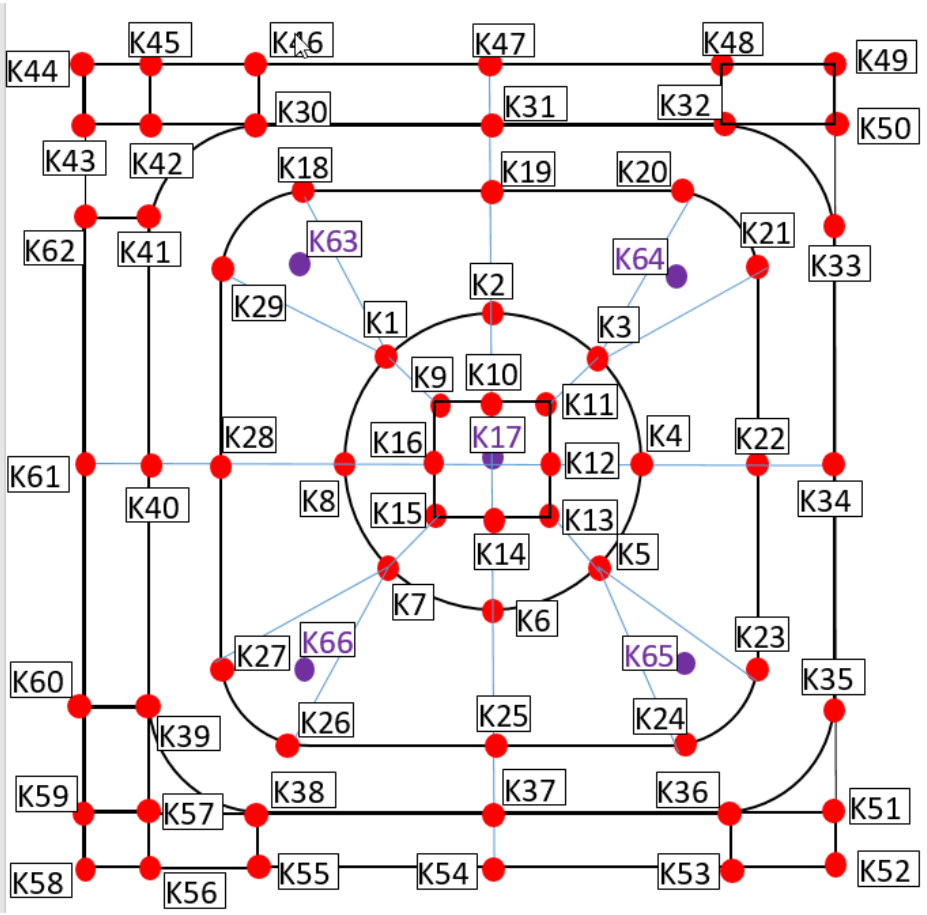


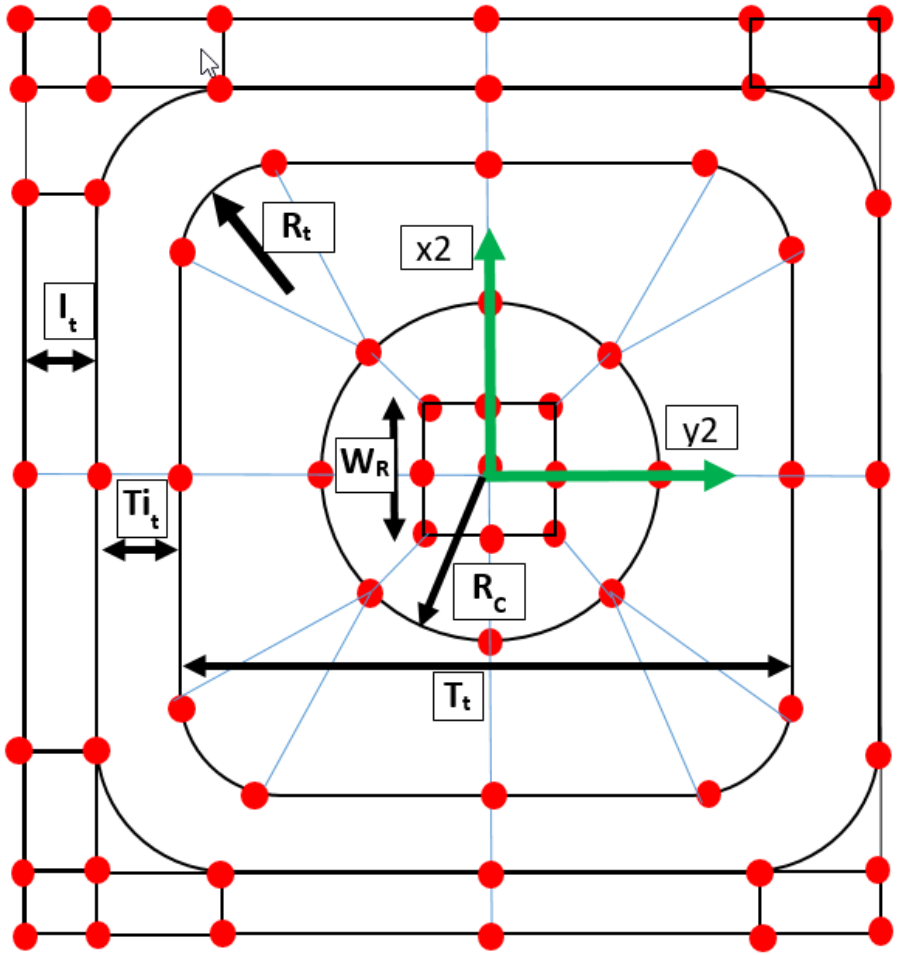
3. Mechanical model (4/21)





3. Mechanical model (5/21)



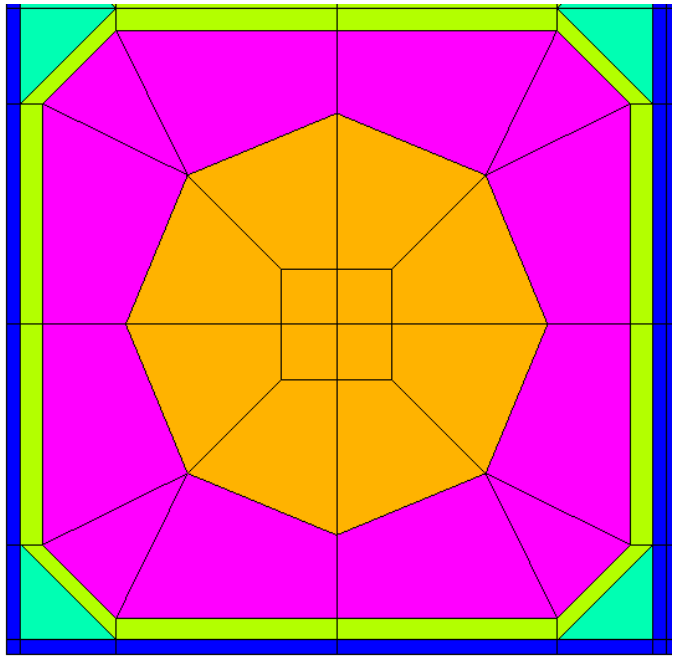


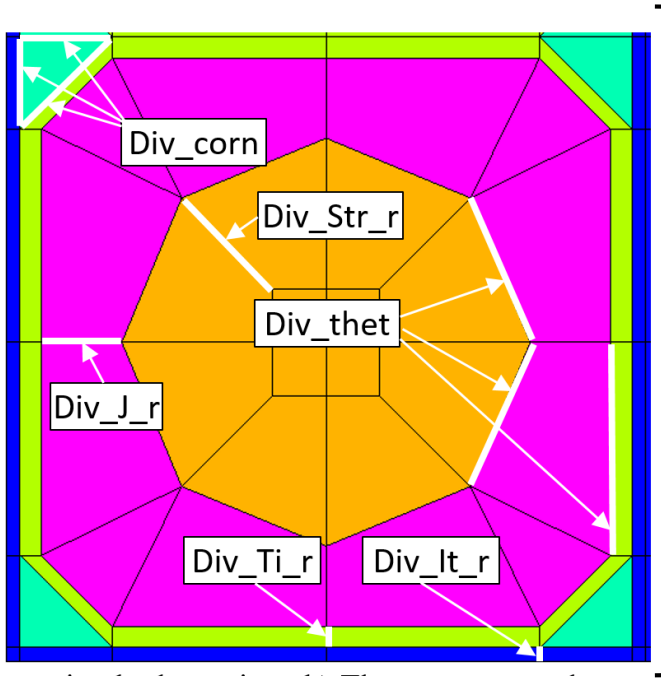
T_t=16.024 mm
Ti_t=0.6 mm
I_t=0.388 mm
R_c=5.75 mm
R_t=2 mm

Geometrical parameters:
R_C – radius of the cable (hole in the jacket)
T_t – turn thickness (jacket thickness)
R_t – fillet radius of the jacket
Ti_t – turn insulation thickness
I_t – interlayer insulation thickness

3. Mechanical model (6/21)

Div_Str_r=1
Div_J_r=1
Div_Ti_r=1
Div_It_r=1
Div_thet=1
Div_corn=1

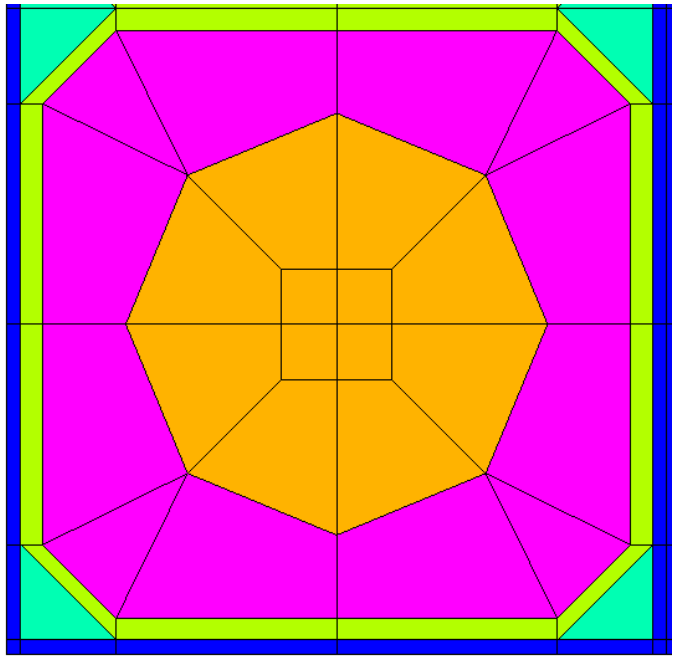


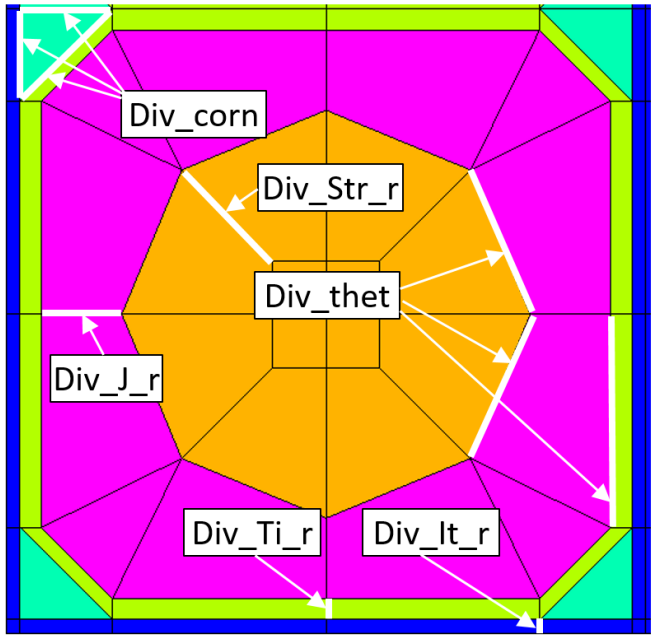


Parametrization of the mesh

3. Mechanical model (7/21)

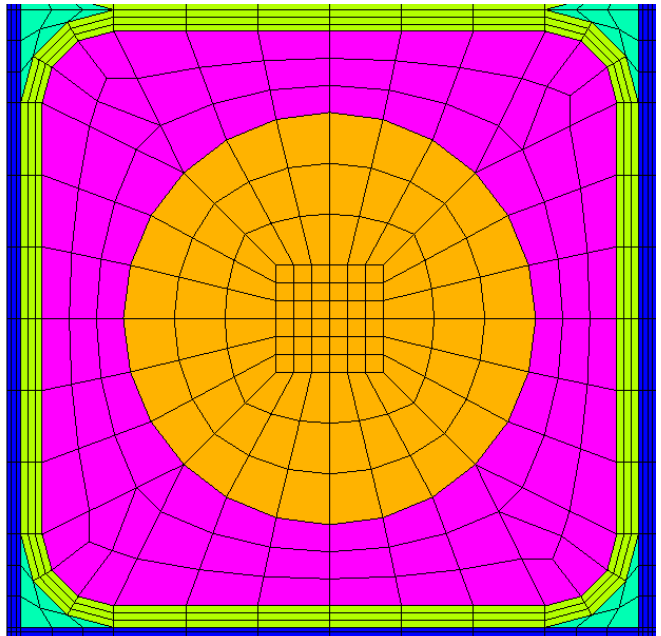
Div_Str_r=1
Div_J_r=1
Div_Ti_r=1
Div_It_r=1
Div_thet=1
Div_corn=1



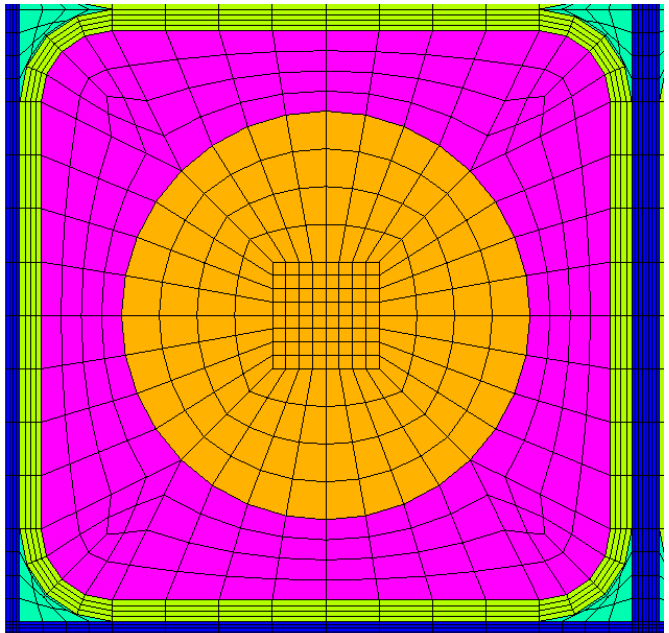


Parametrization of the mesh

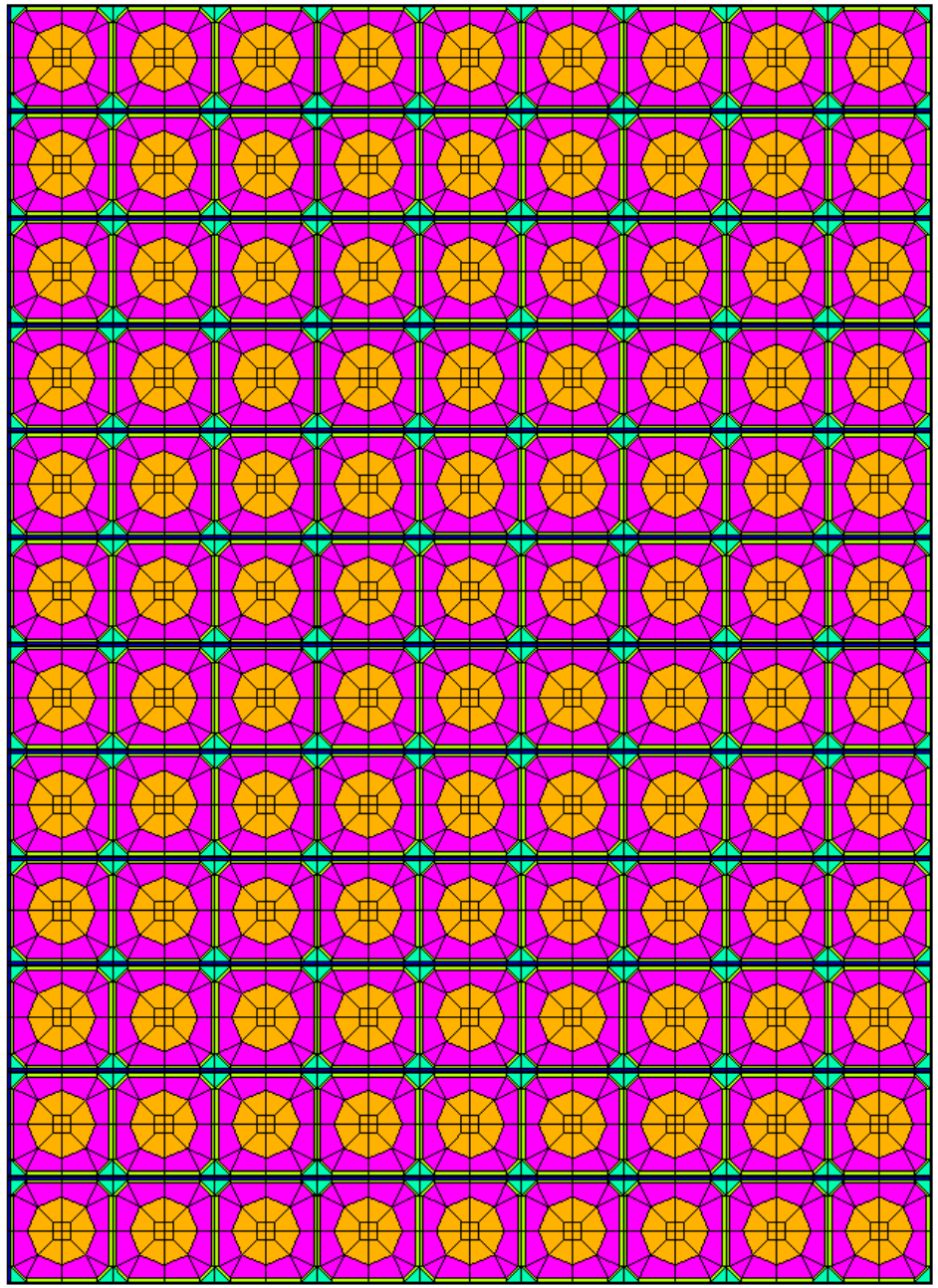
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Div_Ti_r=3
Div_It_r=3
Div_thet=3
Div_corn=3



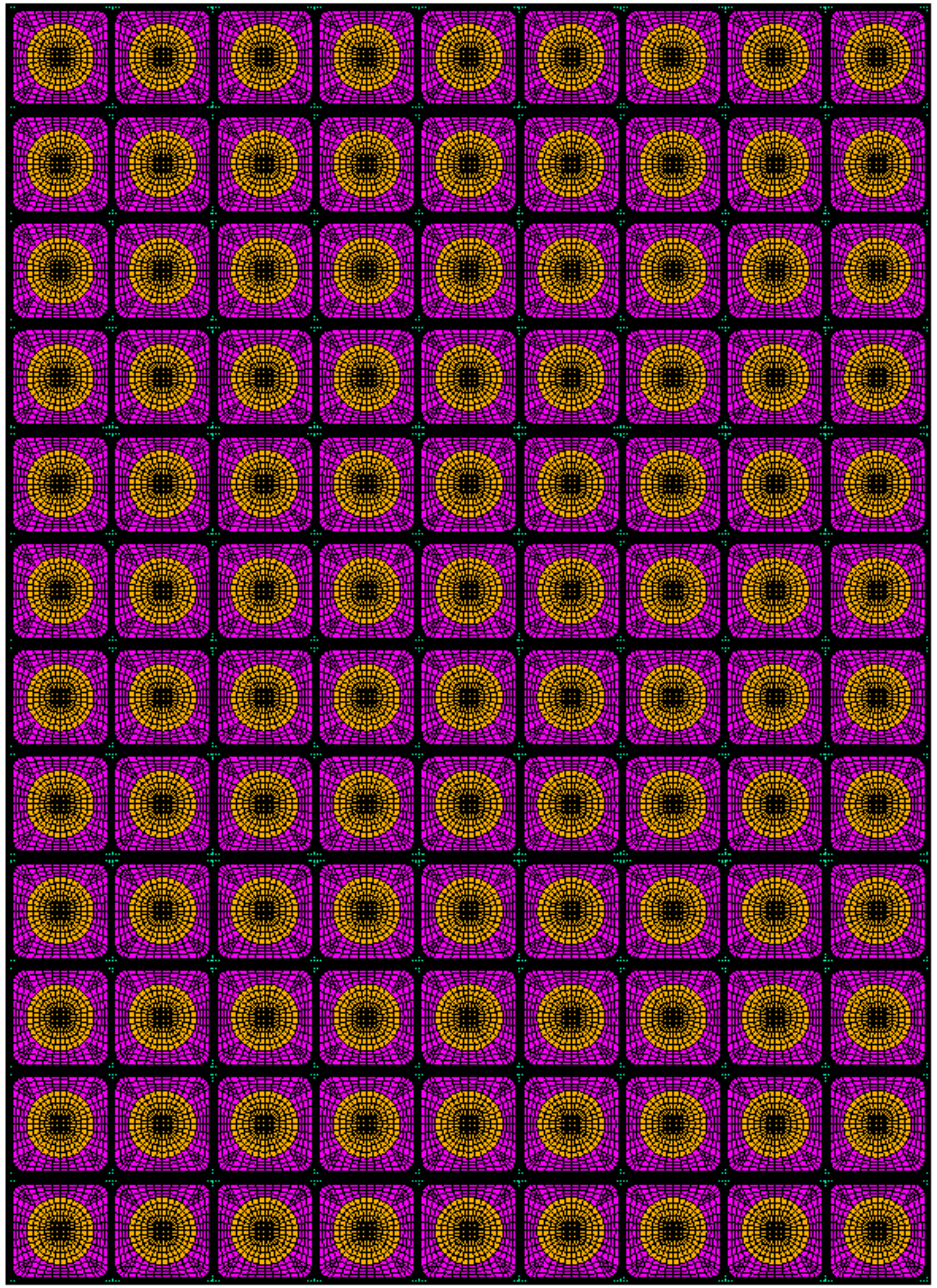
Div_Str_r=4
Div_J_r=4
Div_Ti_r=4
Div_It_r=4
Div_thet=4
Div_corn=4



3. Mechanical model (8/21)



Div_Str_r=1
Div_J_r=1
Div_Ti_r=1
Div_It_r=1
Div_thet=1
Div_corn=1

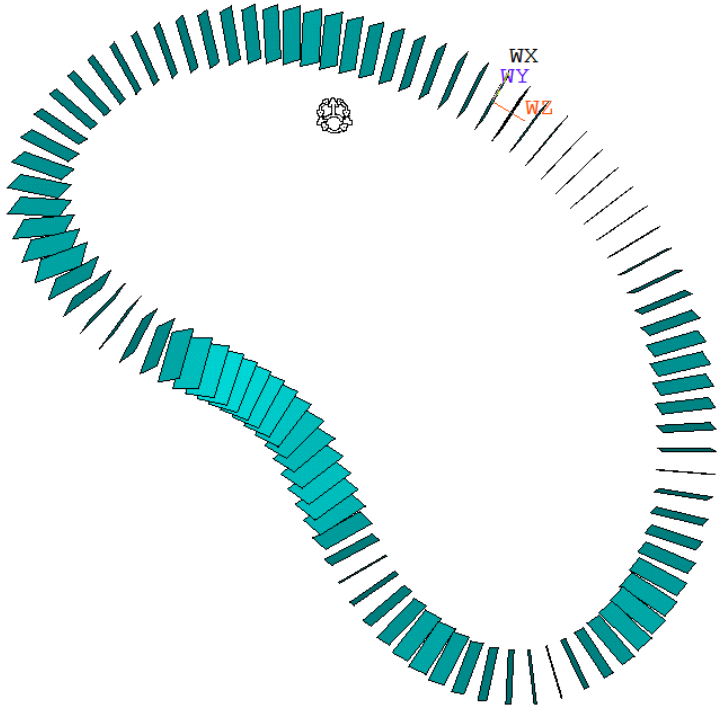


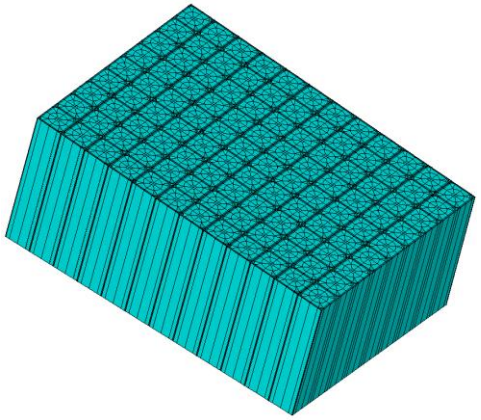
Div_Str_r=4
Div_J_r=4
Div_Ti_r=4
Div_It_r=4
Div_thet=4
Div_corn=4

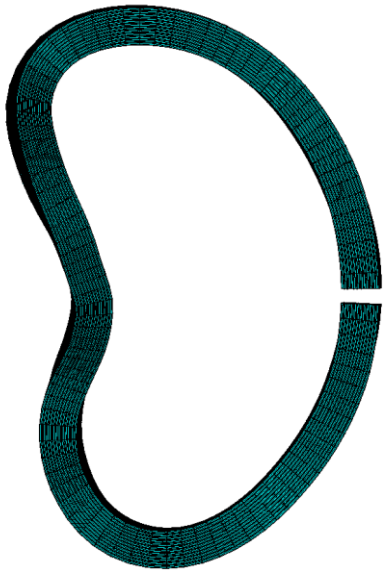
3. Mechanical model (9/21)

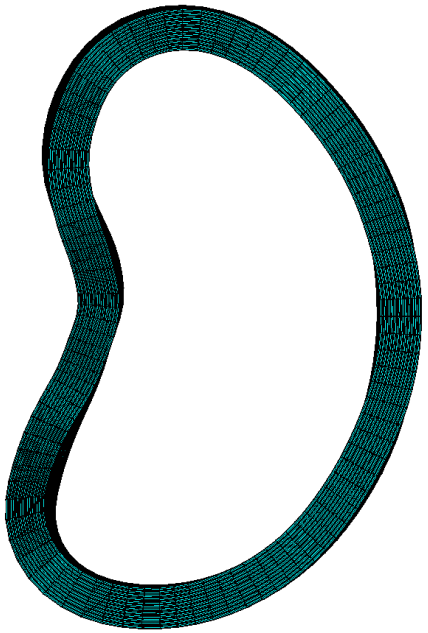
Procedure for creating the 3D mesh along the coil:

1. Copying the 2D mesh to the remaining 95 coordinate systems (96 in total) defined along the coil to account for its curvature (actually these are straight sections)
2. Copying the mesh into middle sections (in case more than 1 elements is needed along the segment
3. Creating the 3D elements via bottom-up method (EGEN command)
4. Applying the material properties to the generated elements

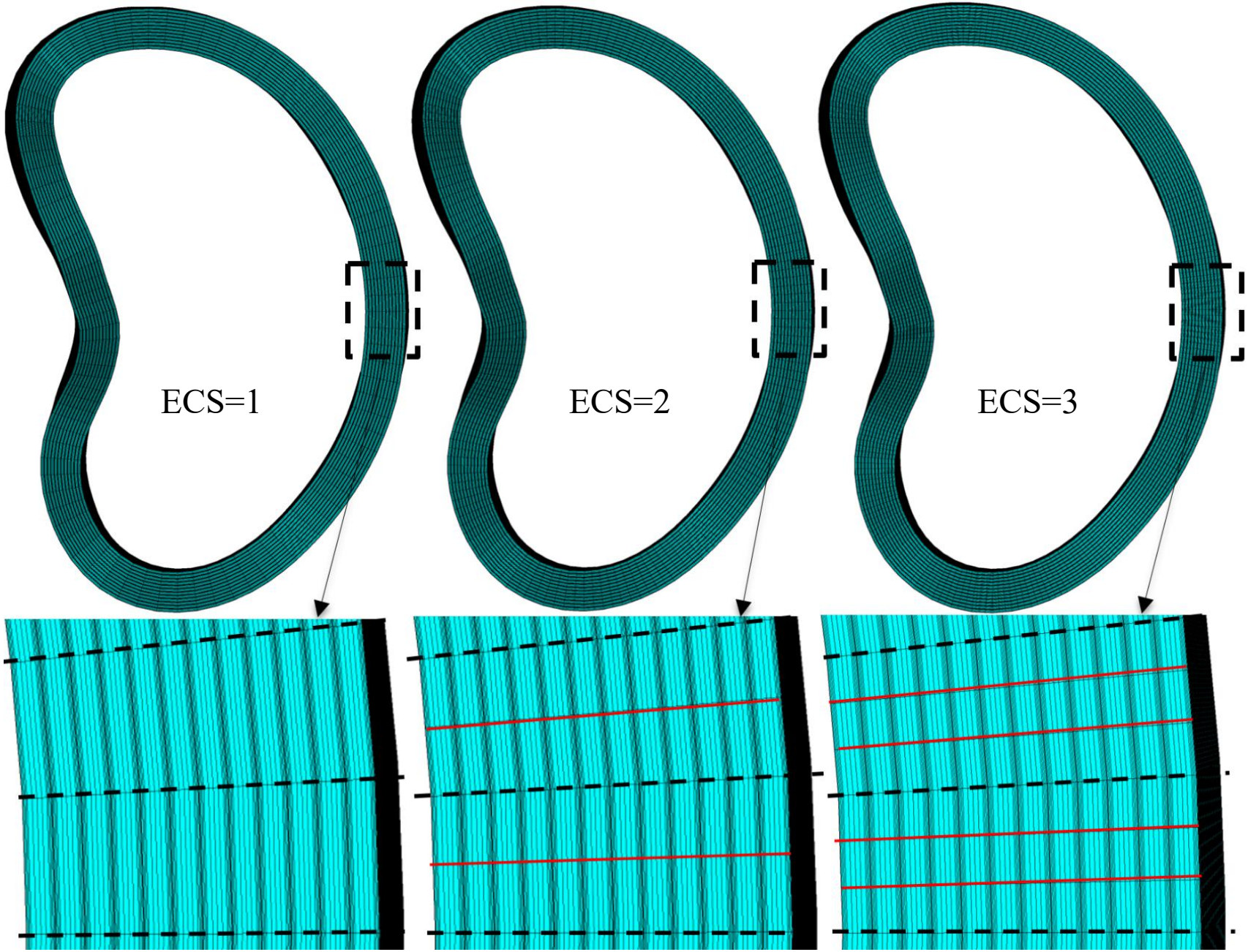




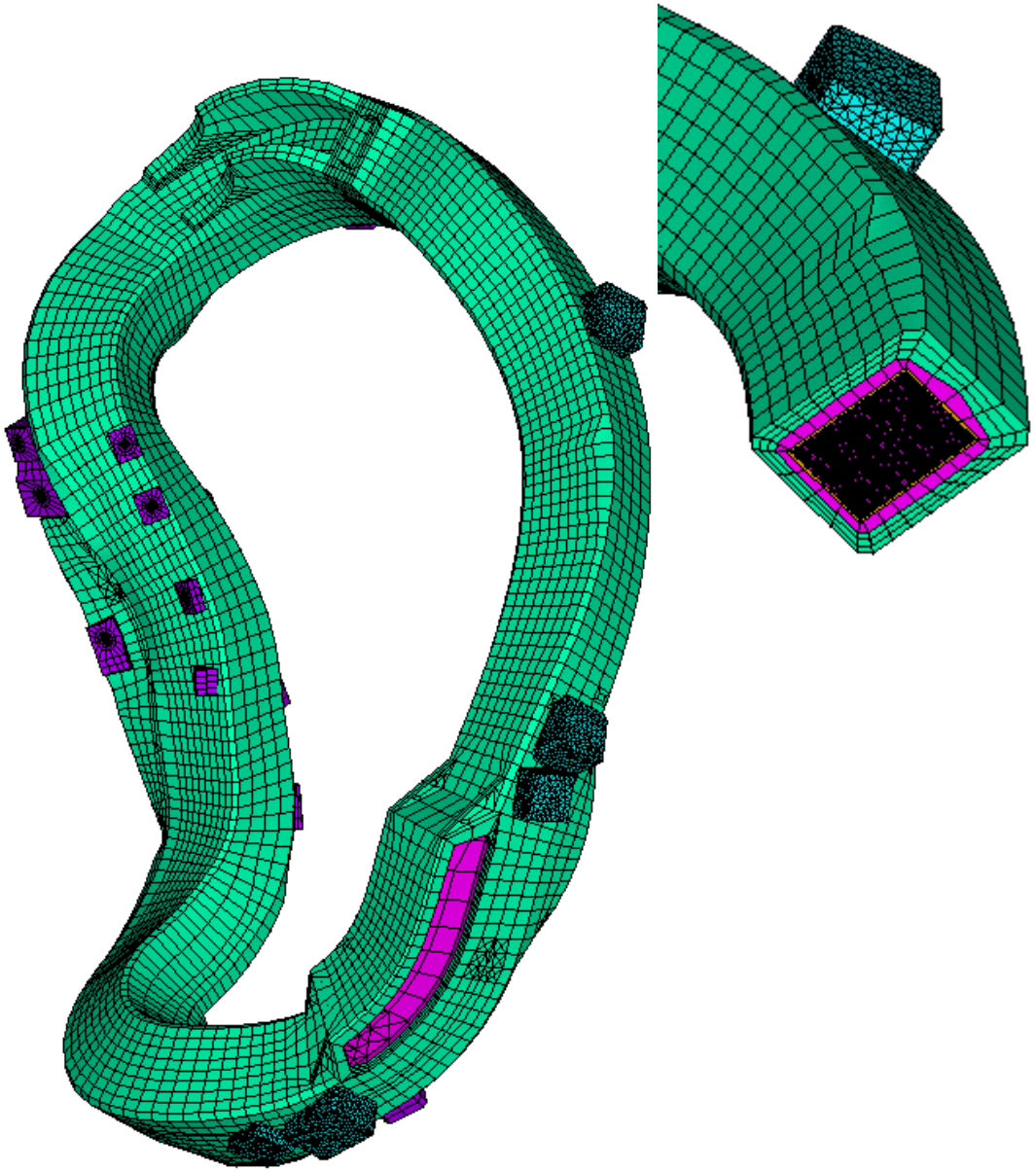


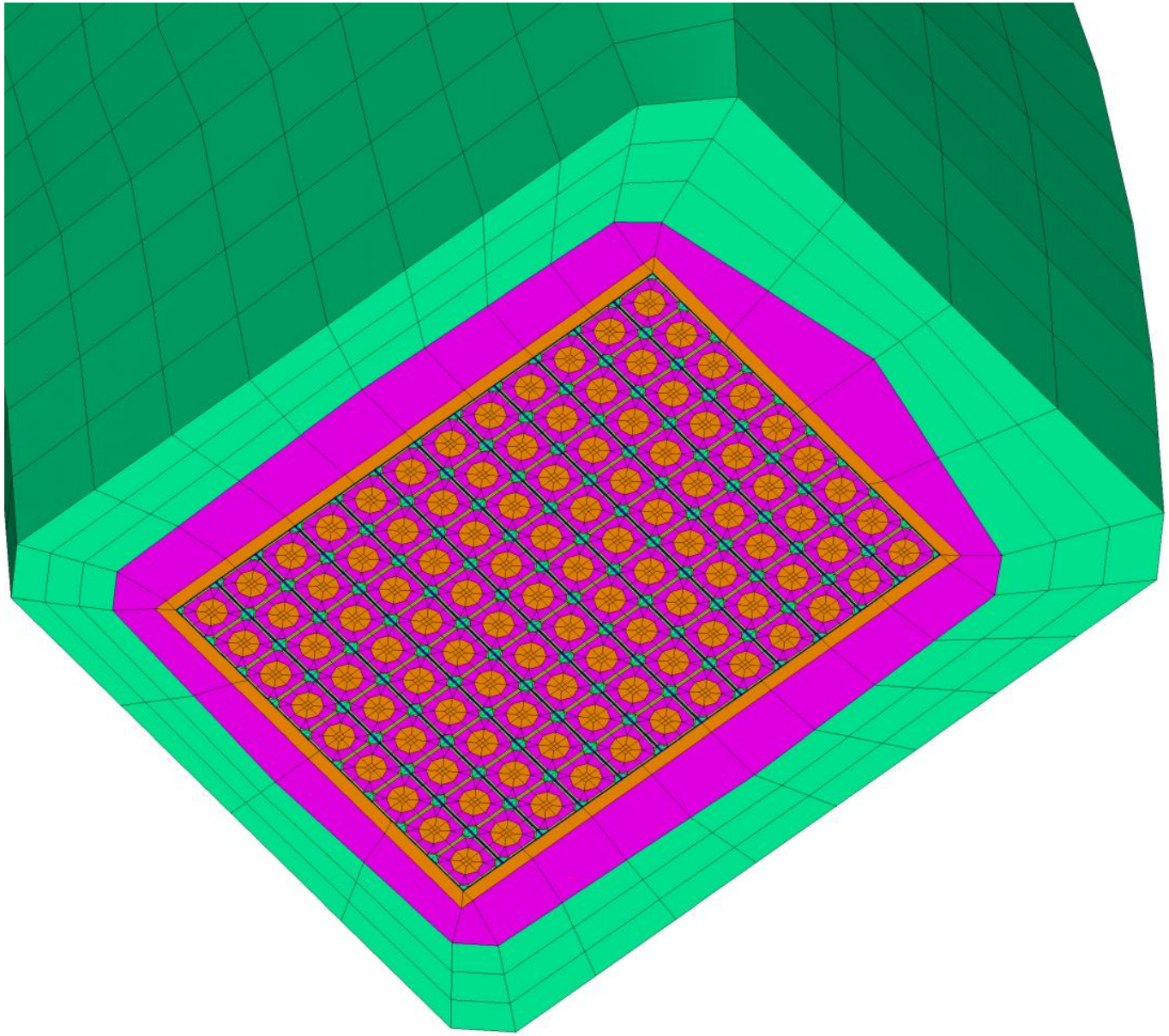


3. Mechanical model (10/21)

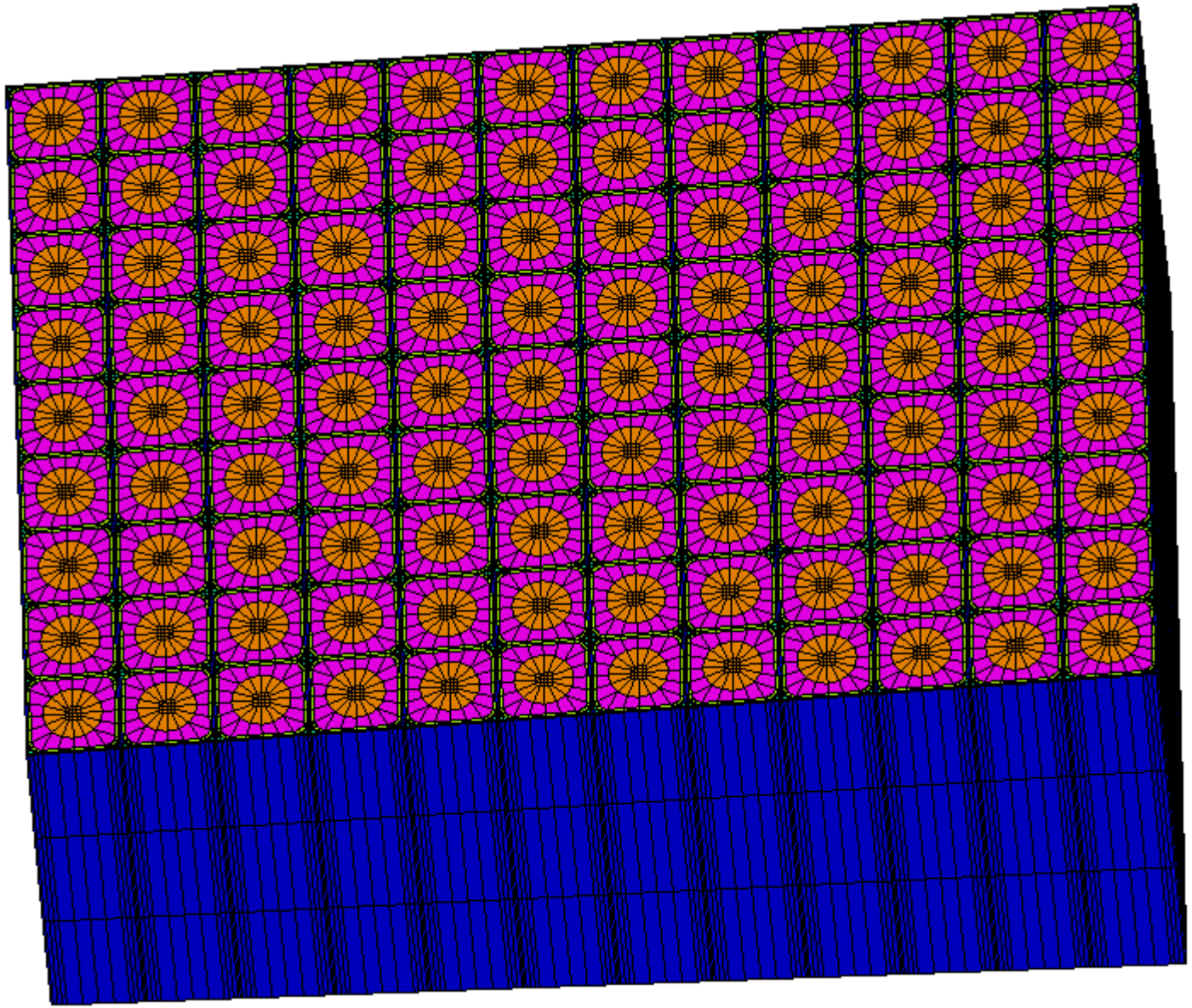


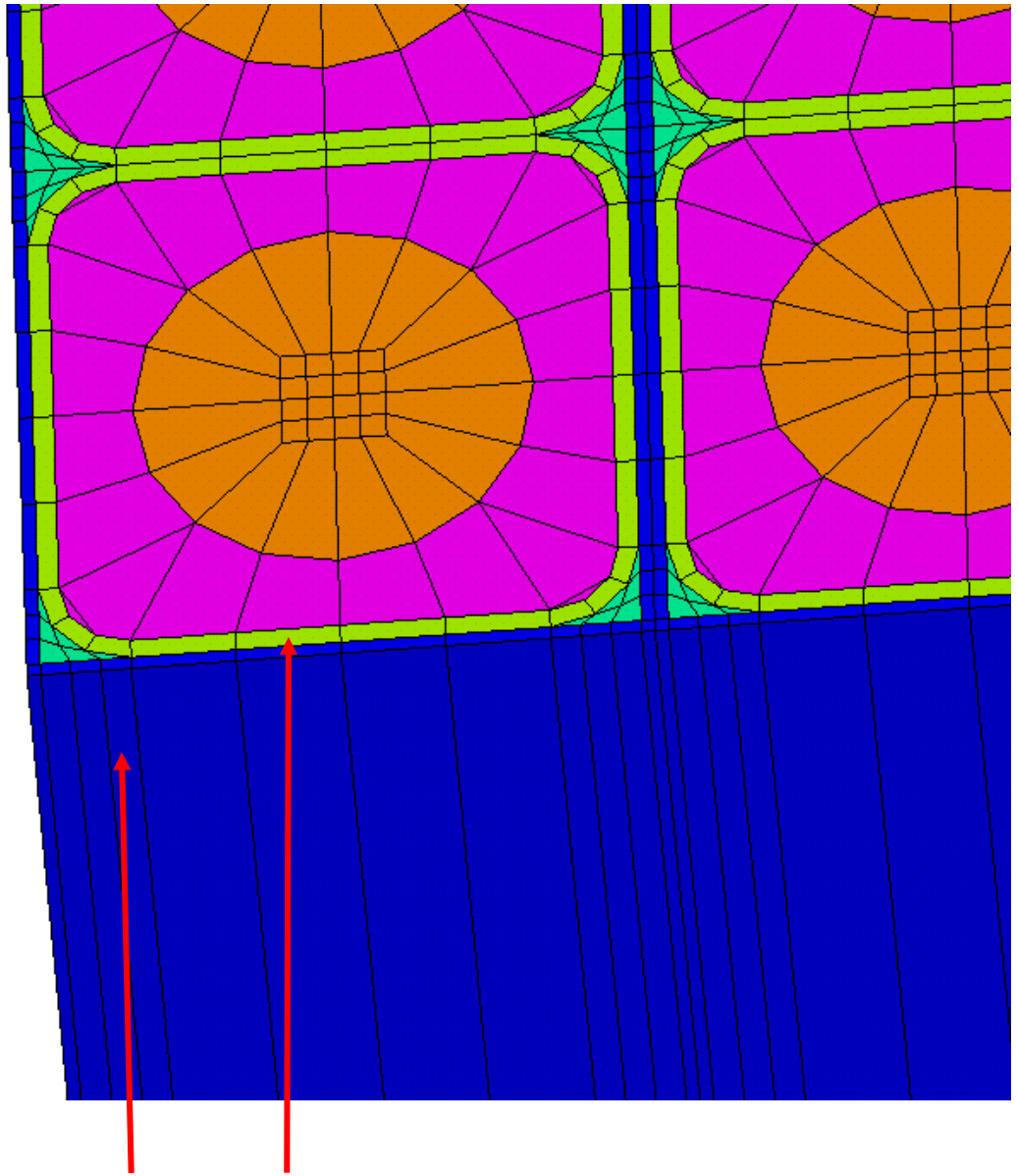
3. Mechanical model (11/21)





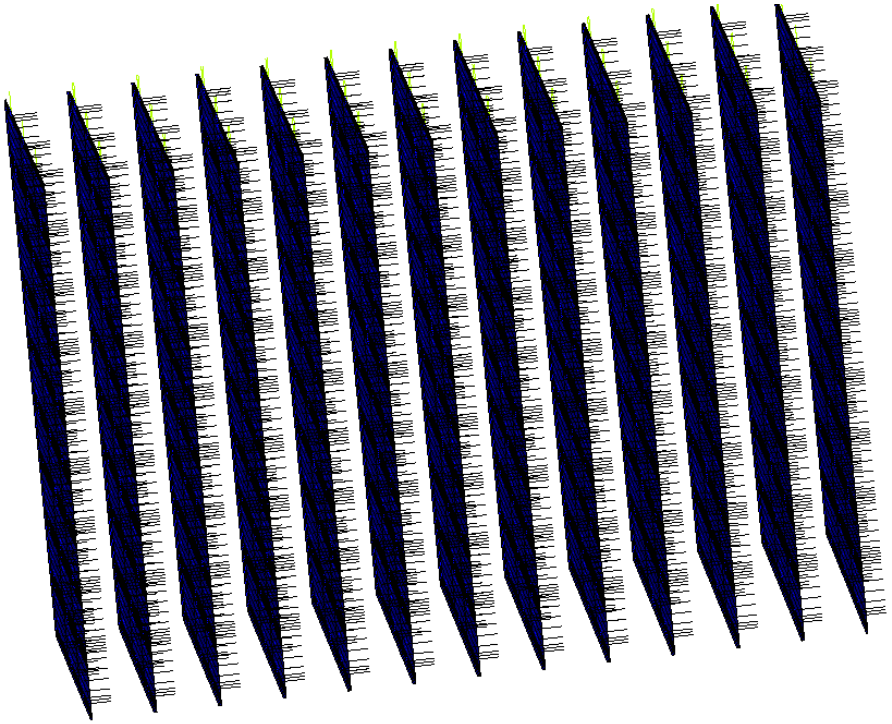
3. Mechanical model (12/21)

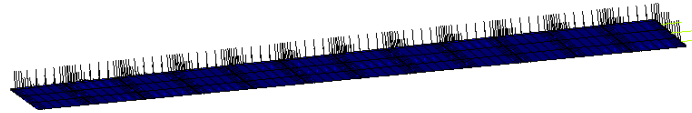


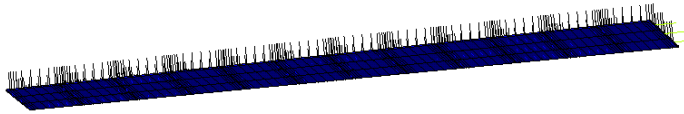


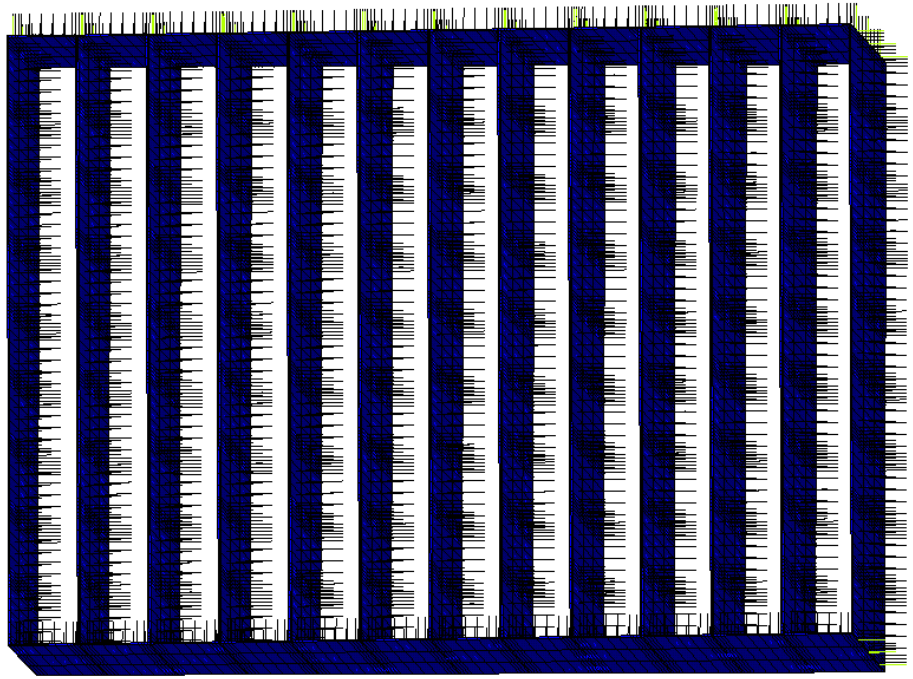
Orthotropic materials: blue, light green

3. Mechanical model (13/21)



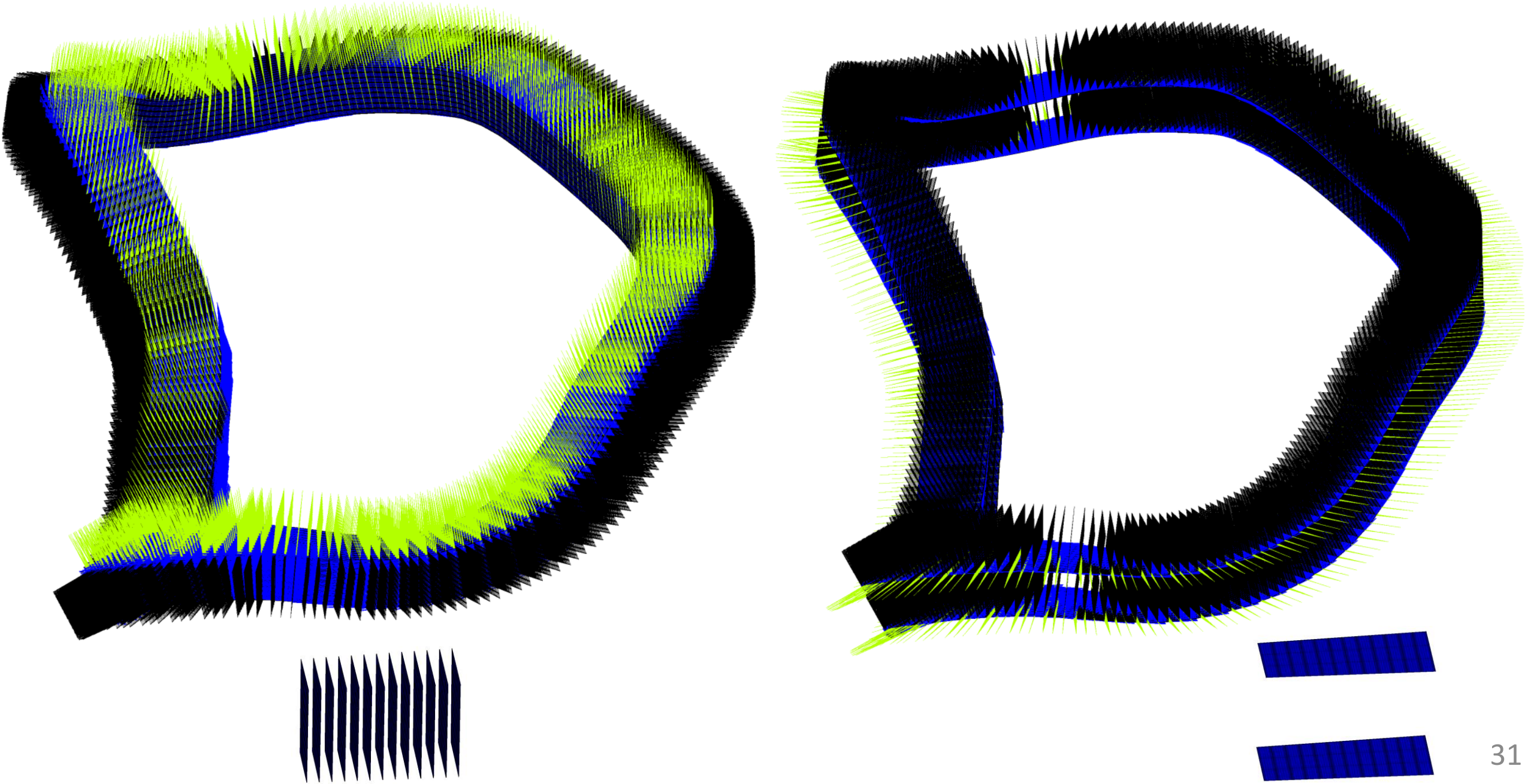




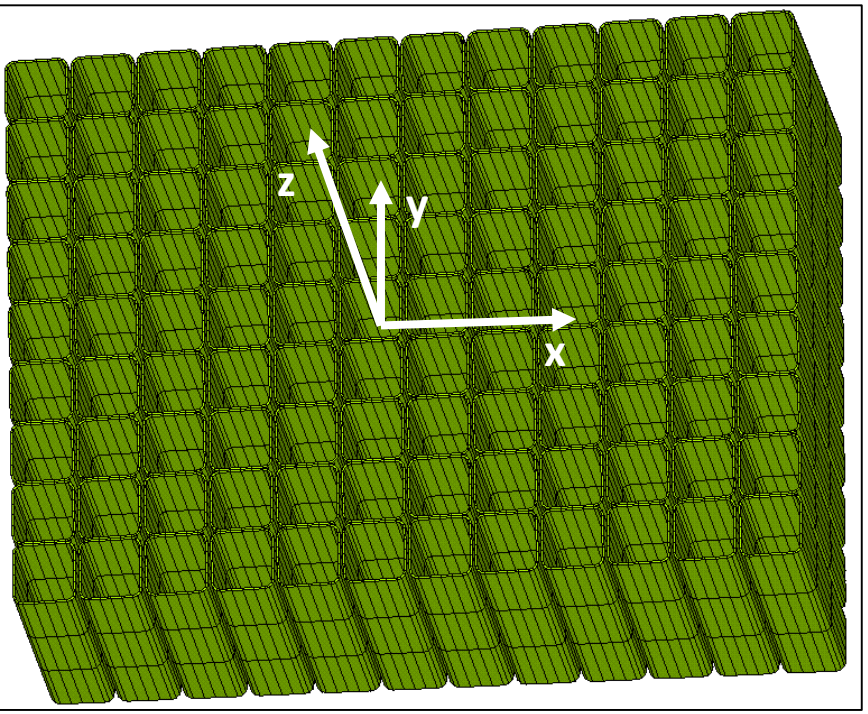


Element coordinate systems

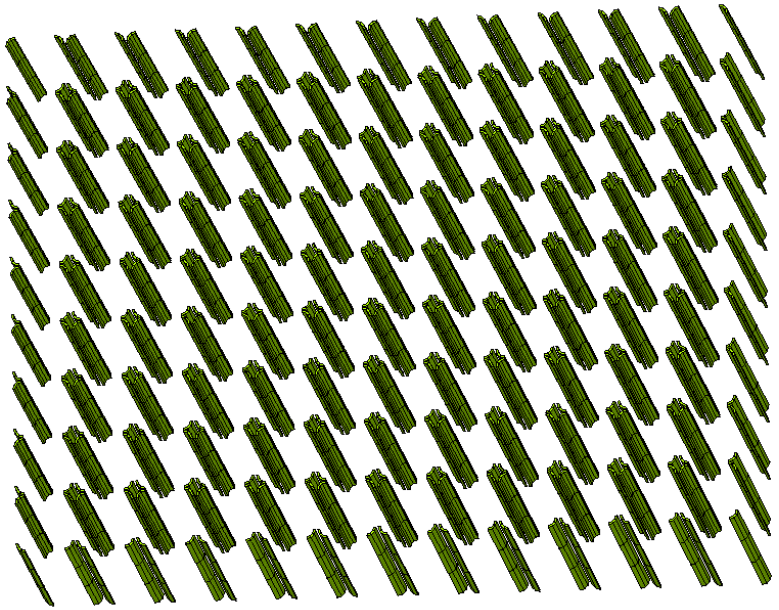
3. Mechanical model (14/21)



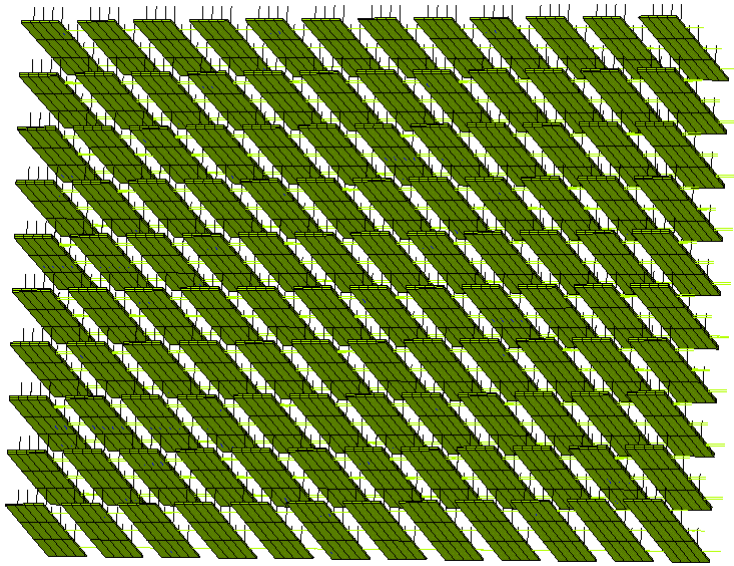
3. Mechanical model (15/21)



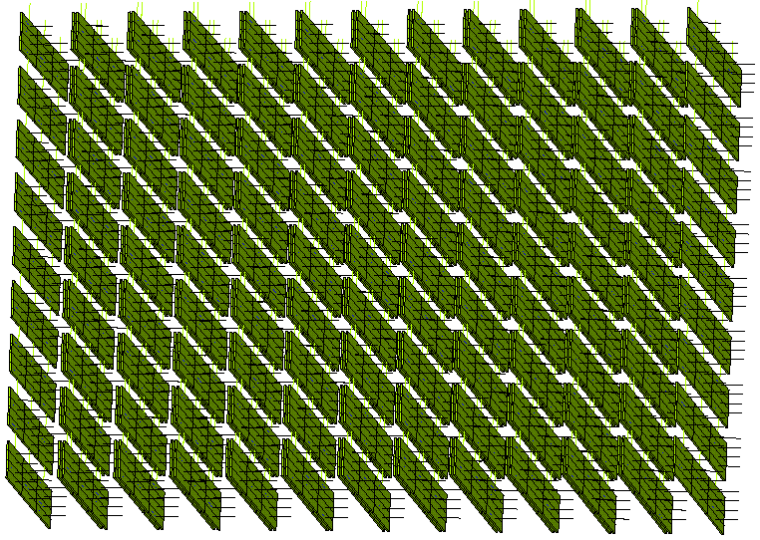
Arcs



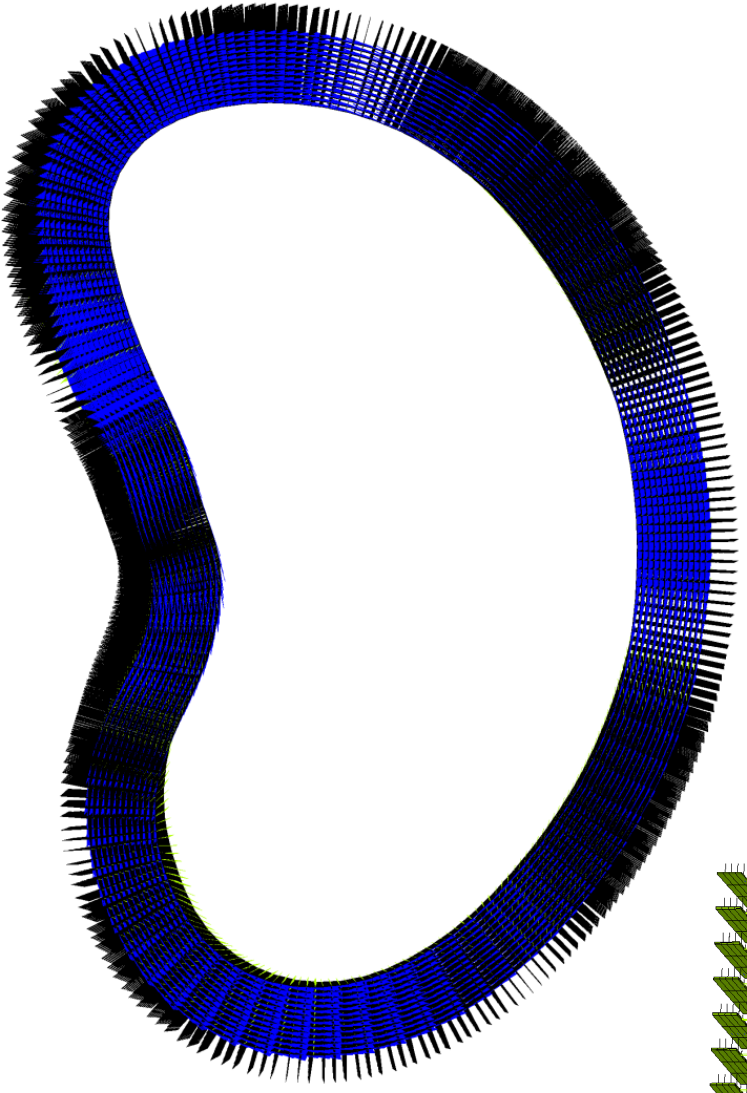
Region1

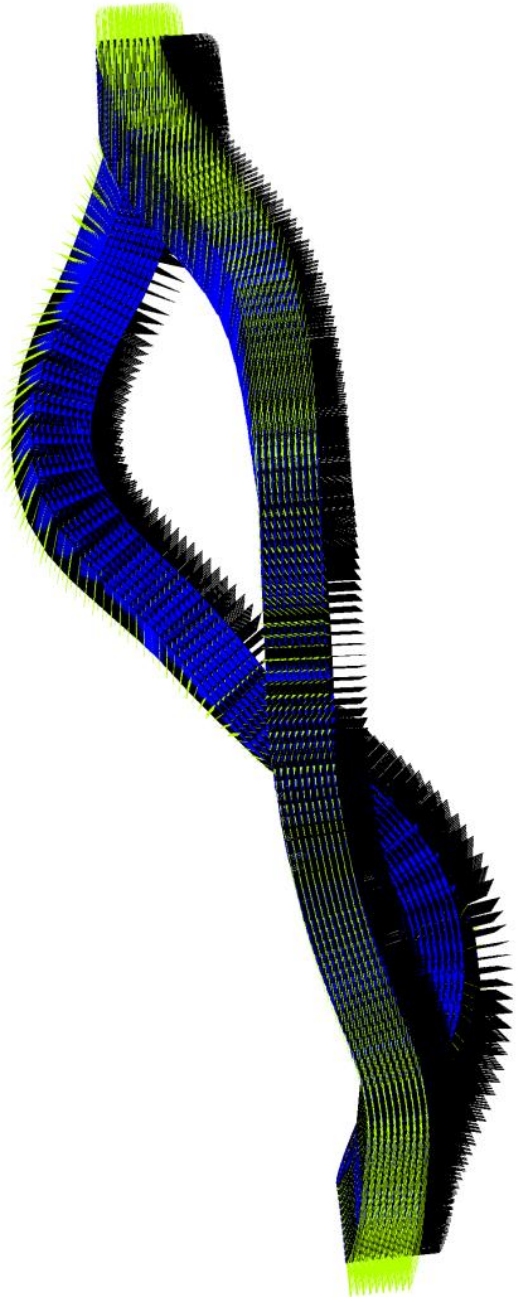


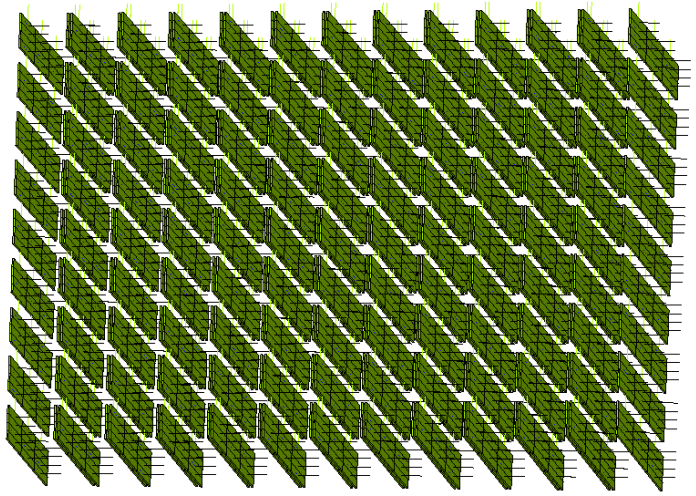
Region2

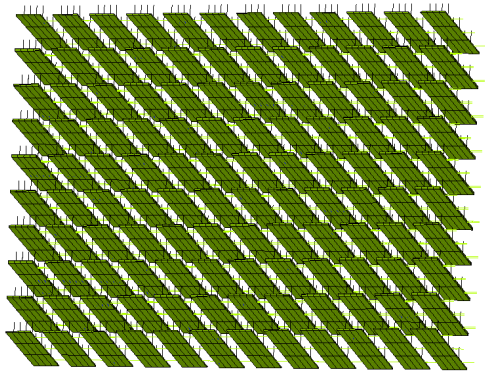


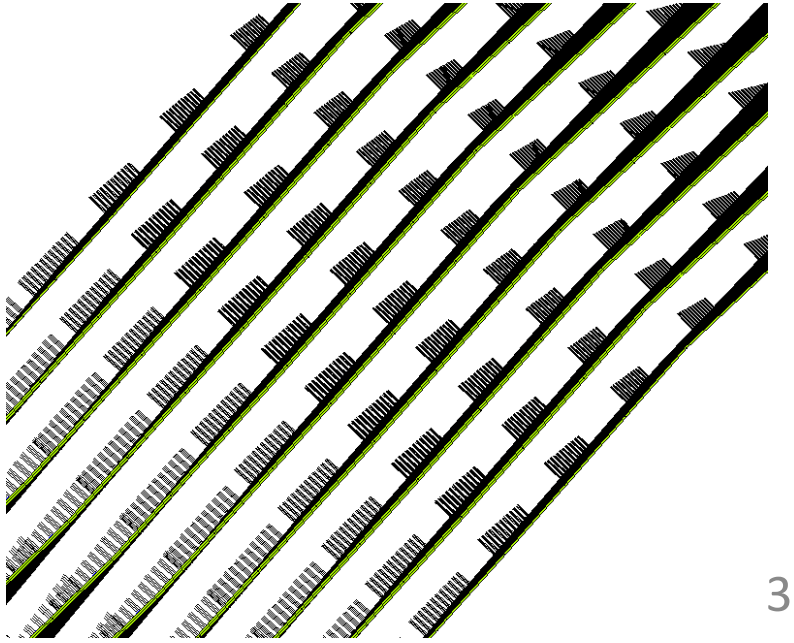
3. Mechanical model (16/21)



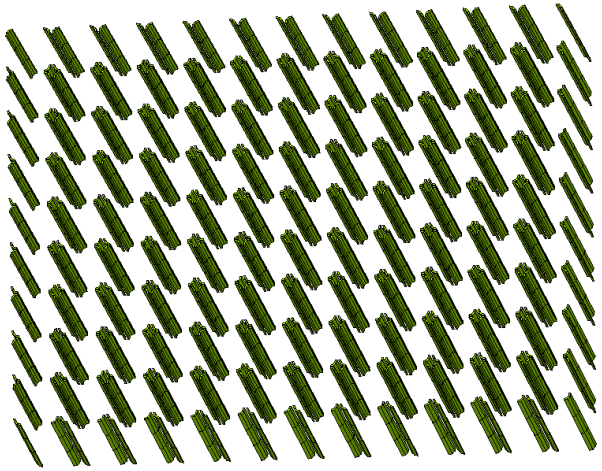






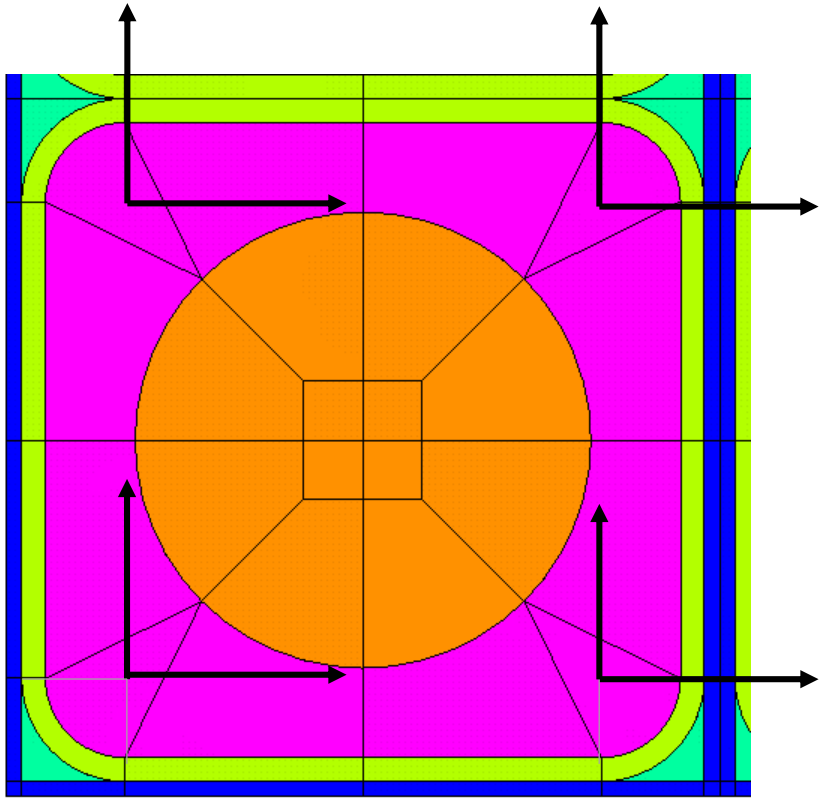


3. Mechanical model (17/21)

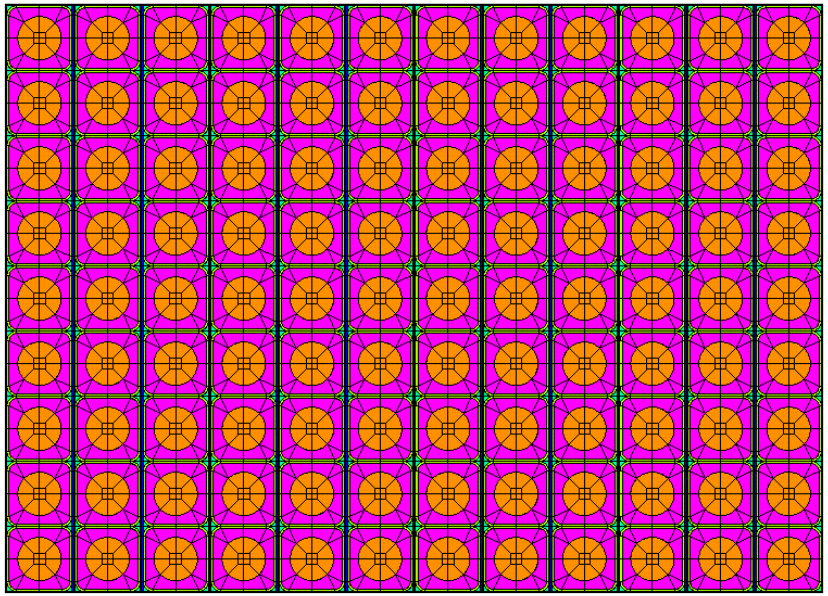




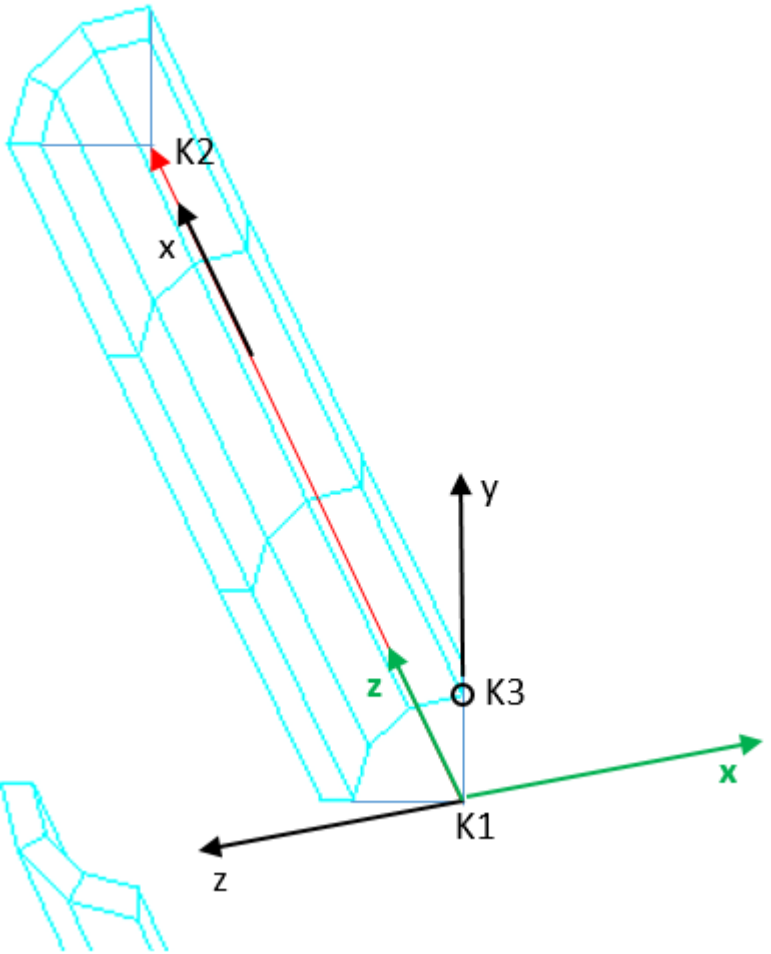
Number of coordinate systems per circumferential segment:
N_turn*N_Layer*4=9*12*4=**432**

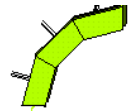


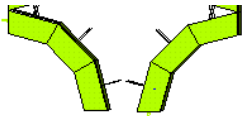
Total number of CSYS required
N_segment*N_turn*N_Layer*4=96*432=**41 472**



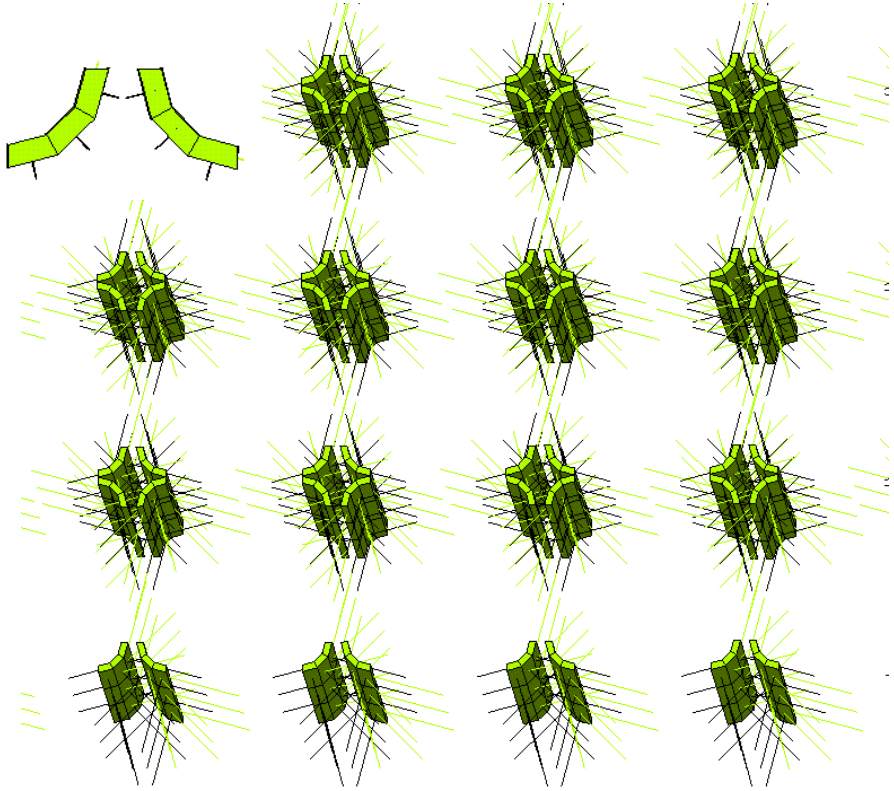
3. Mechanical model (18/21)



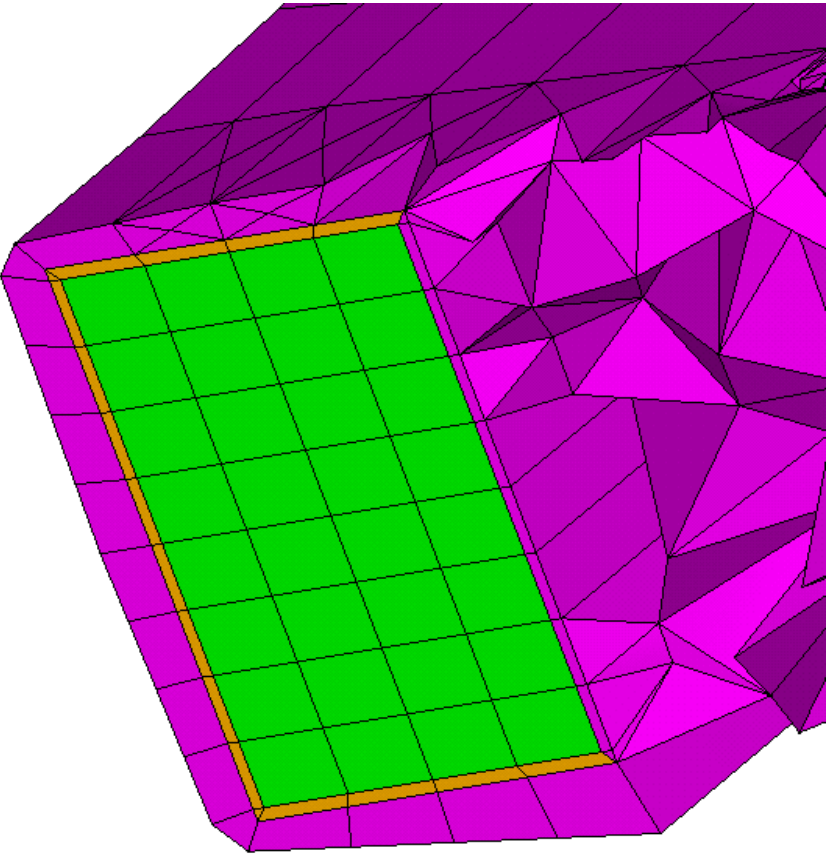


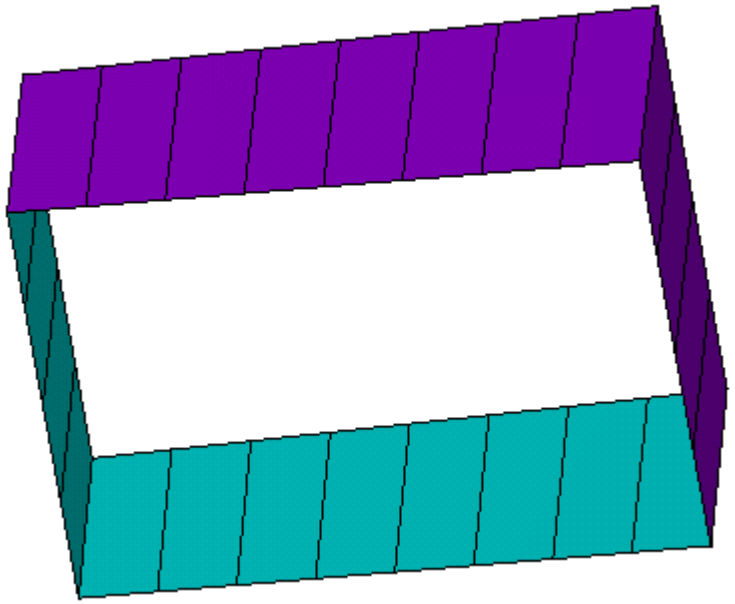




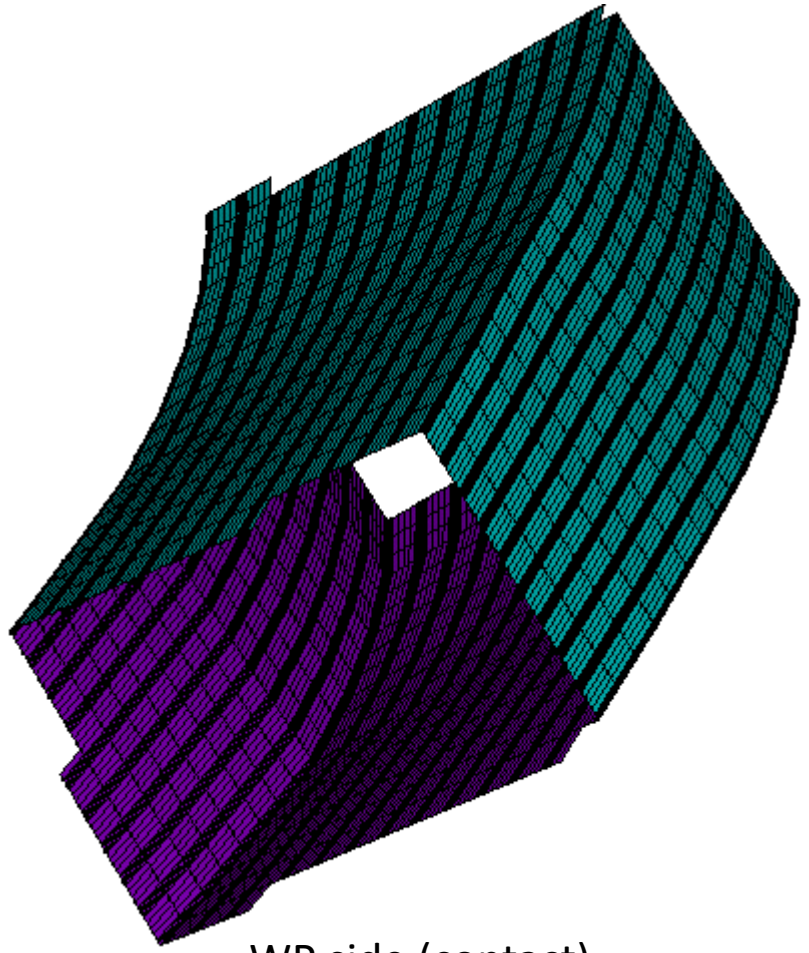


3. Mechanical model (19/21)



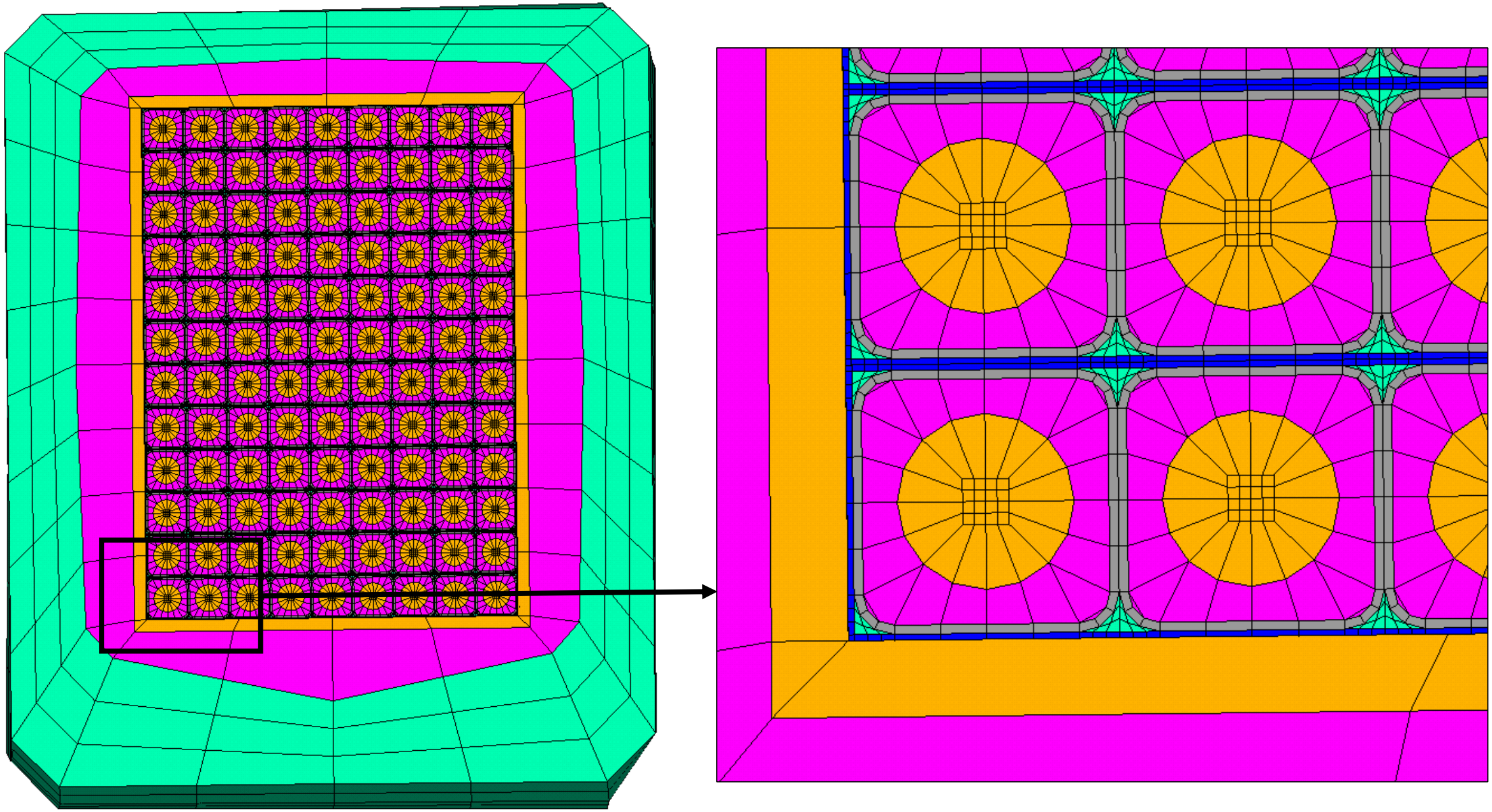


Ground insulation side (target)

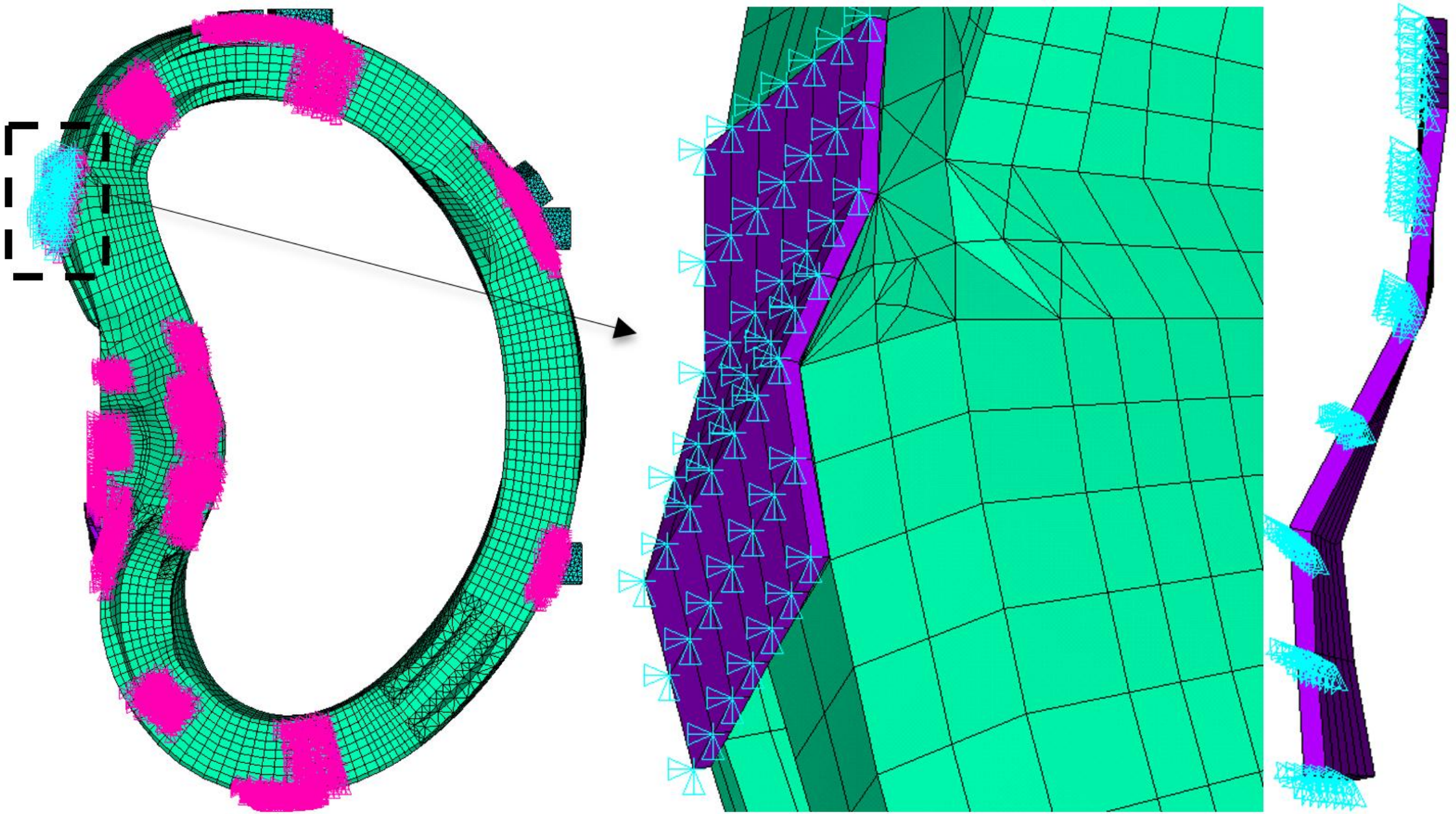


WP side (contact)

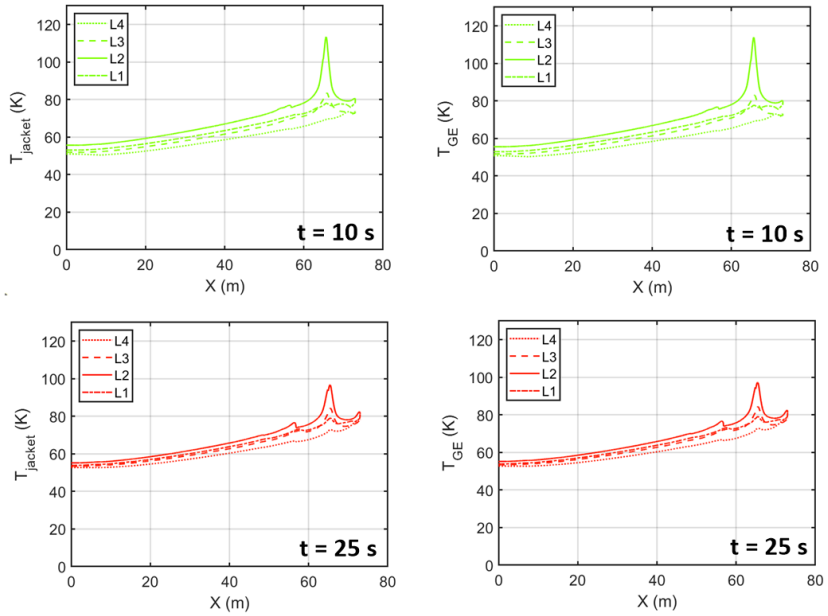
3. Mechanical model (20/21)

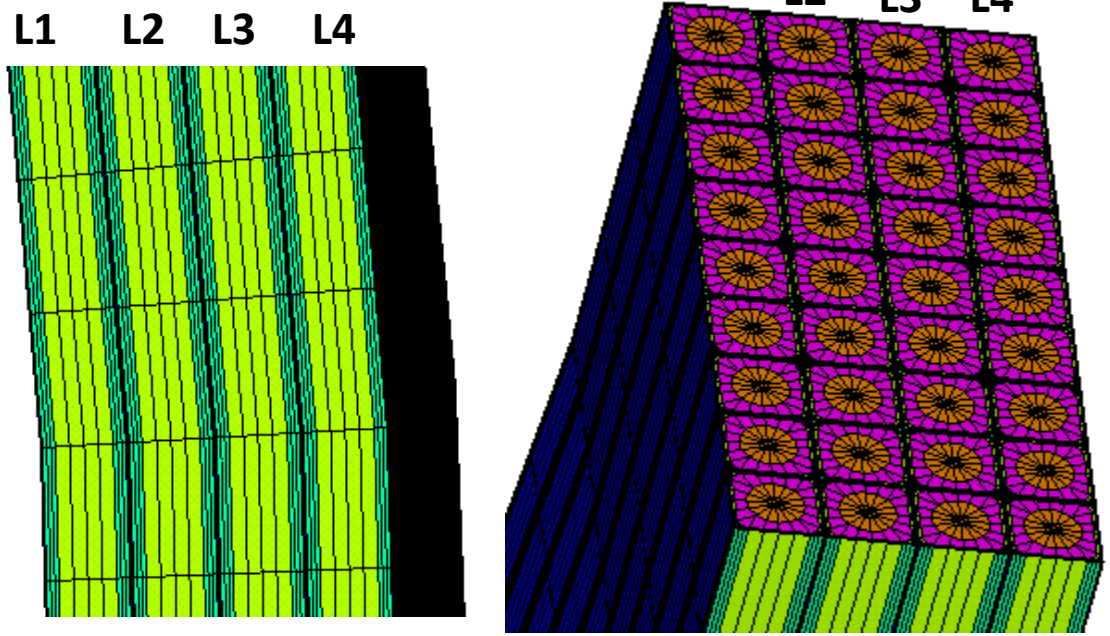


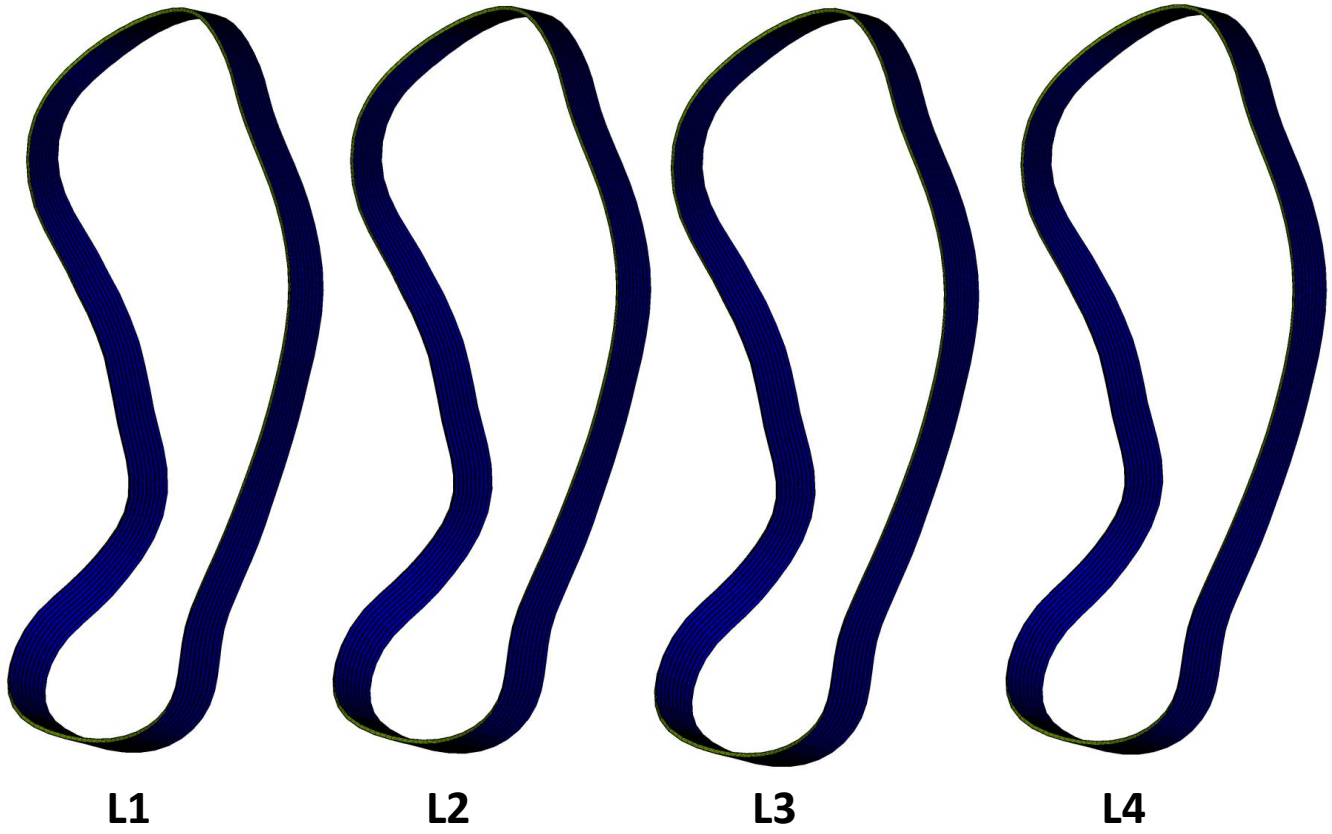
3. Mechanical model (21/21)



4. Importing temperatures from THEA (1/5)

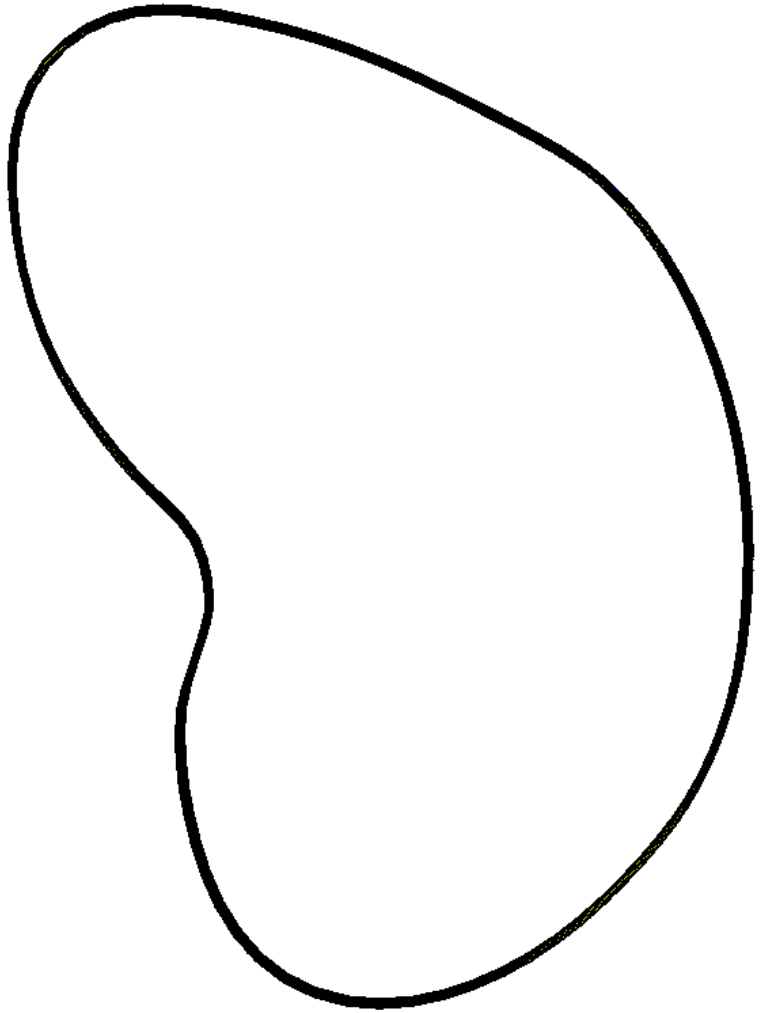


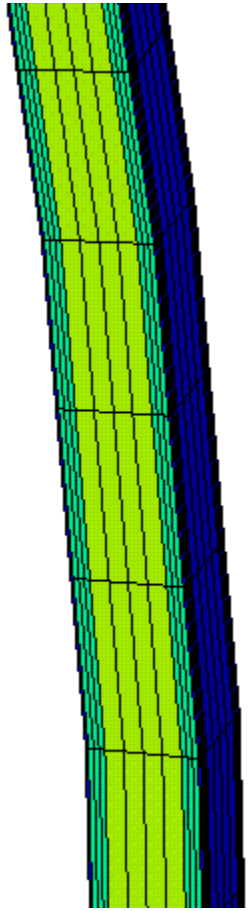


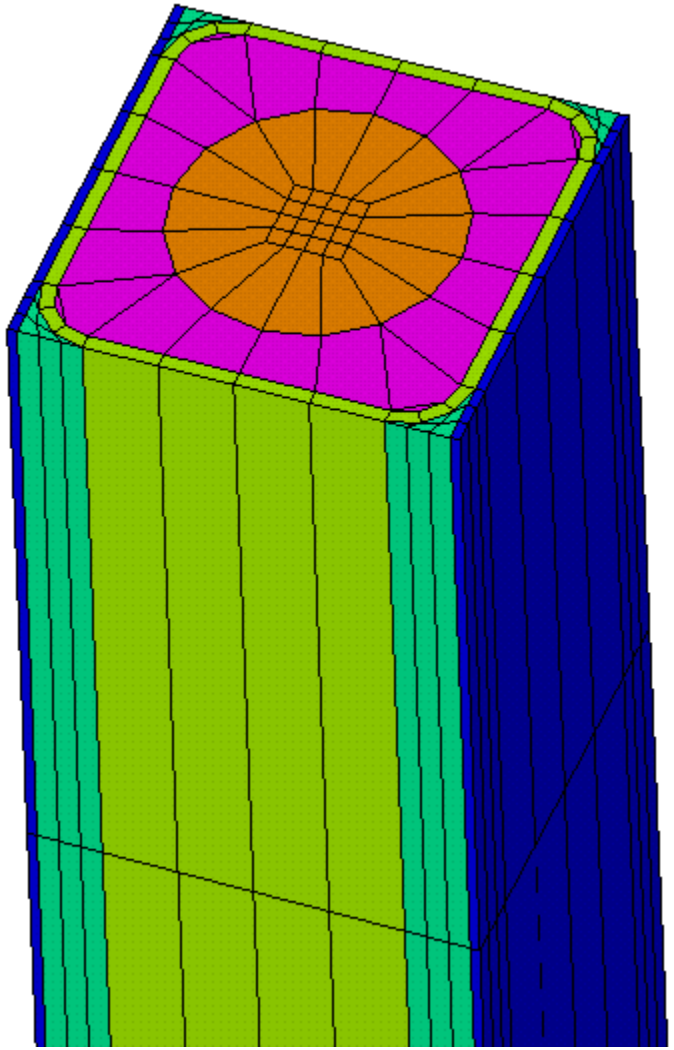


4. Importing temperatures from THEA (2/5)

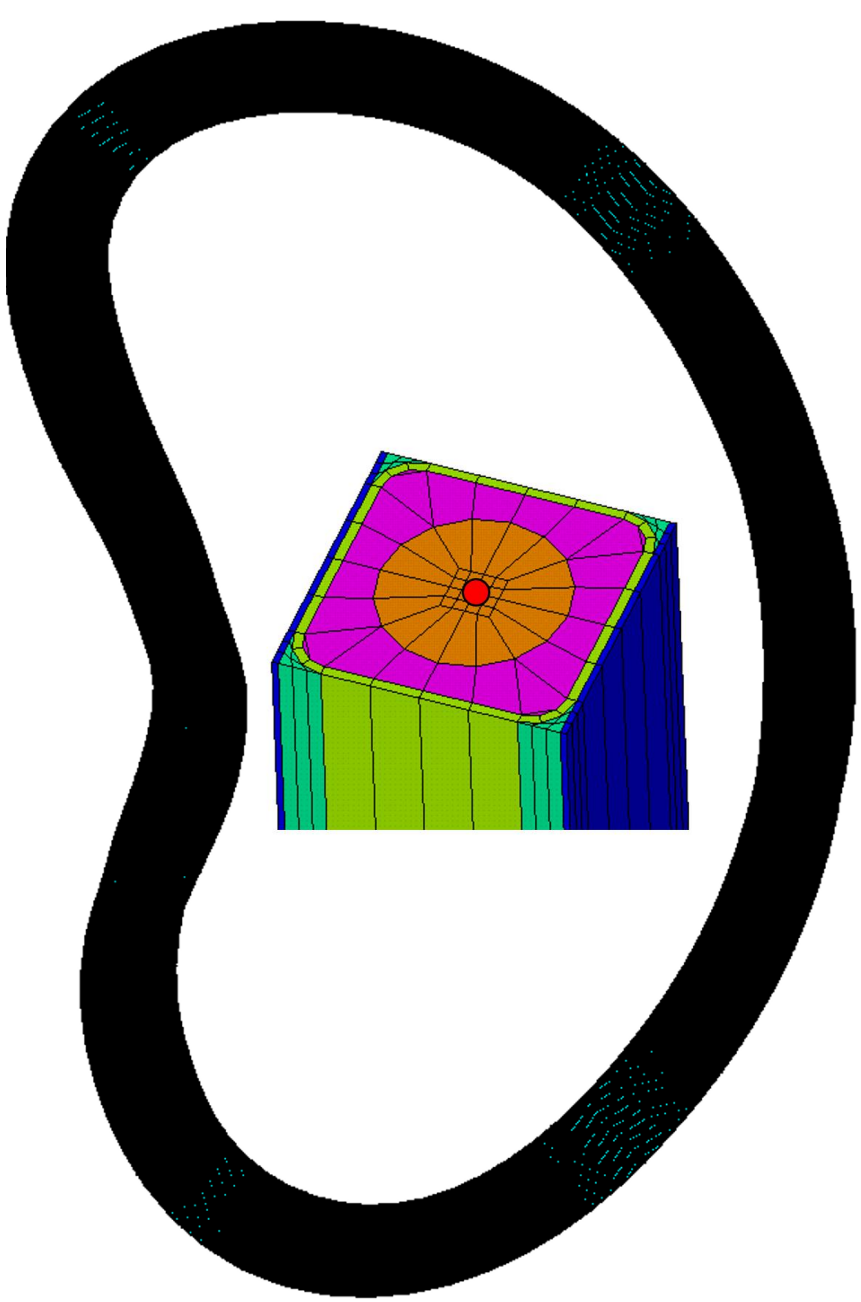
3D representation of the 1D object of THEA

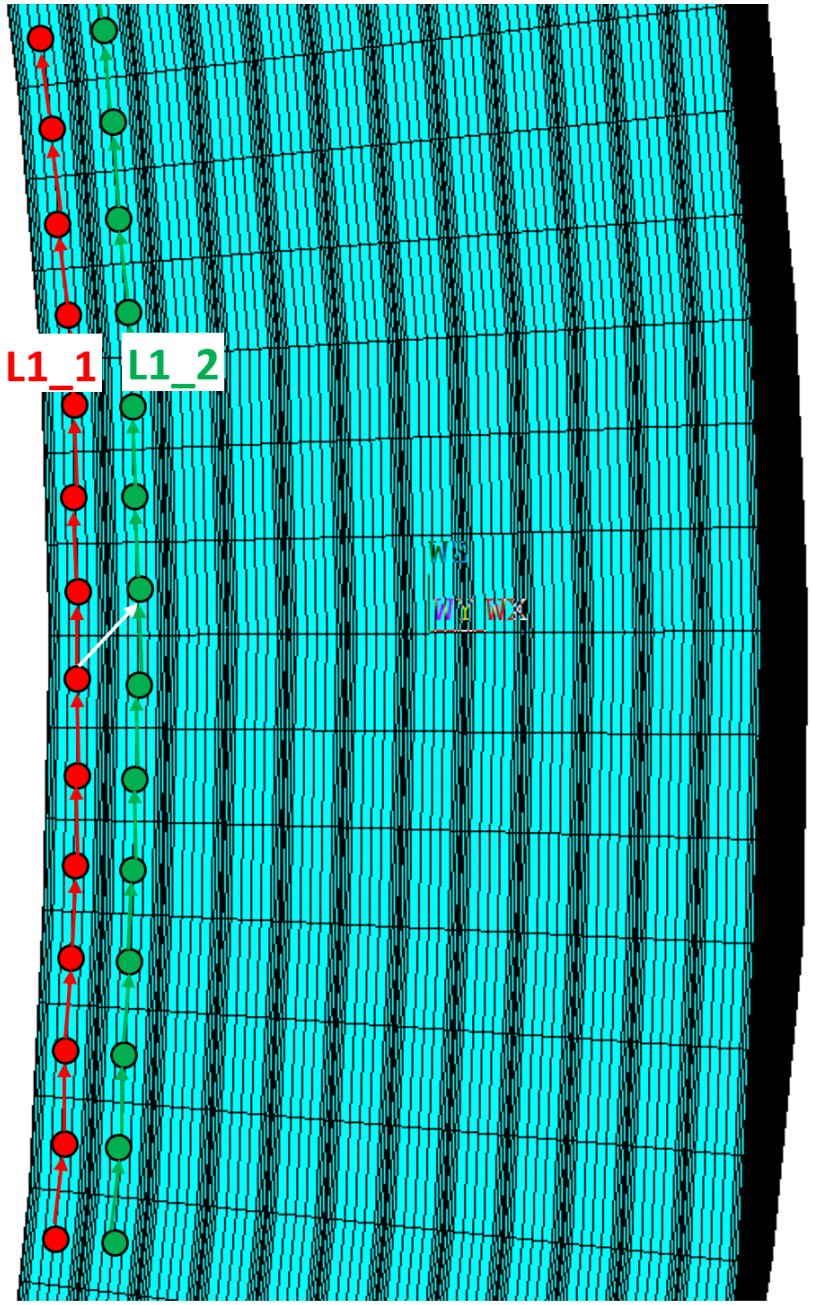




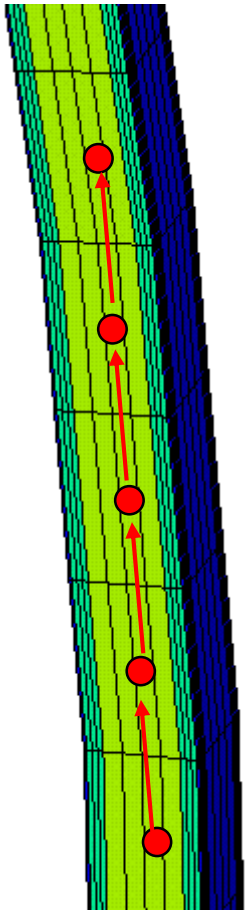


4. Importing temperatures from THEA (3/5)



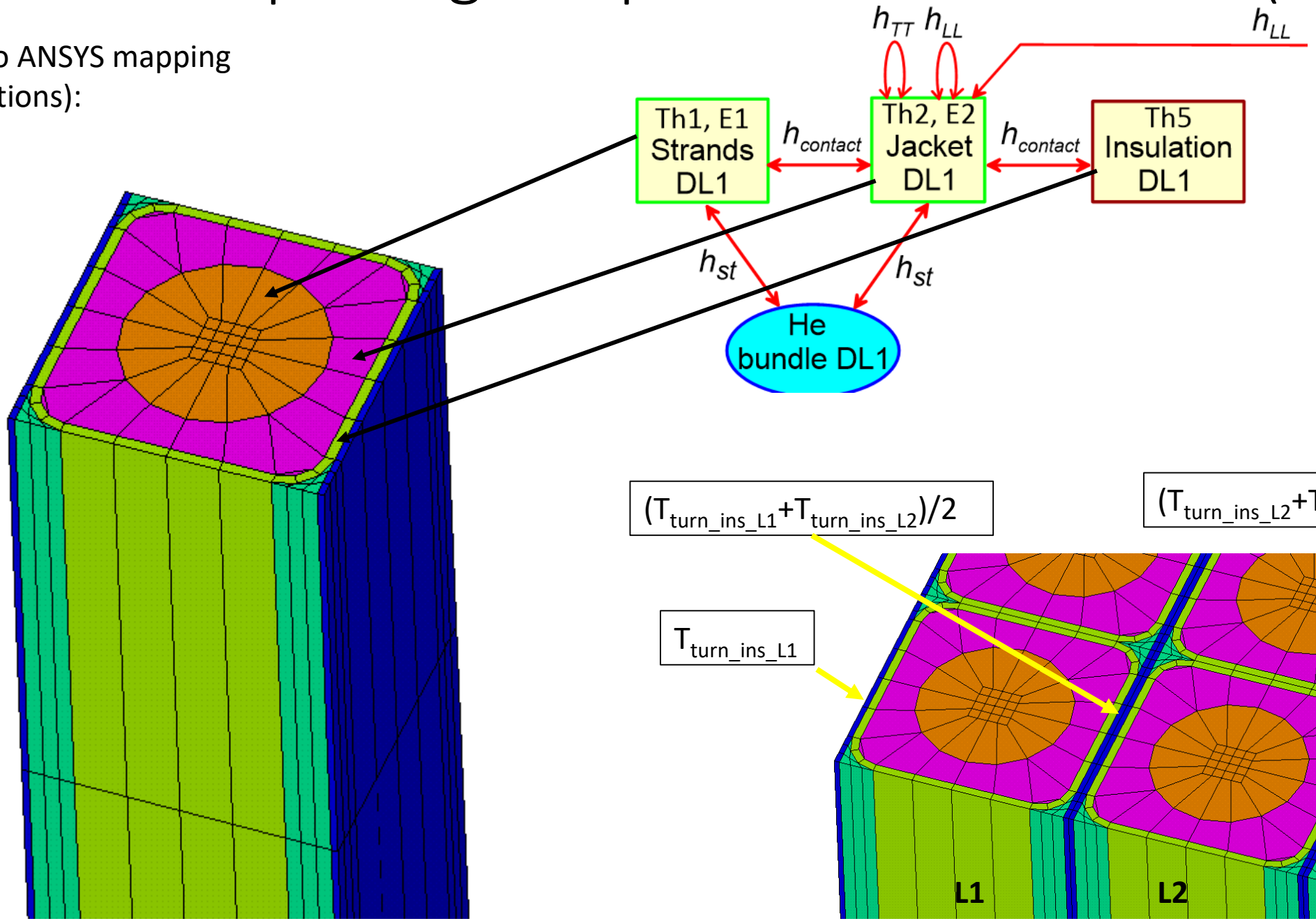


The distance between centers from the x=0 positions the elements on 1D line (as in THEA)



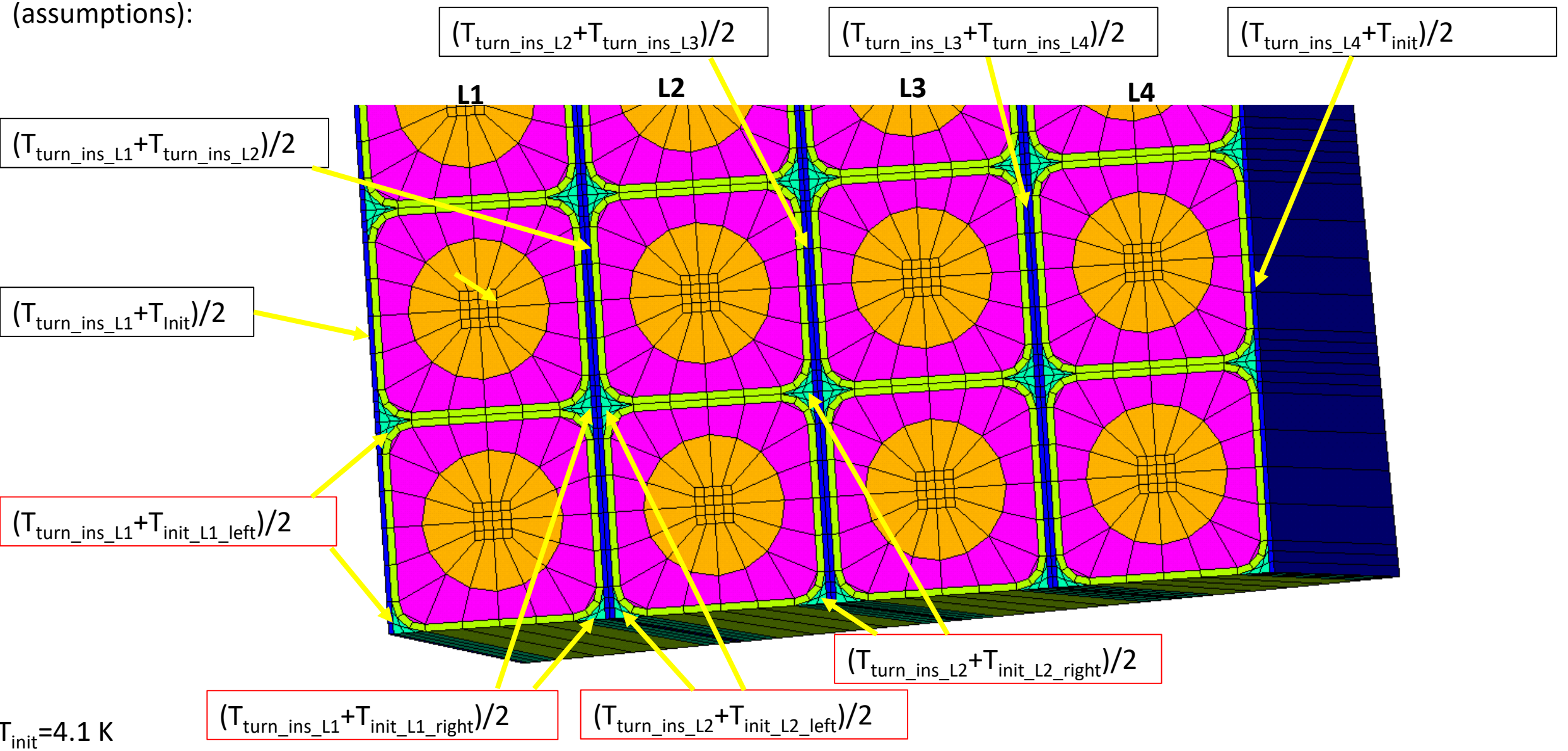
4. Importing temperatures from THEA (4/5)

THEA->to ANSYS mapping (assumptions):



4. Importing temperatures from THEA (5/5)

THEA->to ANSYS mapping (assumptions):



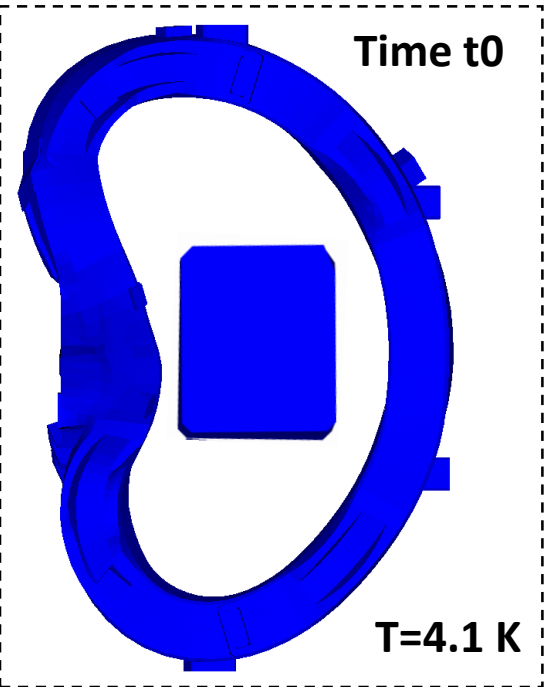
T_{init}=4.1 K

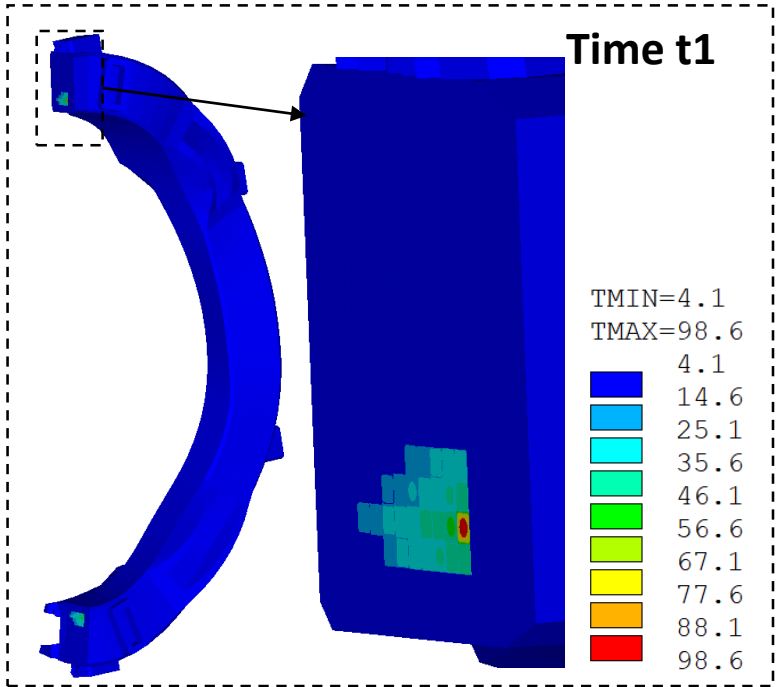
5. Solution and results (3D mechanical + 1D) (1/14)

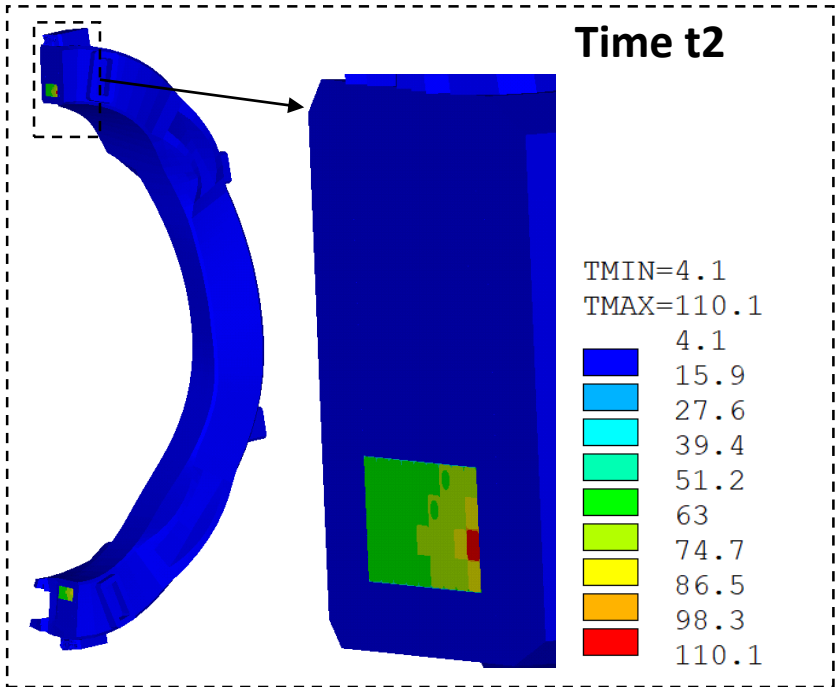
Load steps:

1) Uniform temperature of 4.1 K (cool-down) (t0)
2) Application of temperature from THEA at time moment 1 (t1)
3) Application of temperature from THEA at time moment 2 (t2)
4) Application of temperature from THEA at time moment 3 (t3)
5) Application of temperature from THEA at time moment 4 (t4)
6) .
7) .
8) .
9) Application of temperature from THEA at time moment n (tn)

	t_1 [s]	t_2 [s]	t_3 [s]	t_4 [s]	t_5 [s]	t_6 [s]	t_7 [s]	t_8 [s]	t_9 [s]
Thea time (physical)	0.1	0.5	1	2	5	8	10	20	25
Ansys time (load step)	1	2	3	4	5	6	7	8	9

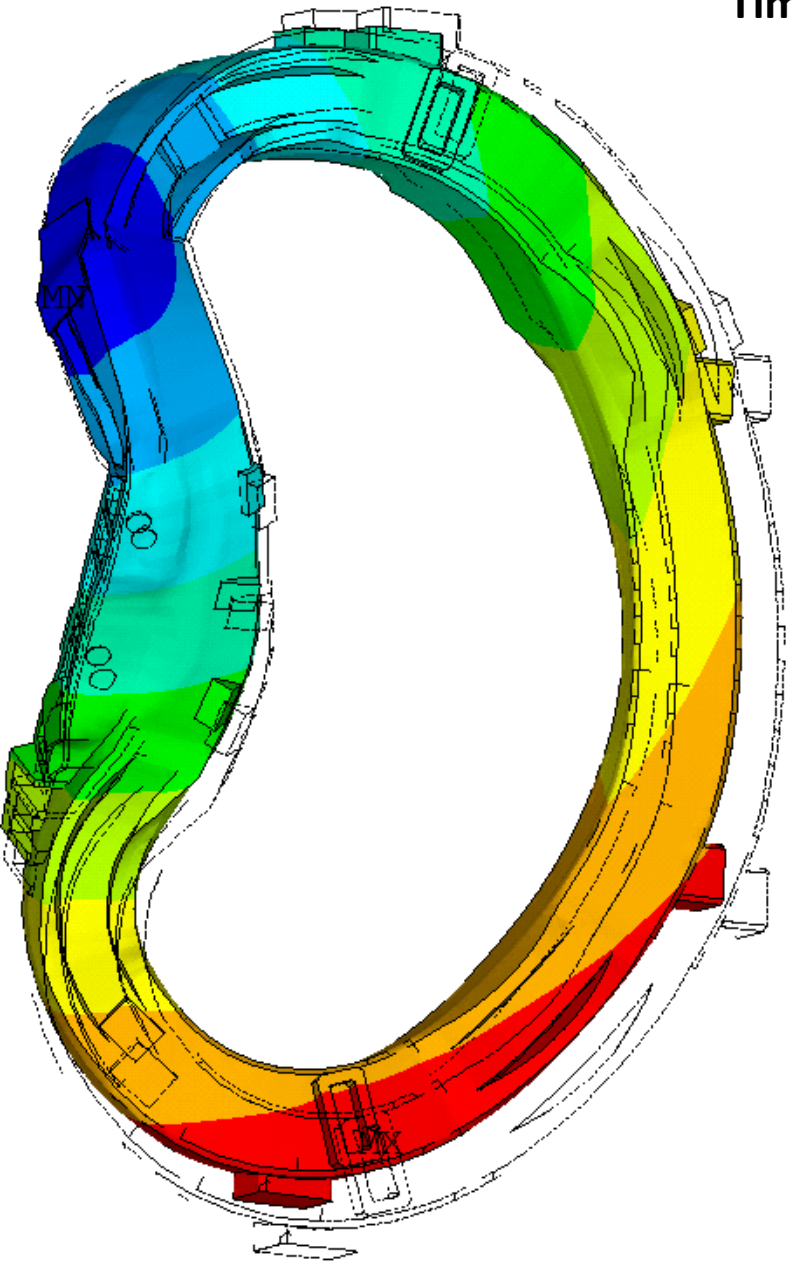


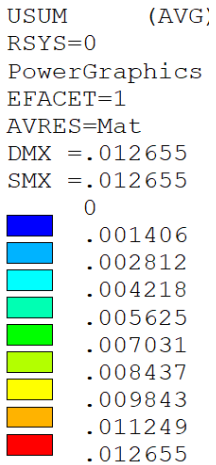


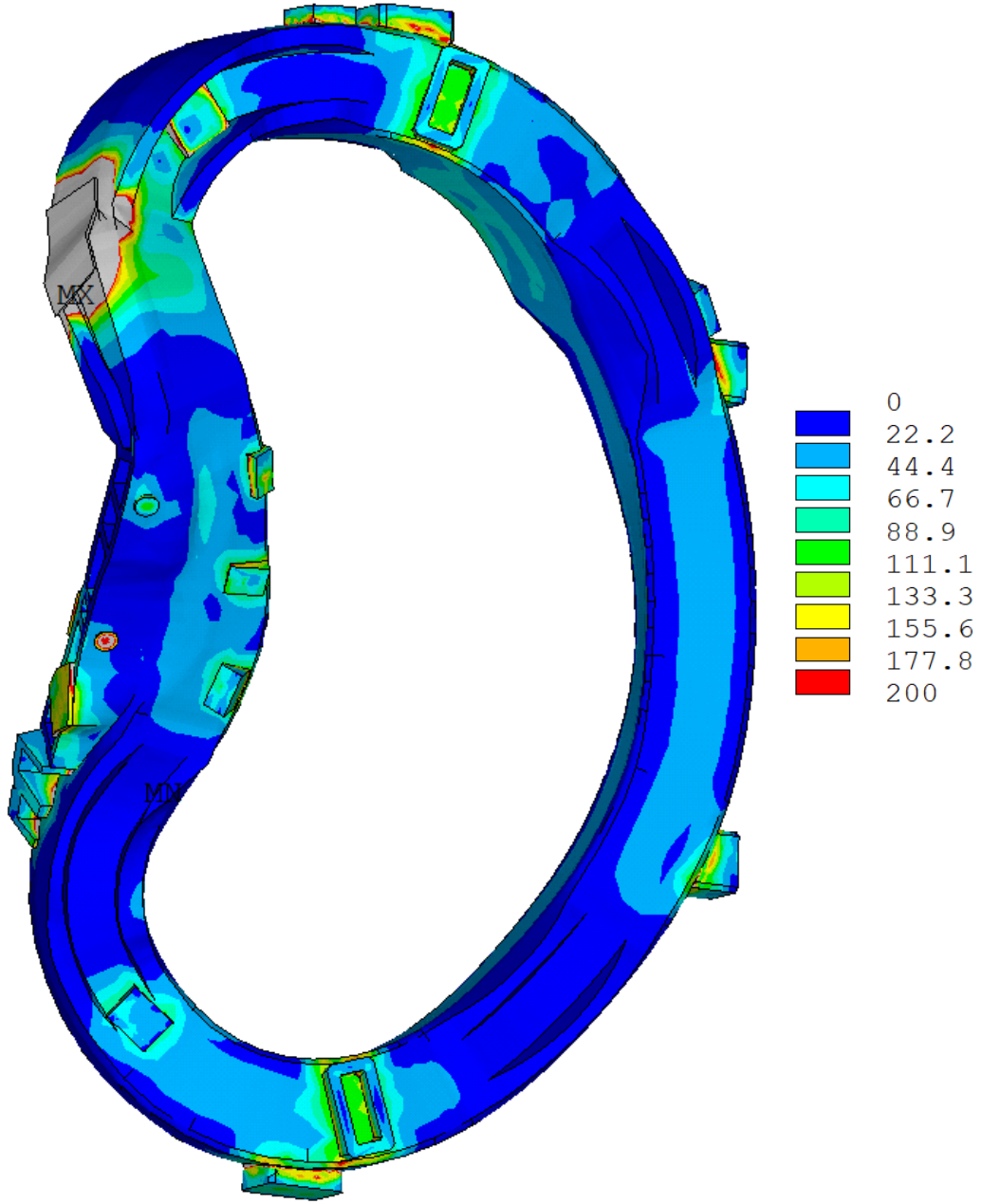


5. Solution and results (3D mechanical + 1D) (2/14)

Time t0 (after cool-down)

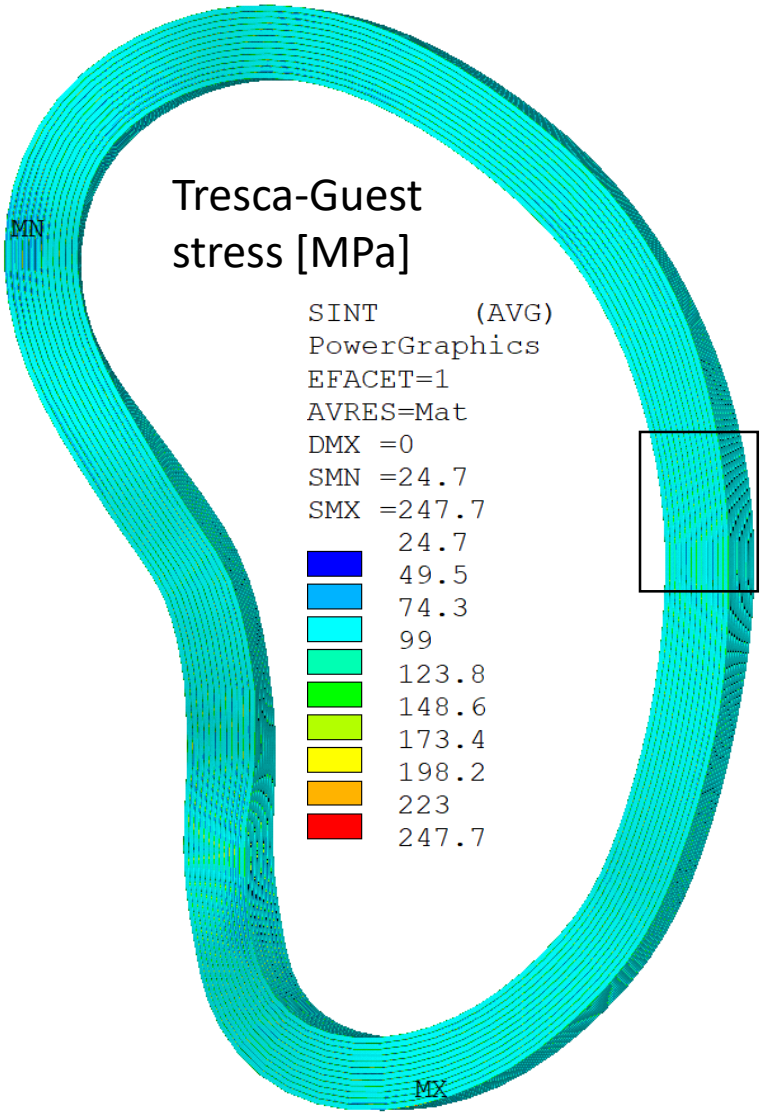


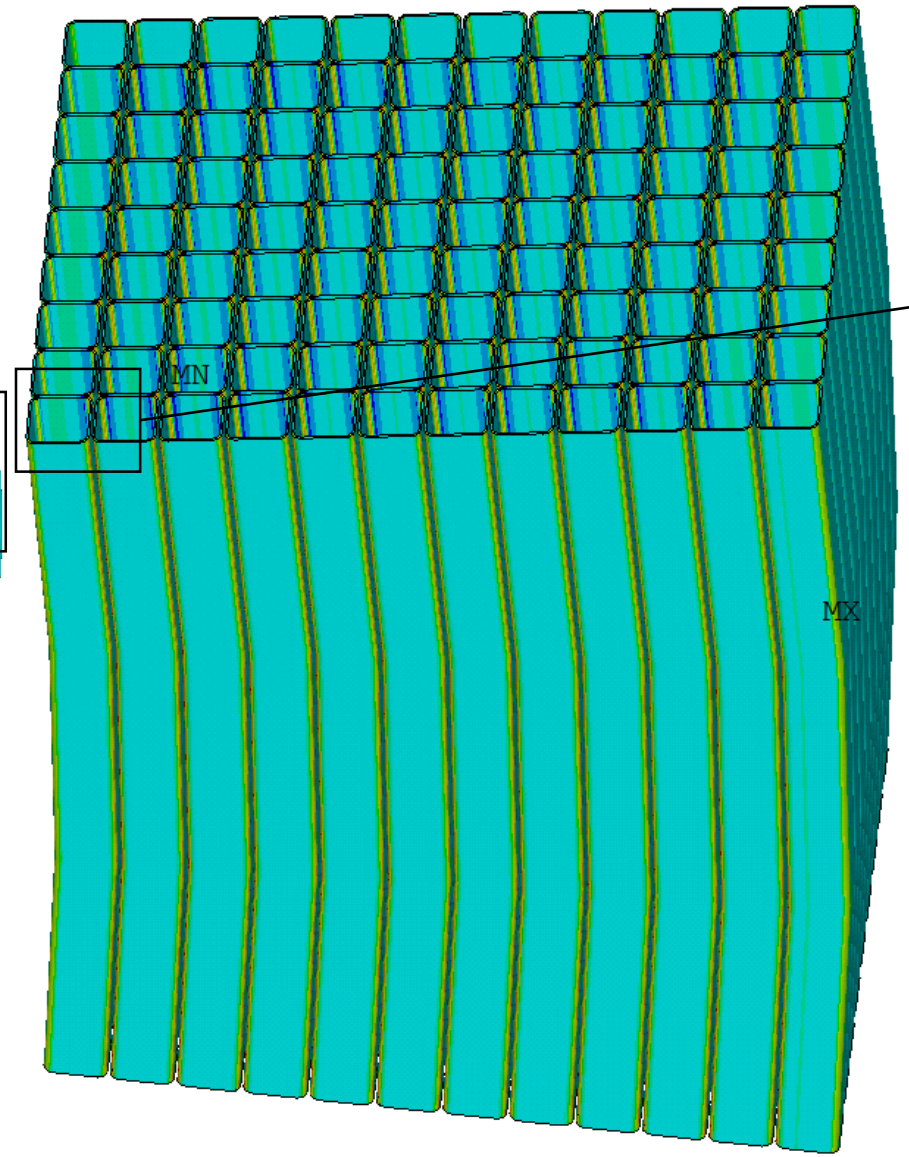


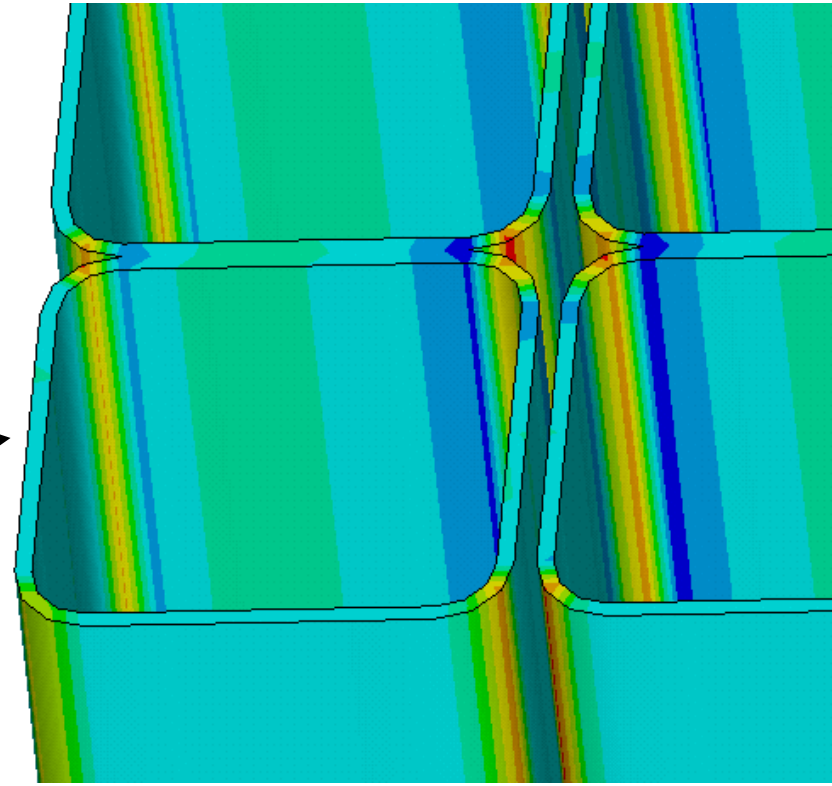


5. Solution and results (3D mechanical + 1D) (3/14)

Time t0 (after cool-down)







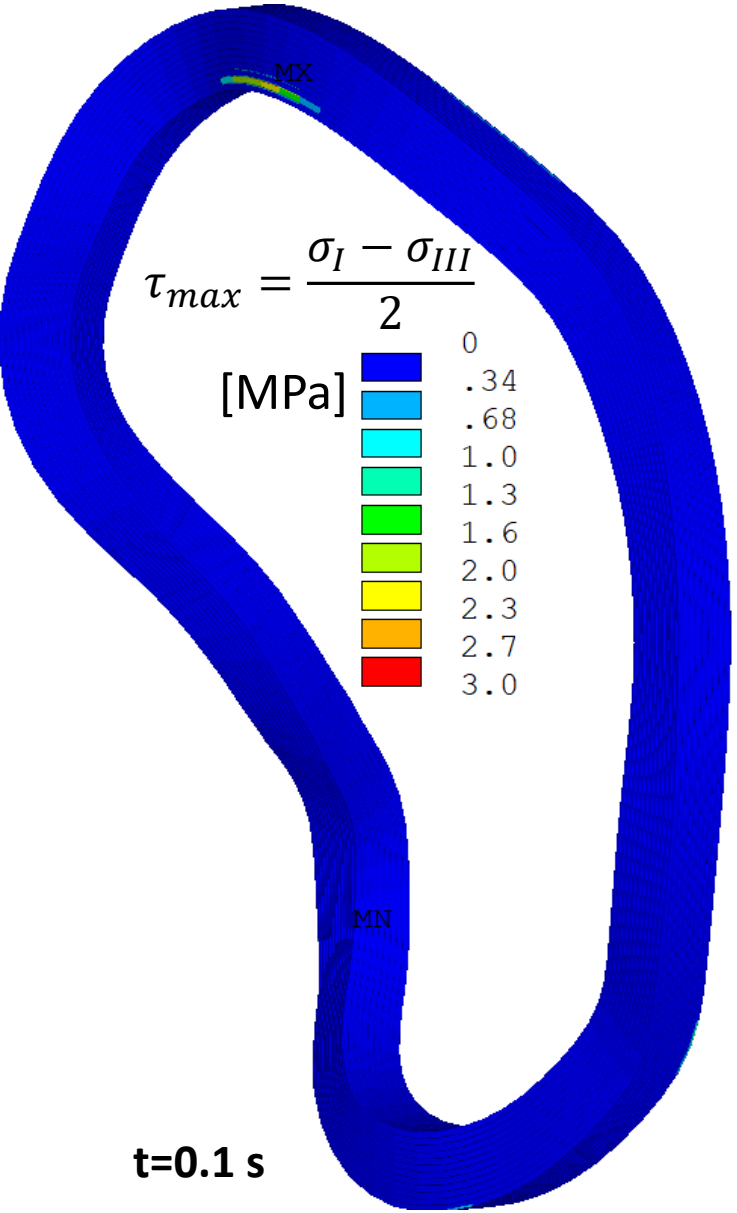
Tresca-Guest
stress [MPa]

43.2
57.6
72
86.3
100.7
115.1
129.5
143.9
158.3
172.7

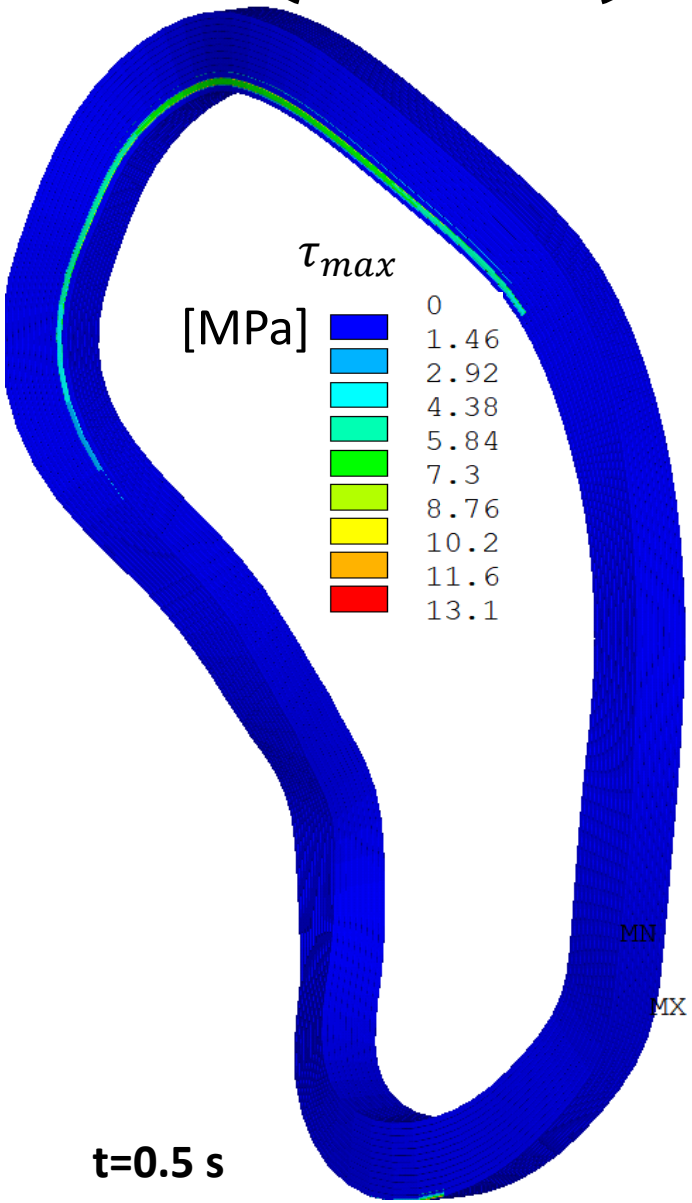
ECS=1

5. Solution and results (3D mechanical + 1D) (4/14)

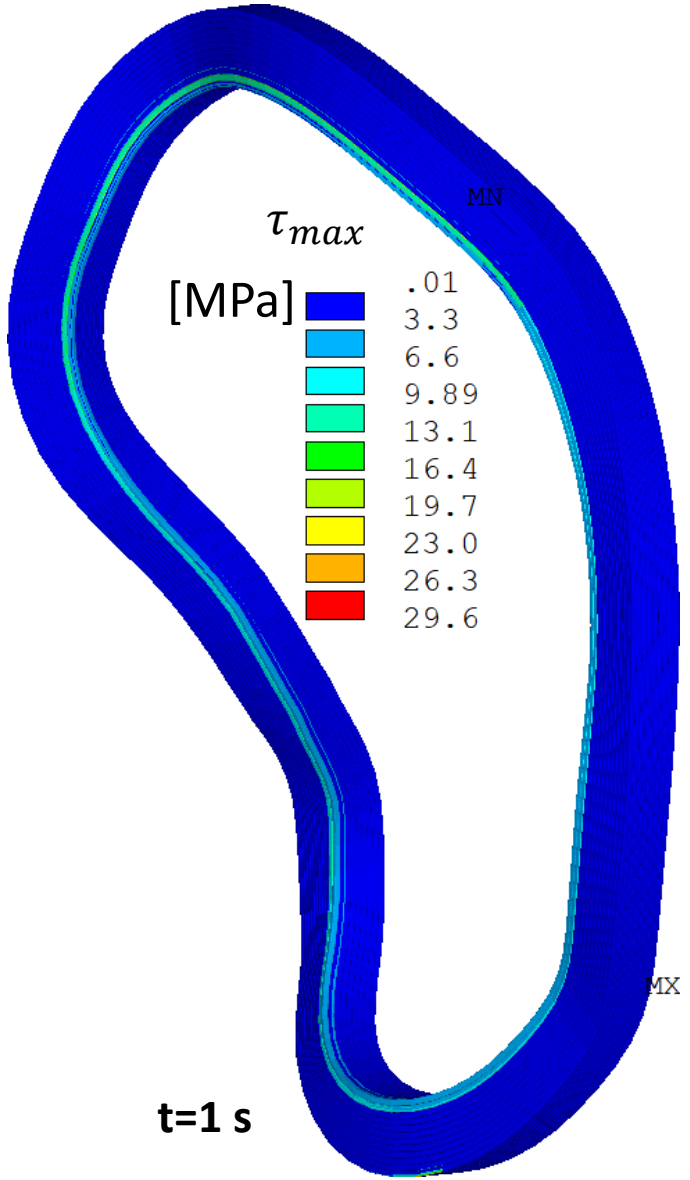
$$\Delta Stress = Results(time_i) - Results(t0)$$



t=0.1 s



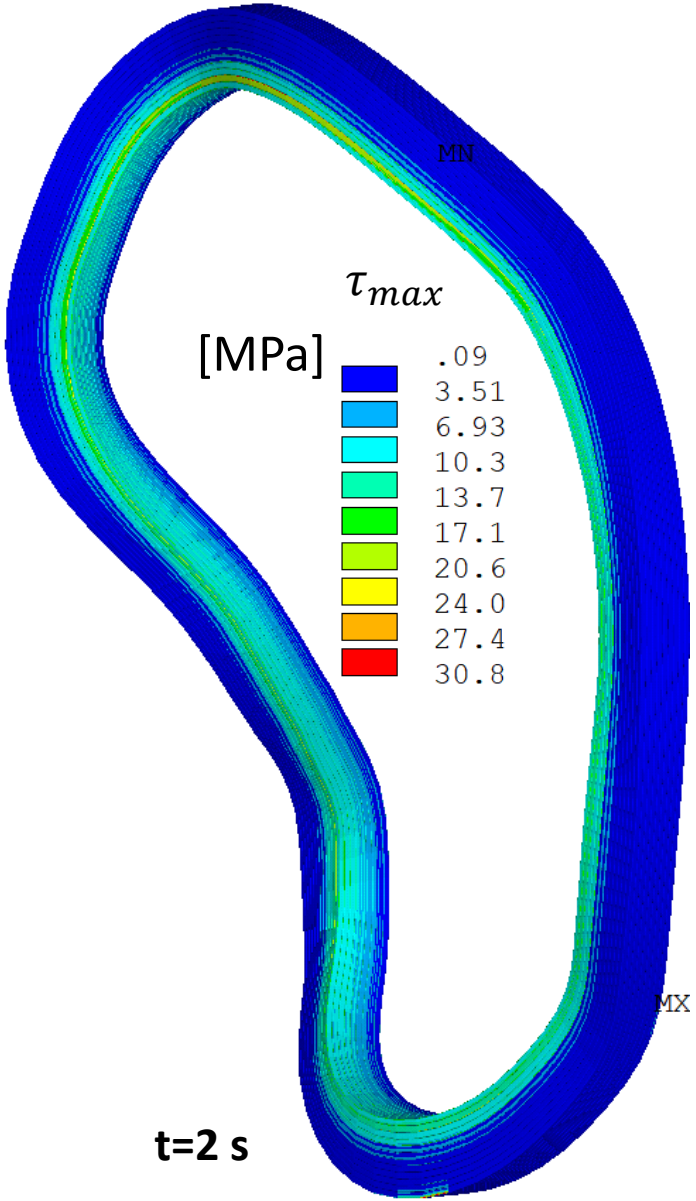
t=0.5 s



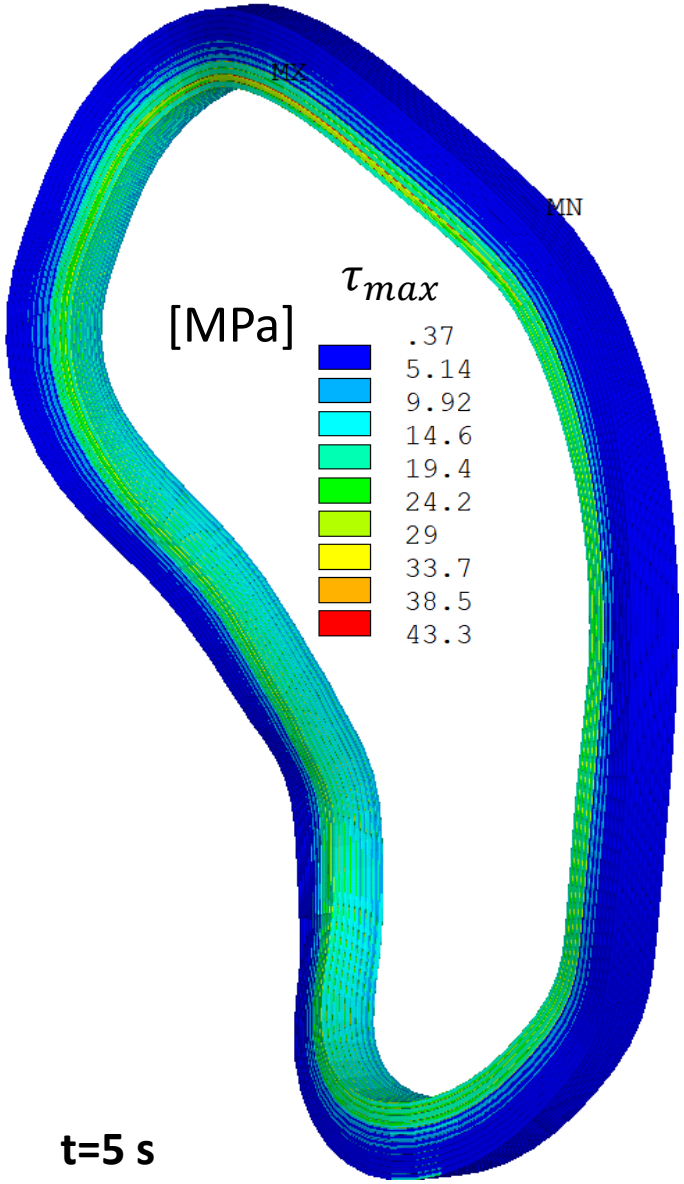
t=1 s

5. Solution and results (3D mechanical + 1D) (5/14)

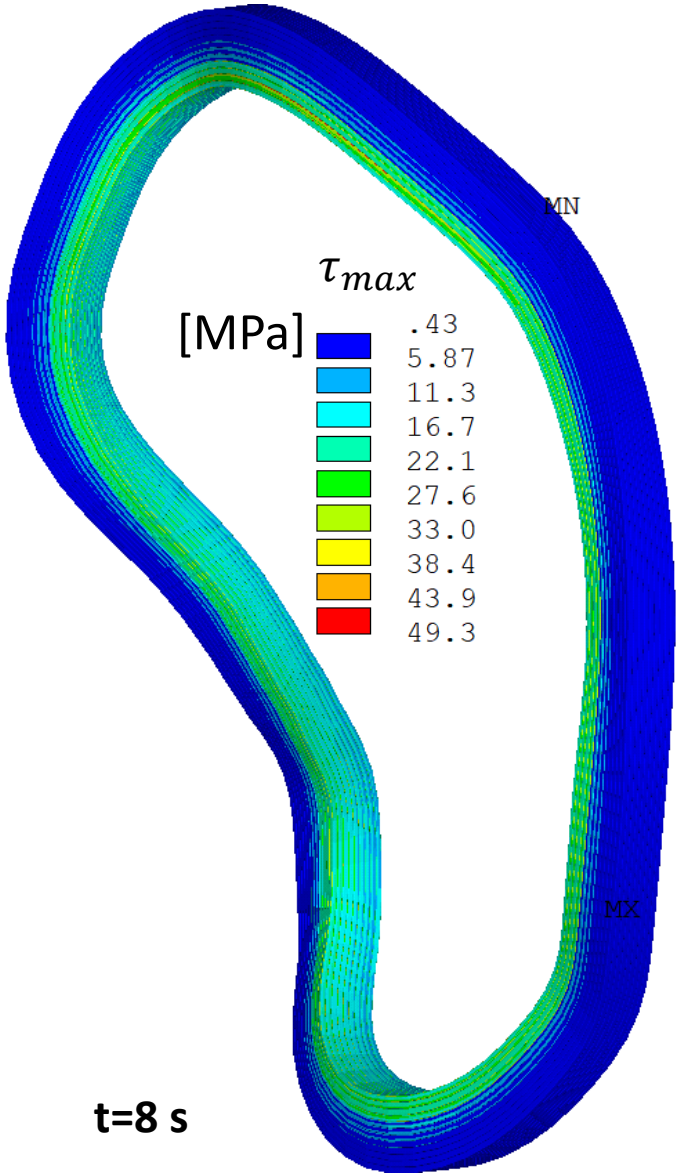
$$\Delta Stress = Results(time_i) - Results(t0)$$



t=2 s

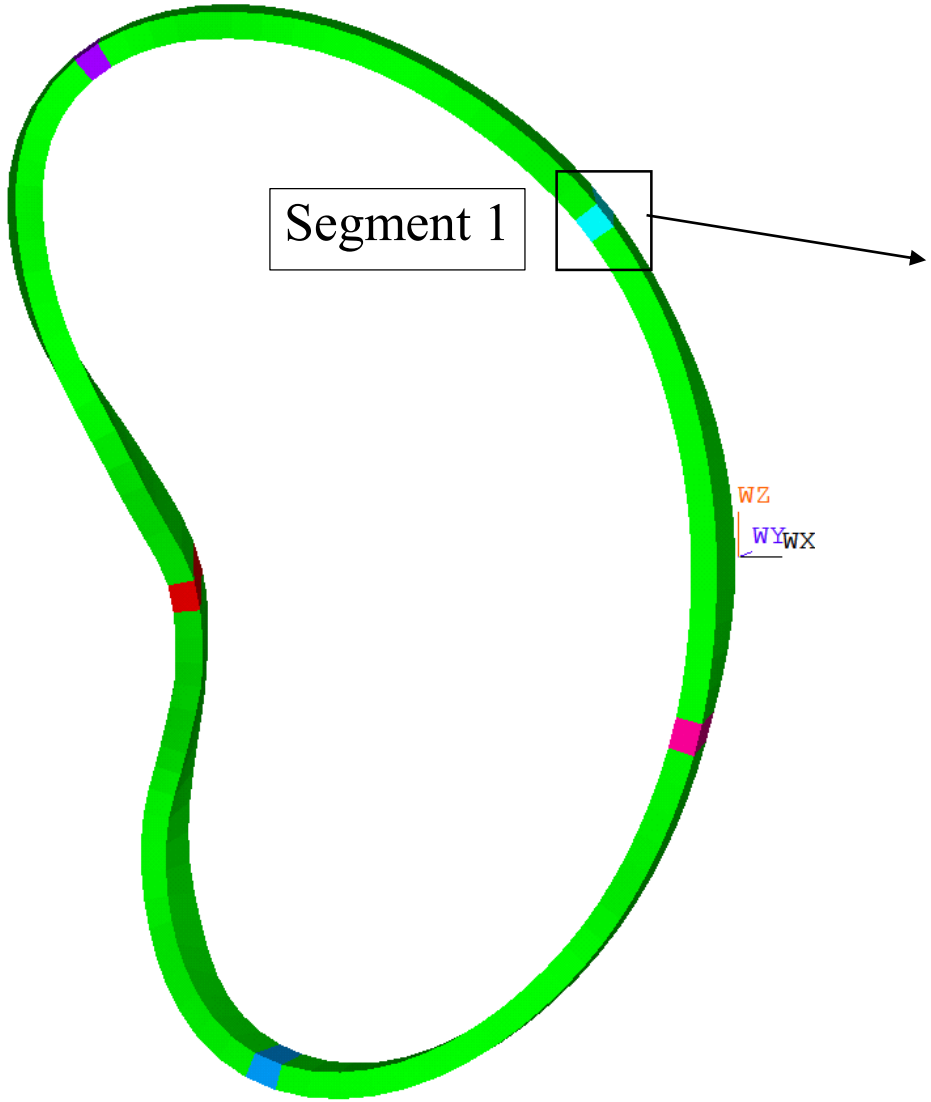


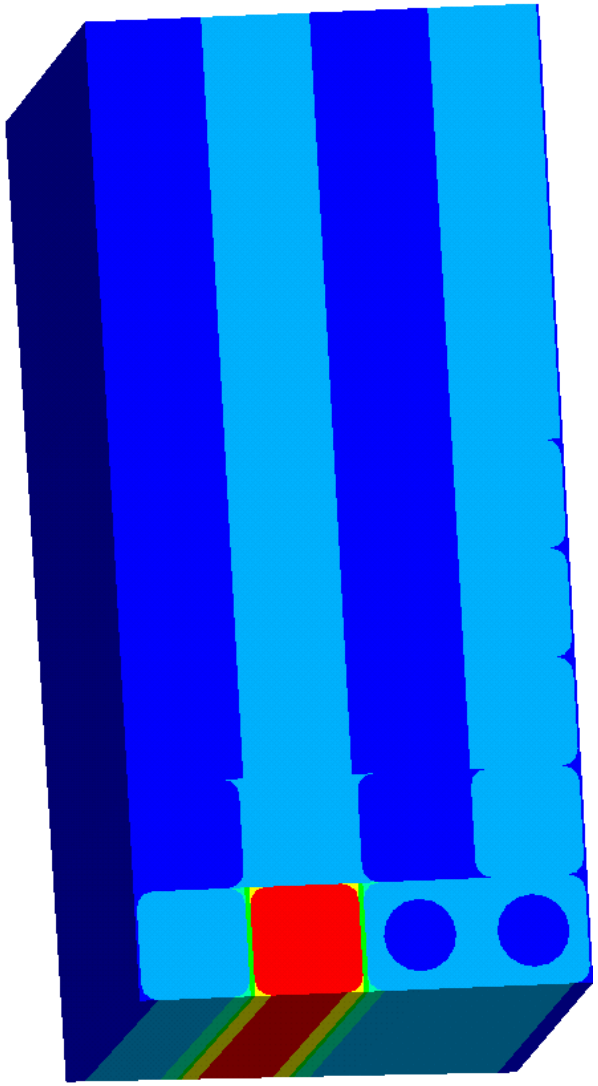
t=5 s

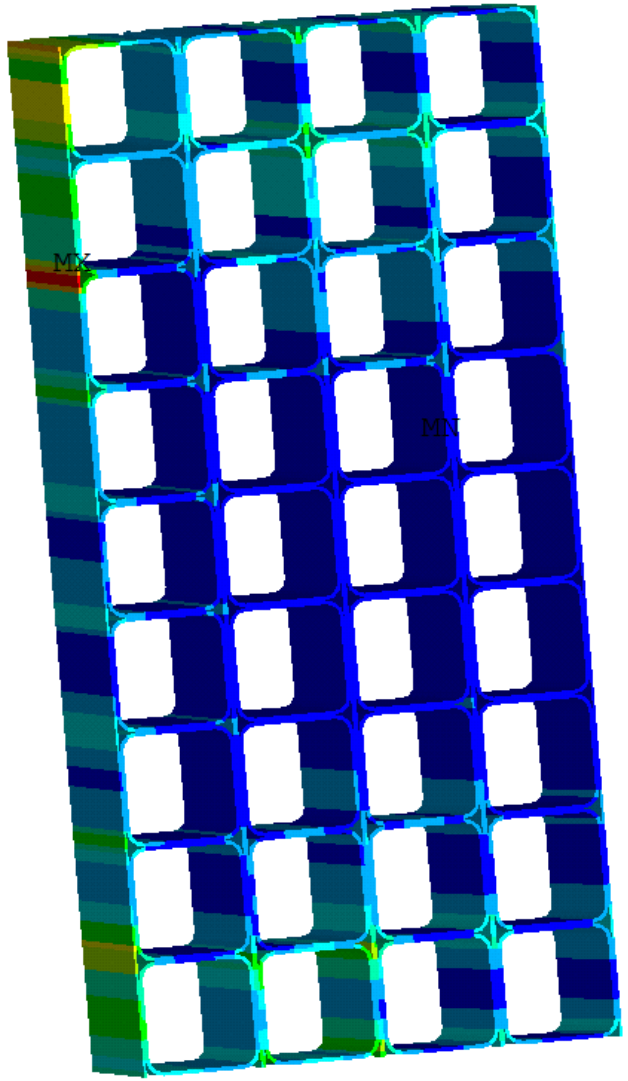


t=8 s

5. Solution and results (3D mechanical + 1D) (6/14)



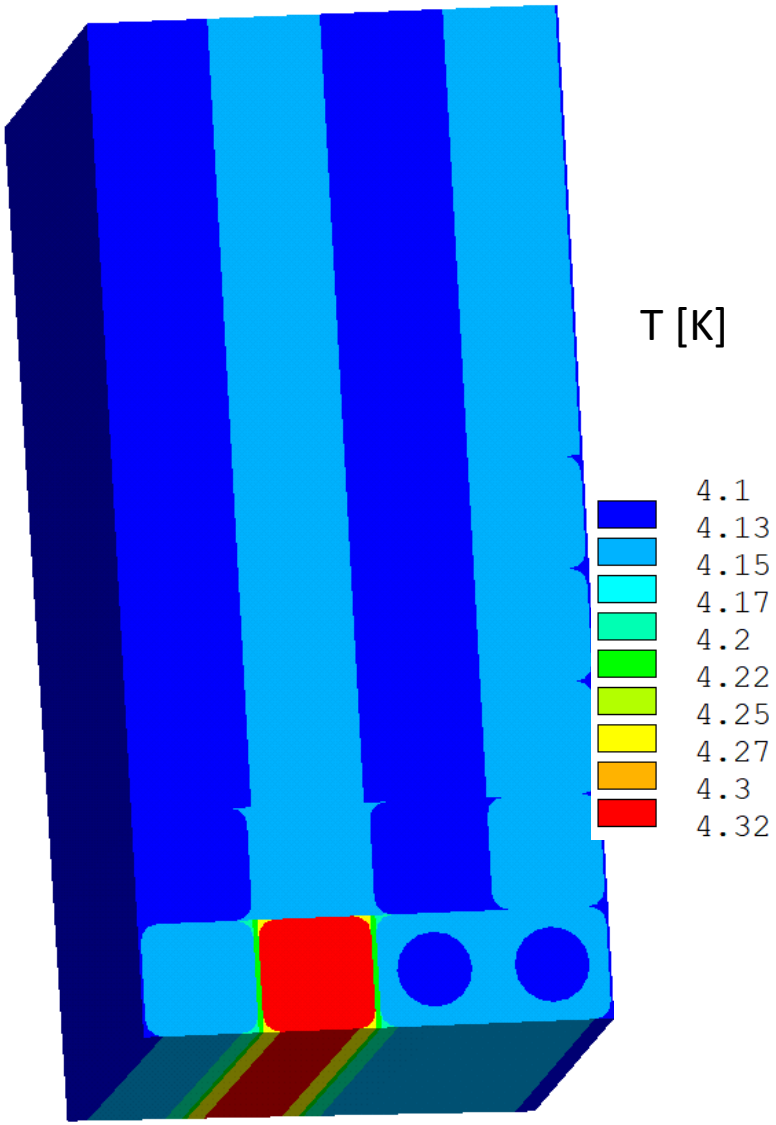




5. Solution and results (3D mechanical + 1D) (7/14)

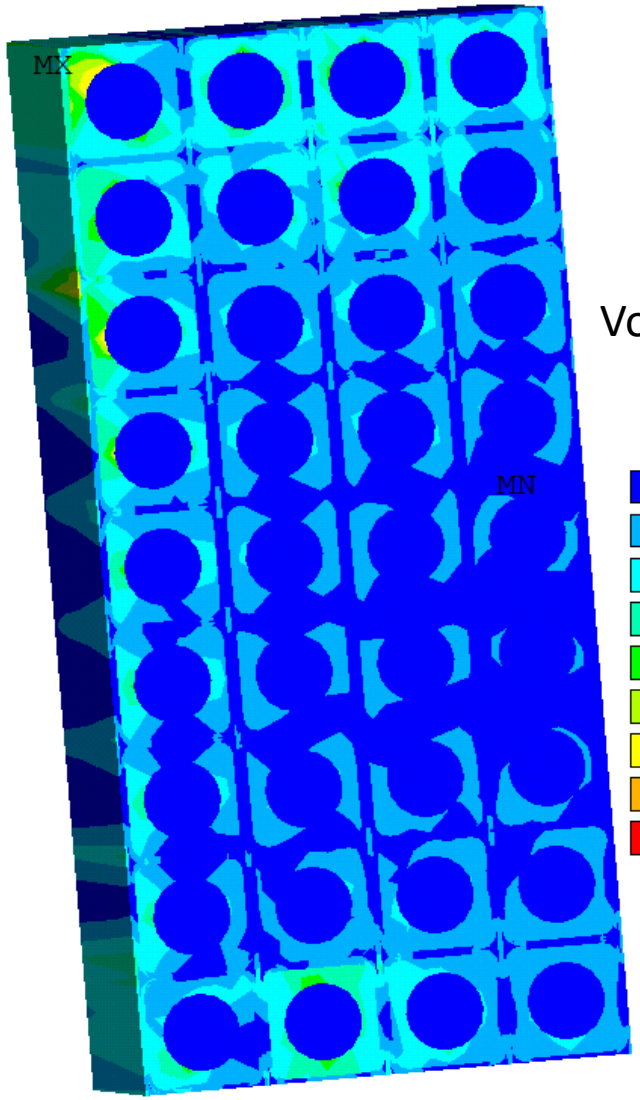
t=0.1 s

$$\Delta Stress = Results(time_i) - Results(t0)$$



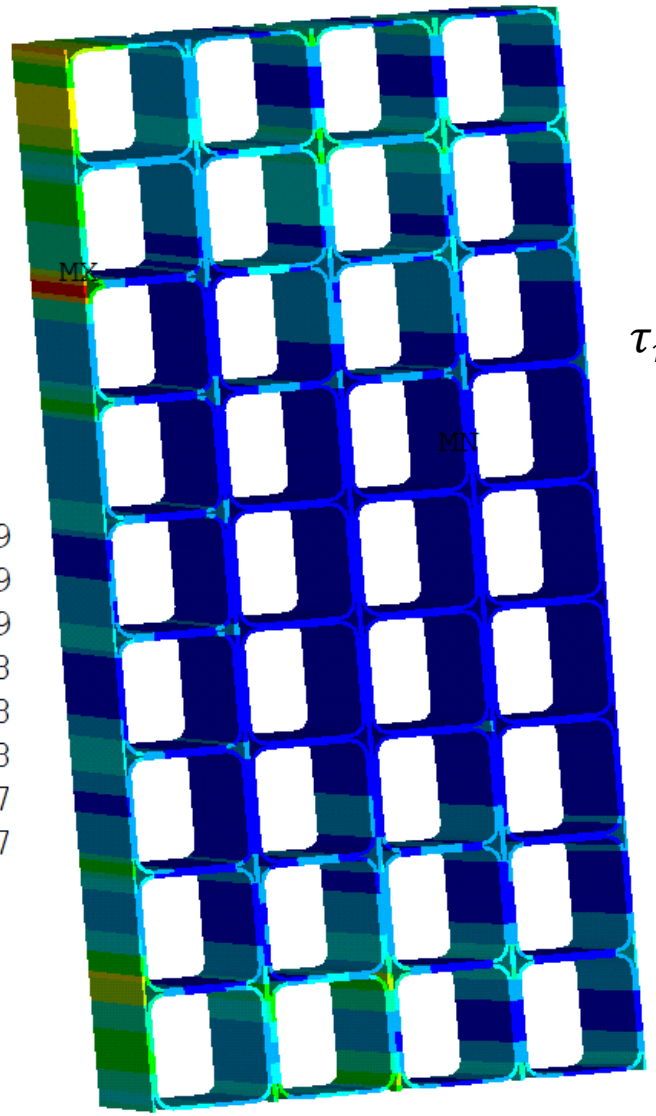
T [K]

4.1
4.13
4.15
4.17
4.2
4.22
4.25
4.27
4.3
4.32



Von Mises [MPa]

0
.1
.19
.29
.39
.48
.58
.68
.77
.87



$$\tau_{max} = \frac{\sigma_I - \sigma_{III}}{2}$$

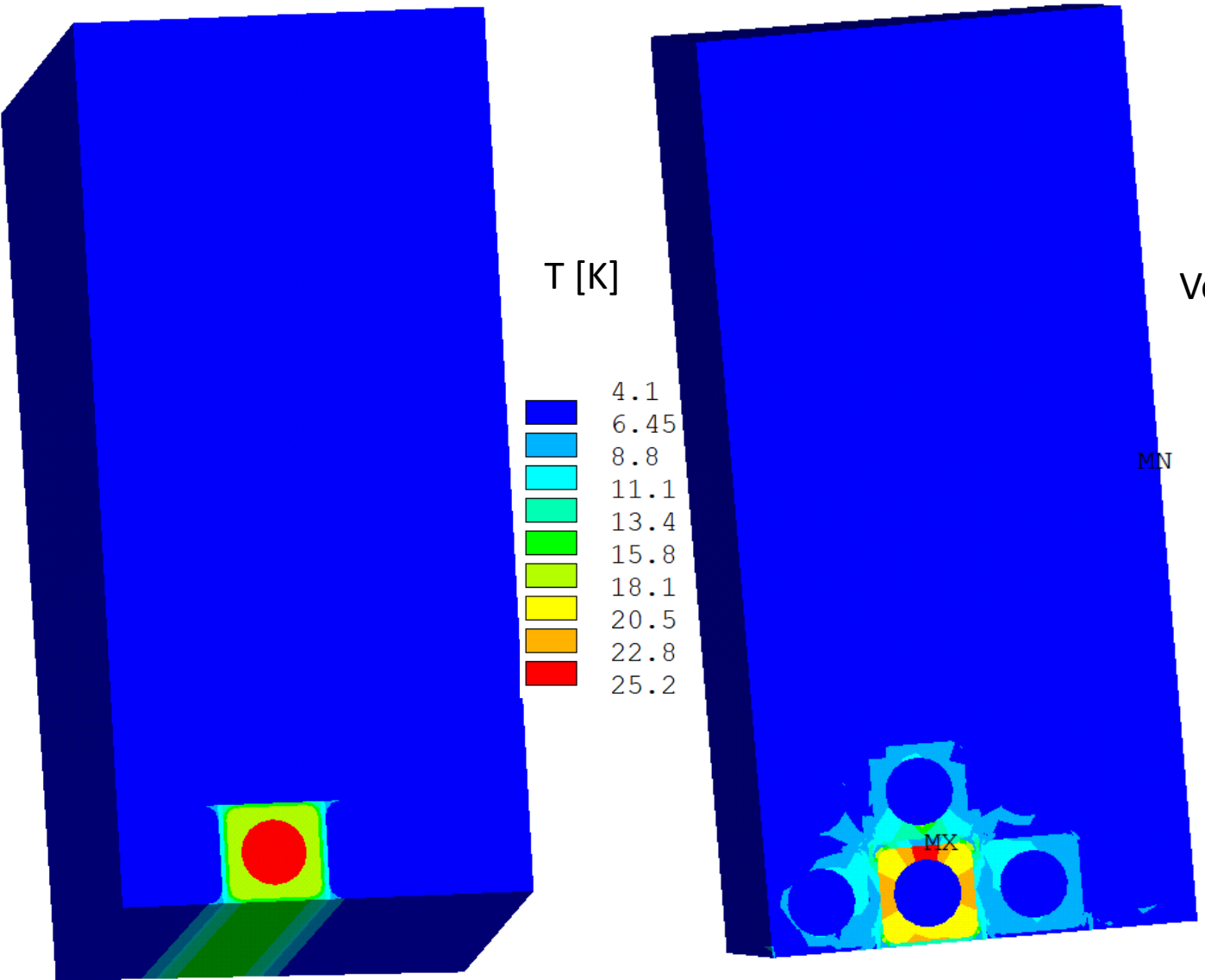
[MPa]

.01
.04
.07
.09
.12
.15
.18
.2
.23
.26

5. Solution and results (3D mechanical + 1D) (8/14)

t=0.5 s

$$\Delta Stress = Results(time_i) - Results(t0)$$

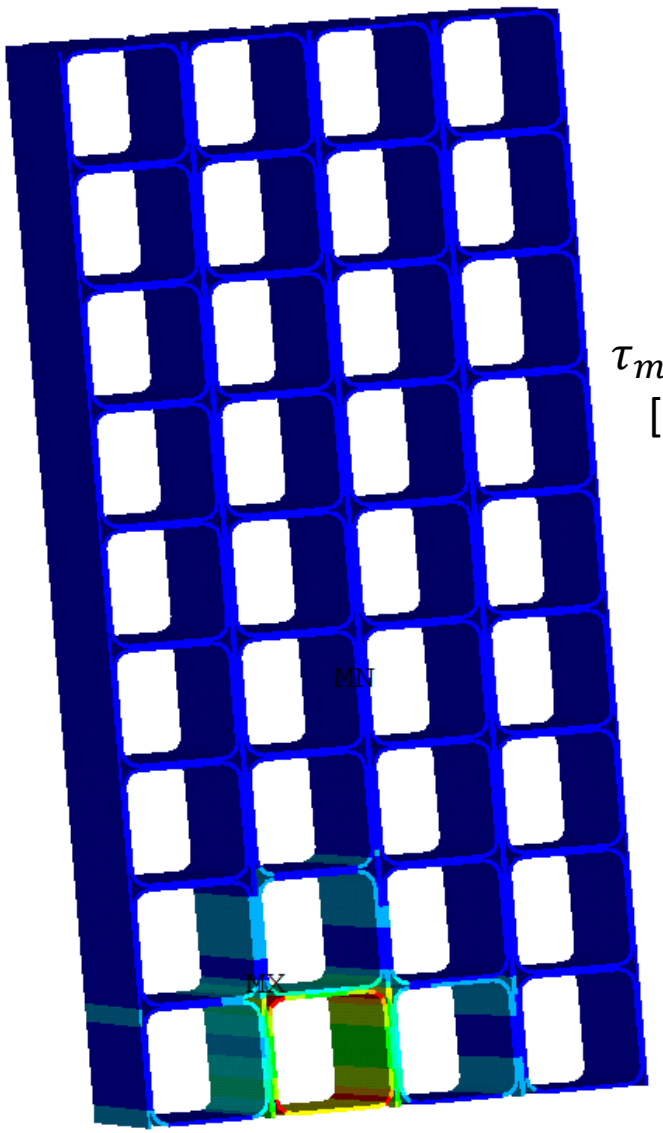


T [K]

4.1
6.45
8.8
11.1
13.4
15.8
18.1
20.5
22.8
25.2

Von Mises [MPa]

0
2.44
4.88
7.32
9.76
12.2
14.6
17.0
19.5
21.9



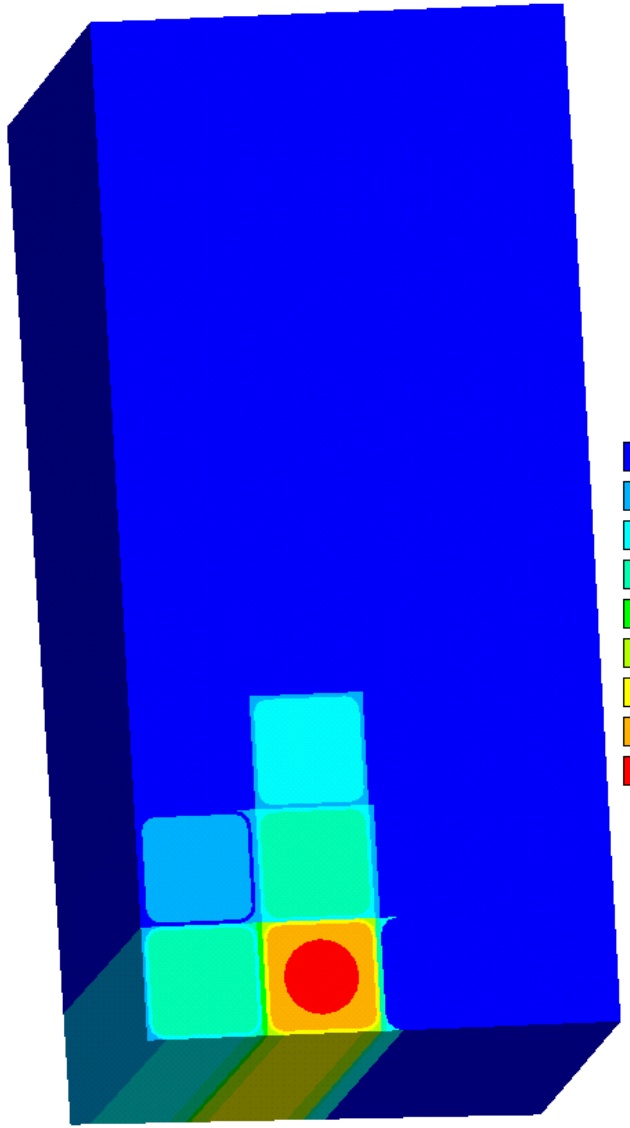
$\tau_{max} = \frac{\sigma_I - \sigma_{III}}{2}$ [MPa]

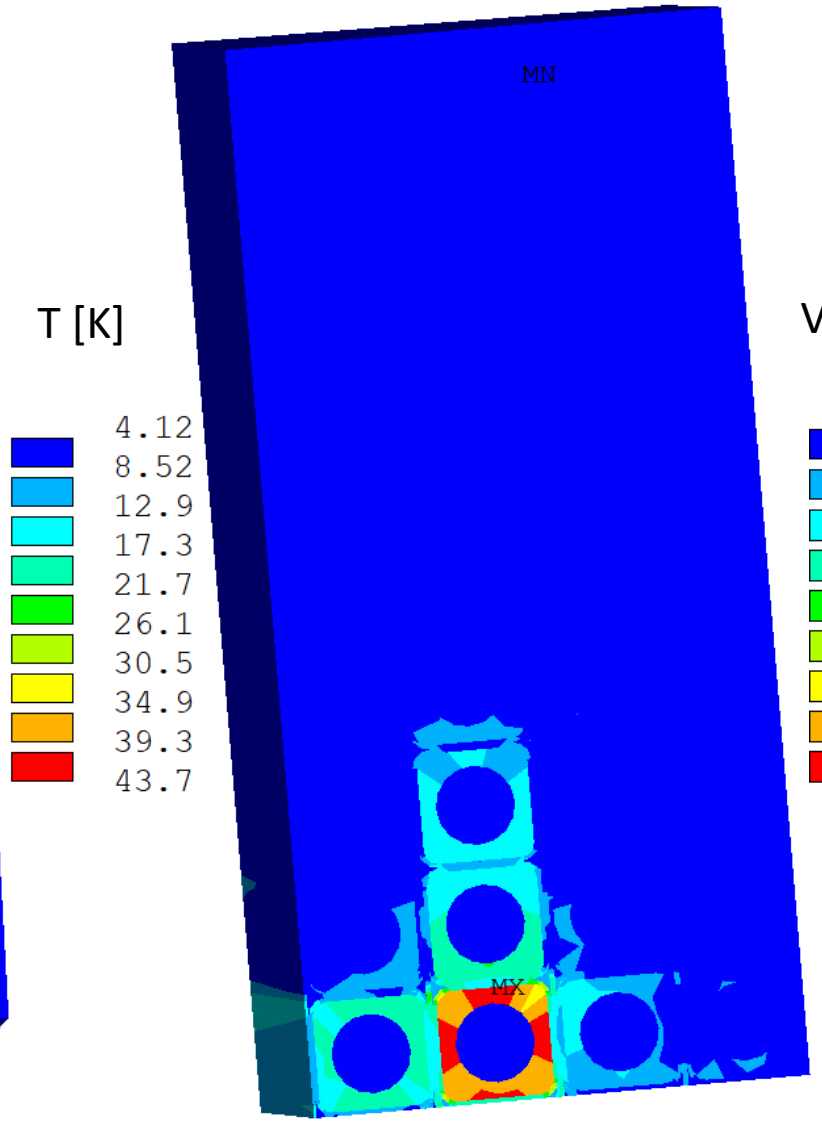
.02
.69
1.35
2.02
2.69
3.36
4.02
4.69
5.36
6.03

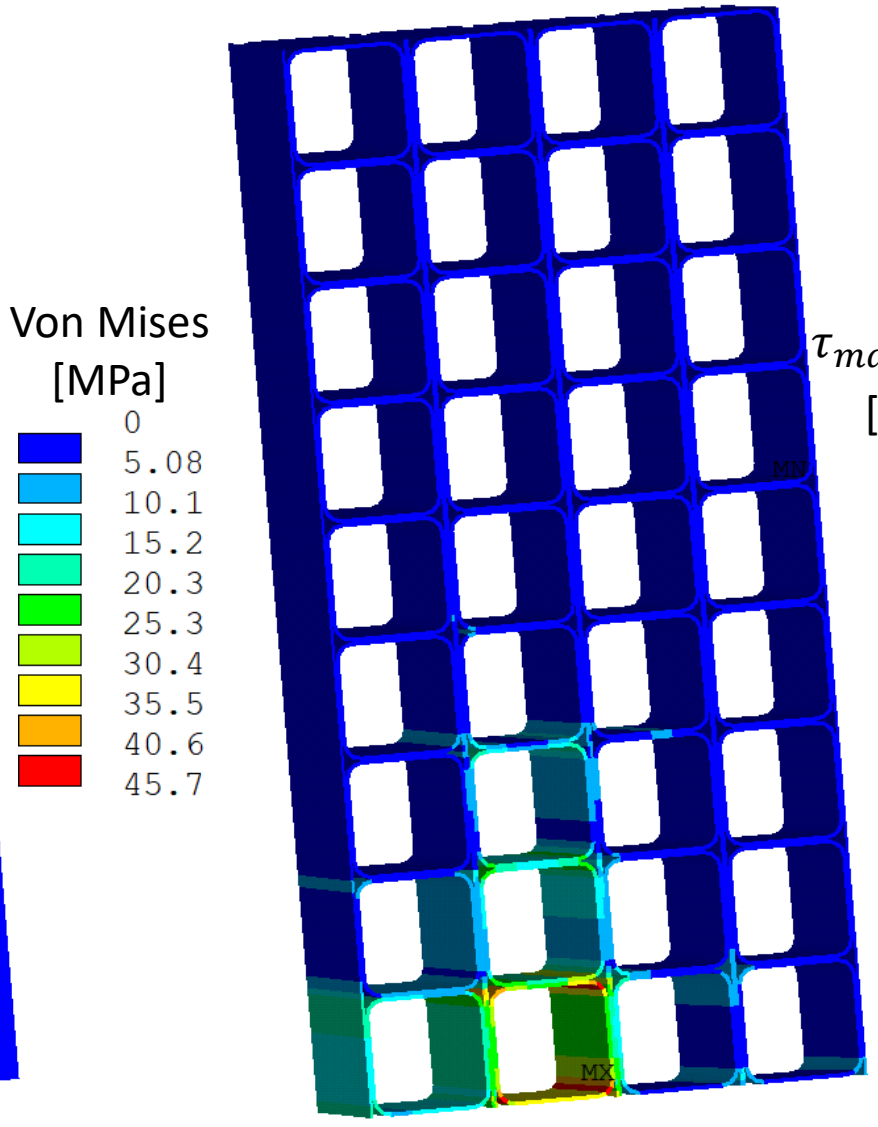
5. Solution and results (3D mechanical + 1D) (9/14)

t=1 s

$$\Delta Stress = Results(time_i) - Results(t0)$$



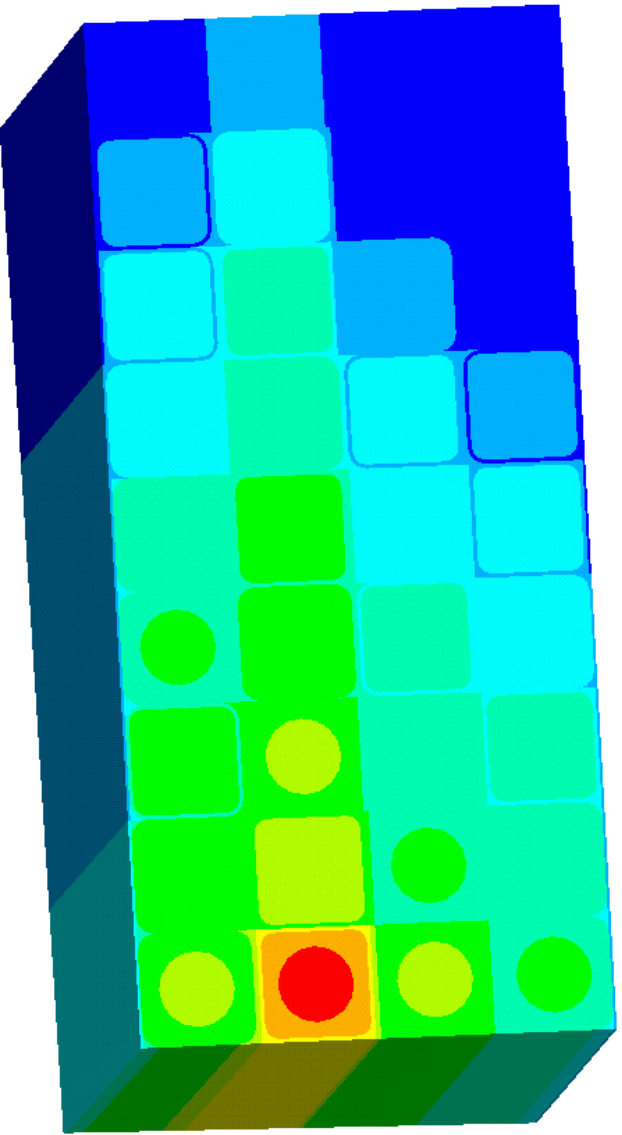




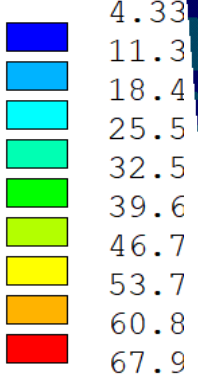
5. Solution and results (3D mechanical + 1D) (10/14)

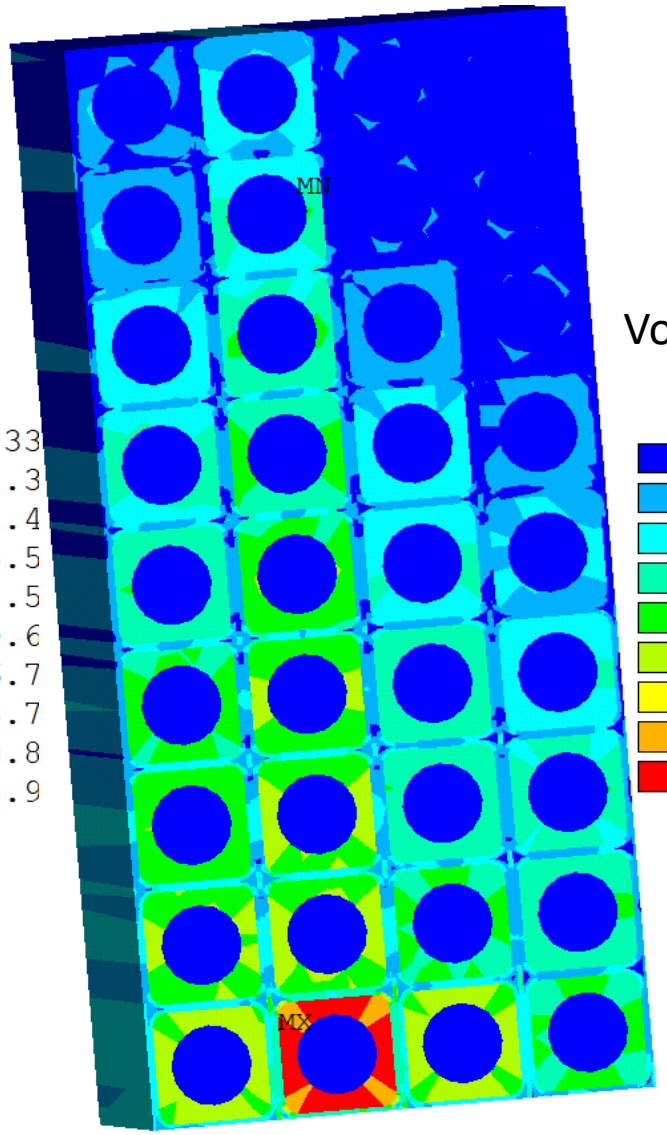
t=2 s

$$\Delta Stress = Results(time_i) - Results(t0)$$

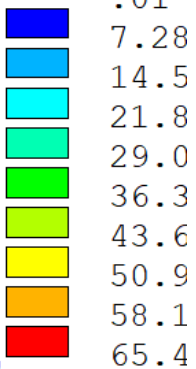


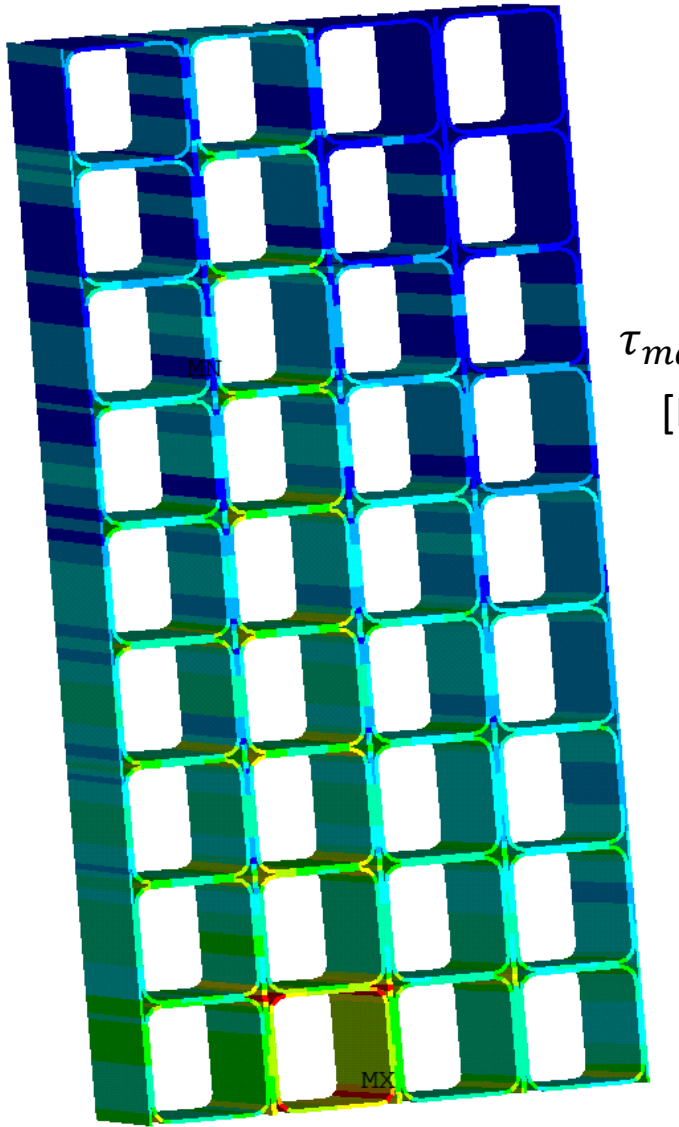
T [K]





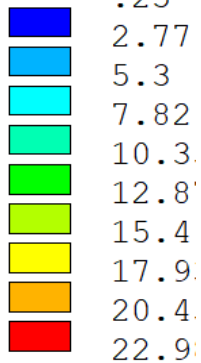
Von Mises [MPa]





$$\tau_{max} = \frac{\sigma_I - \sigma_{III}}{2}$$

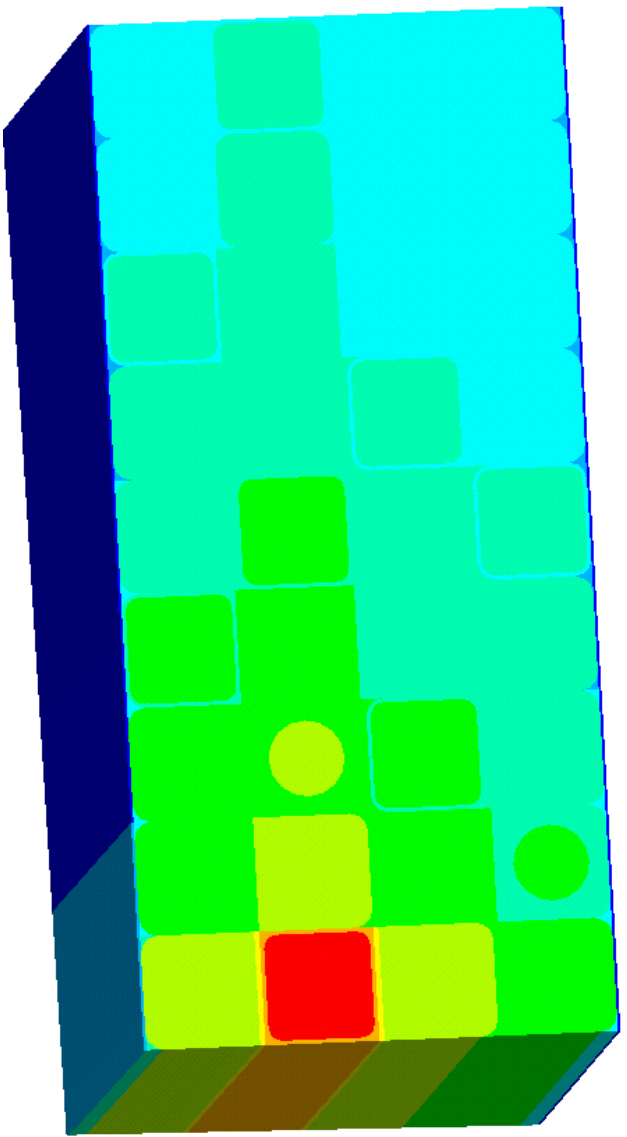
[MPa]

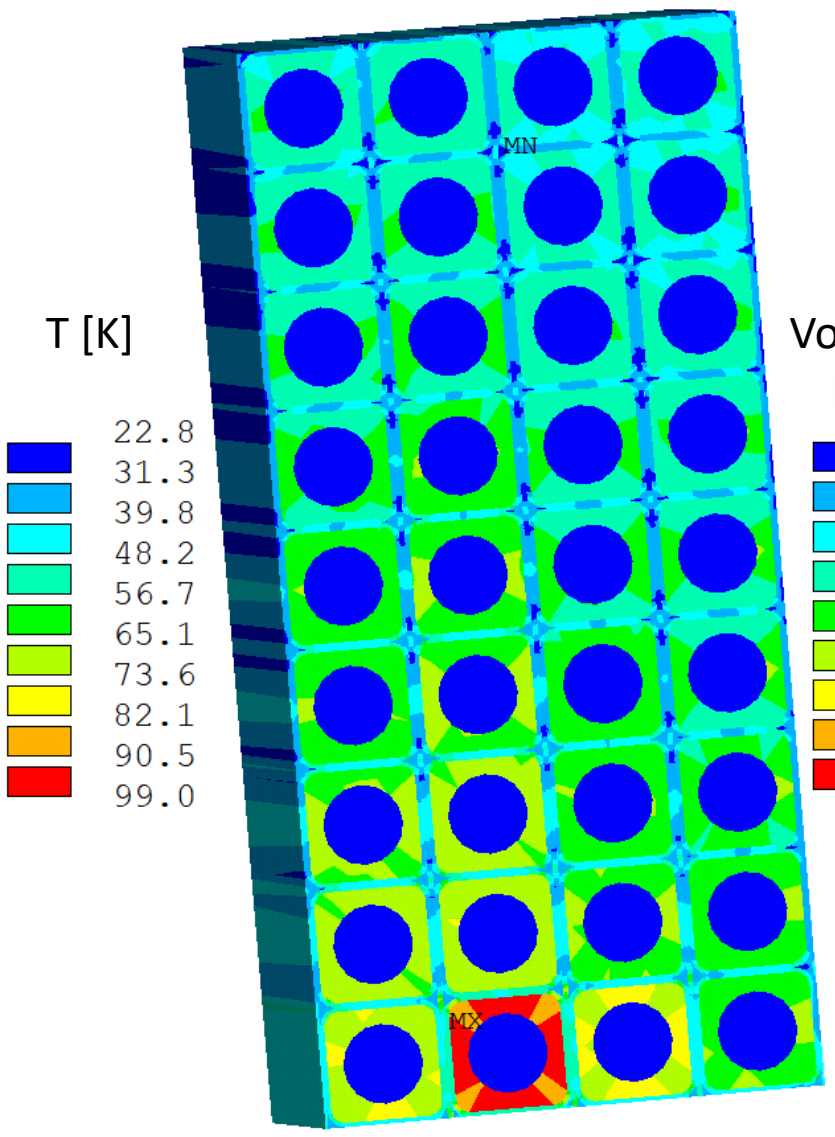


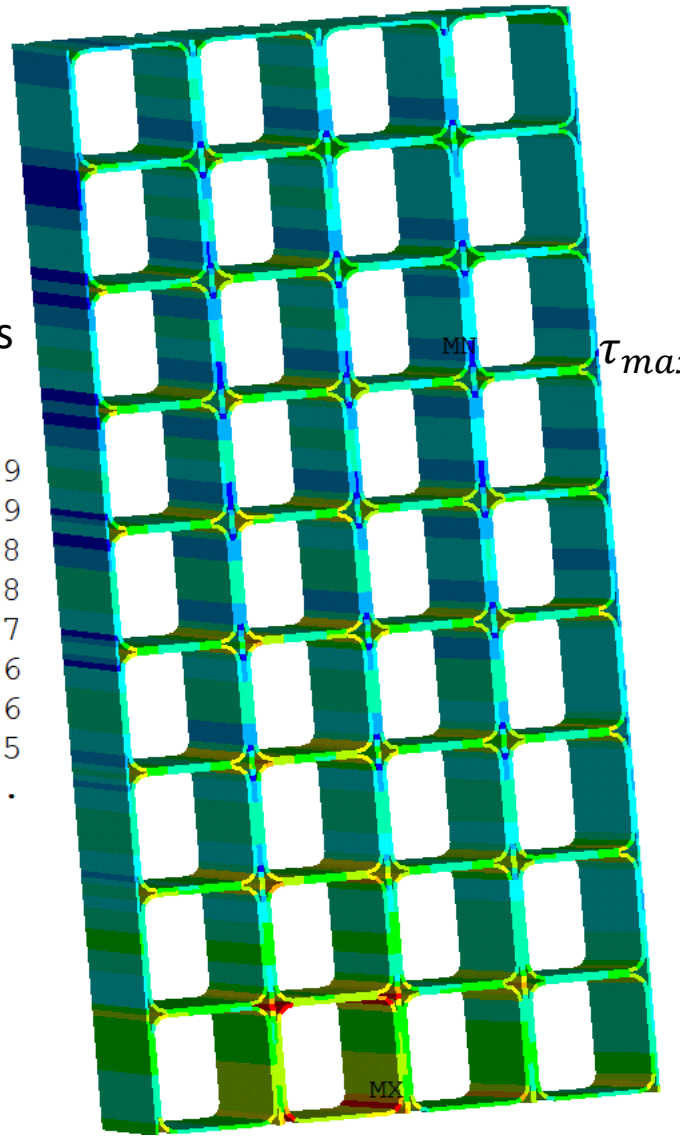
5. Solution and results (3D mechanical + 1D) (11/14)

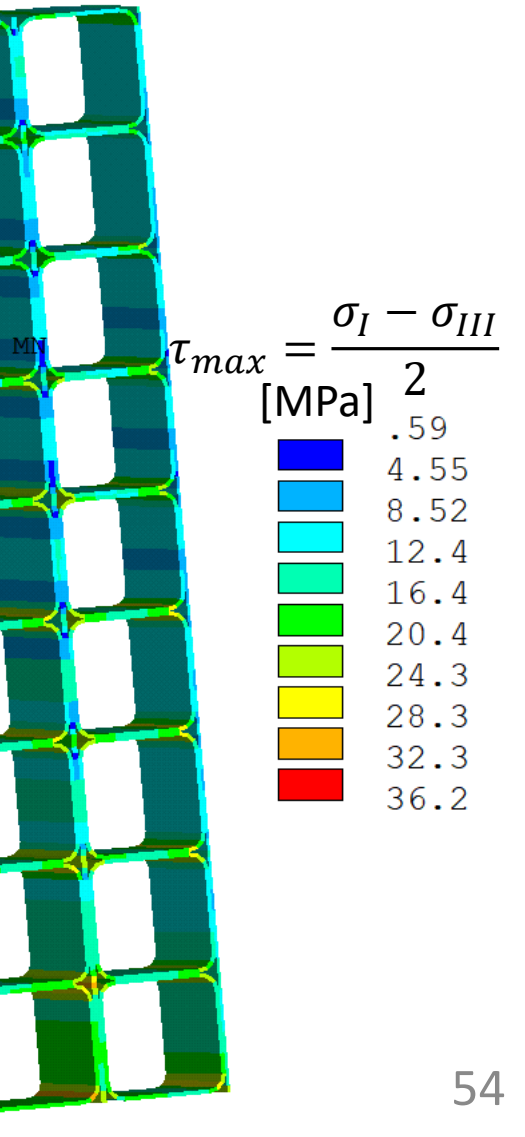
t=5 s

$$\Delta Stress = Results(time_i) - Results(t0)$$





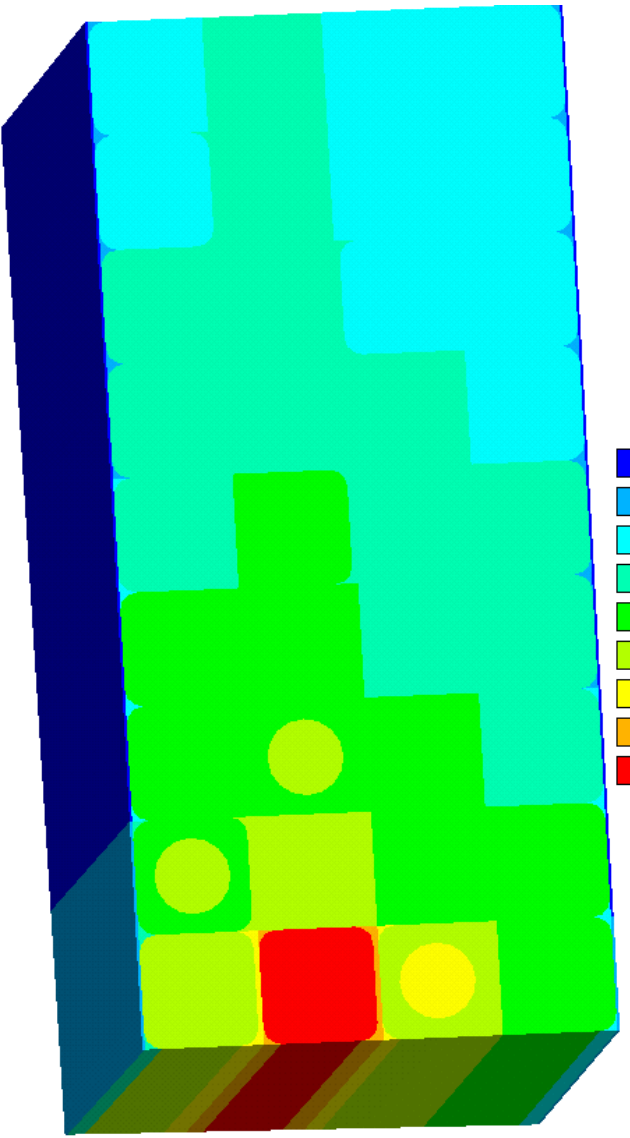




5. Solution and results (3D mechanical + 1D) (12/14)

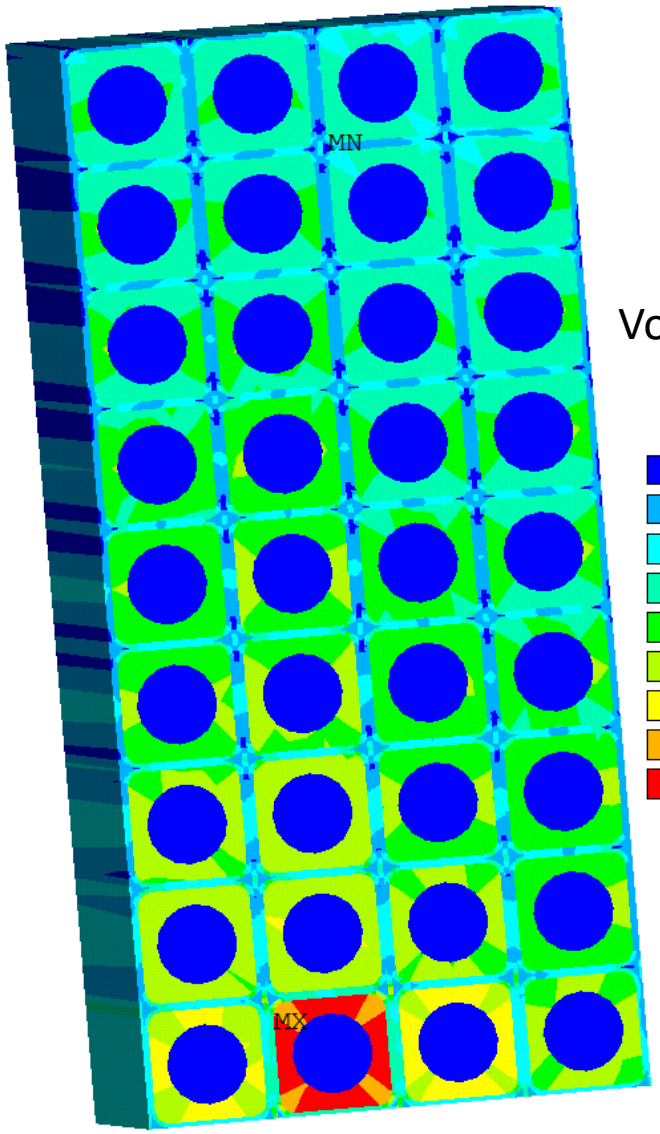
t=8 s

$$\Delta Stress = Results(time_i) - Results(t0)$$



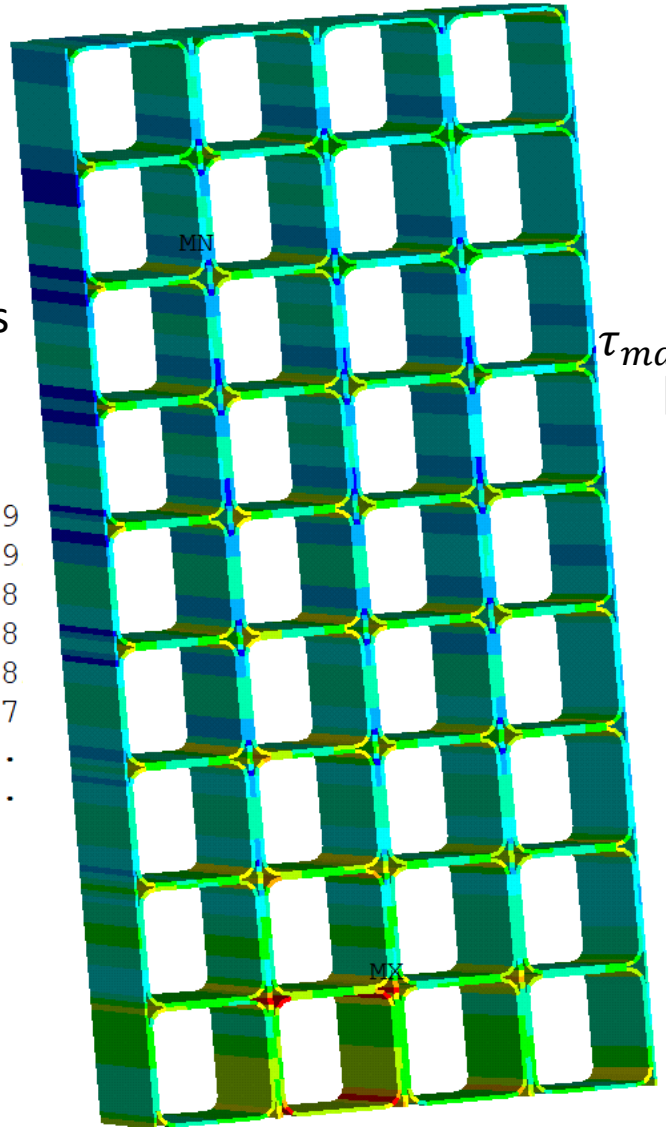
T [K]

26.4
35.2
44
52.7
61.5
70.3
79.1
87.9
96.7
105.



Von Mises [MPa]

.03
13
25.9
38.9
51.8
64.8
77.8
90.7
103.
116.



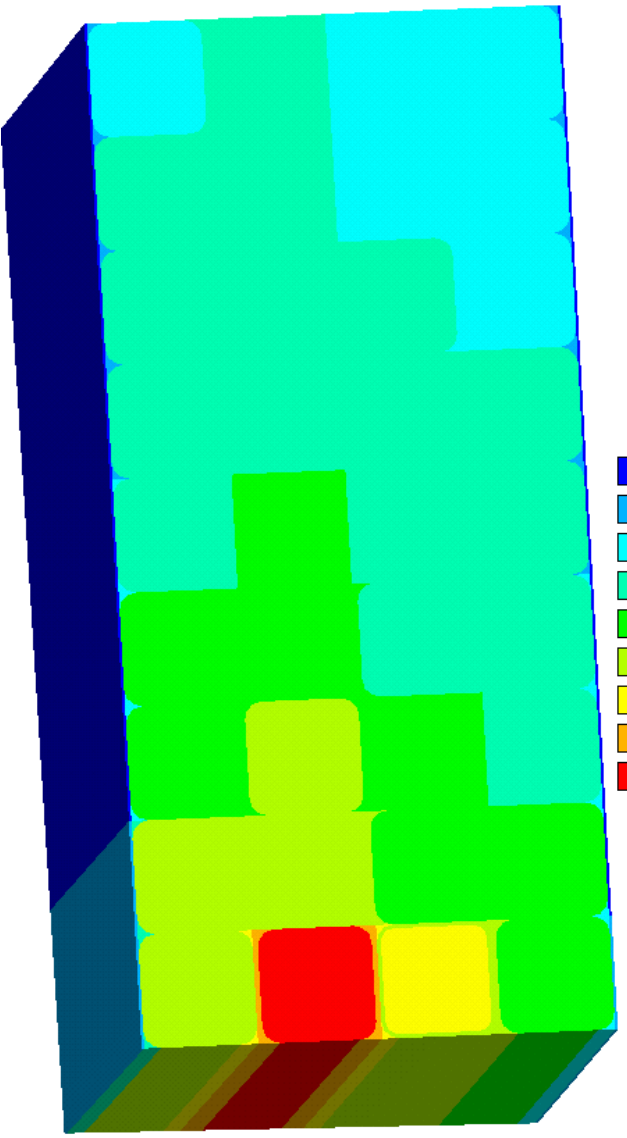
$\tau_{max} = \frac{\sigma_I - \sigma_{III}}{2}$ [MPa]

.64
5.05
9.46
13.8
18.2
22.7
27.1
31.5
35.9
40.3

5. Solution and results (3D mechanical + 1D) (13/14)

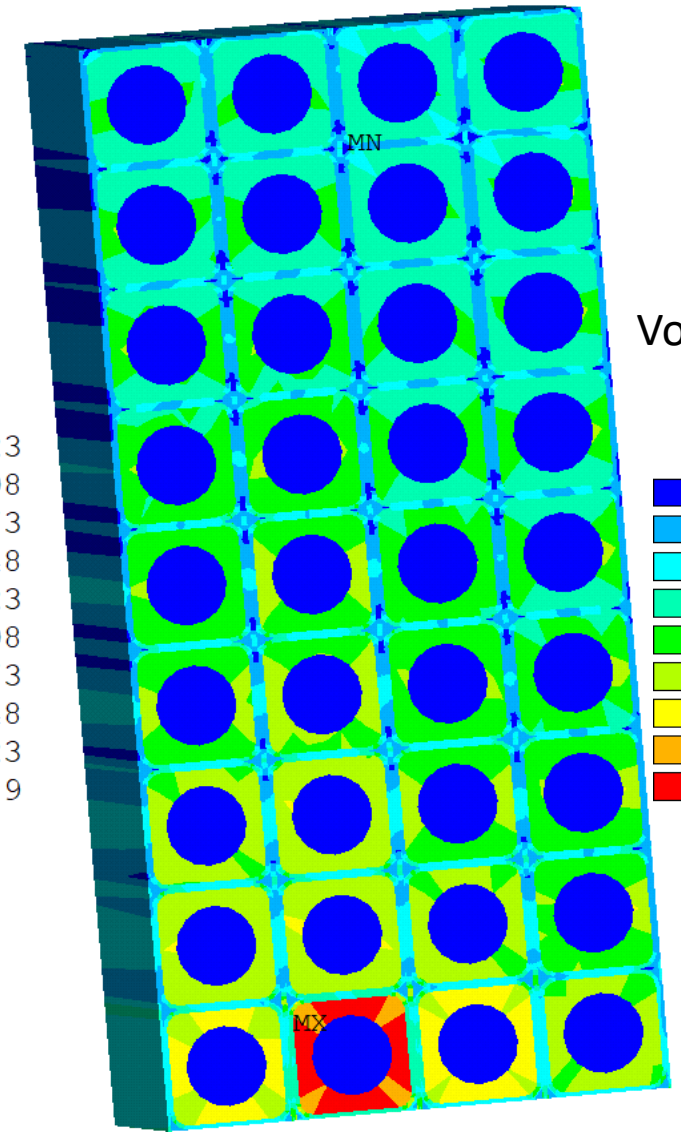
t=10 s

$$\Delta Stress = Results(time_i) - Results(t0)$$



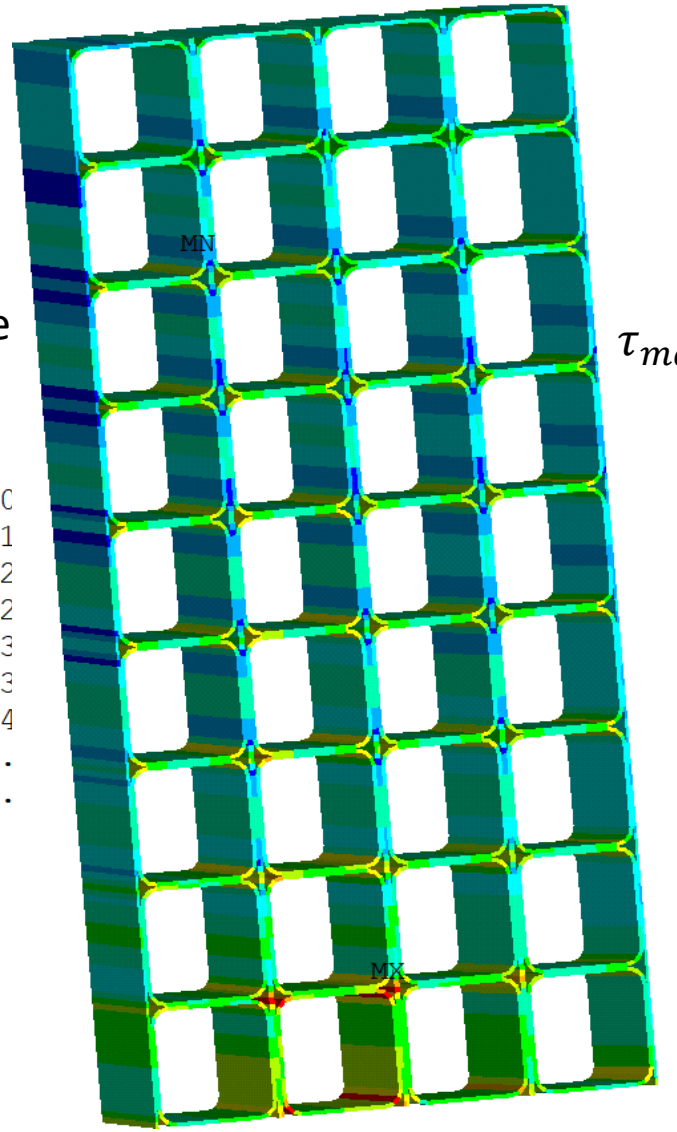
T [K]

27.23
35.98
44.73
53.48
62.23
70.98
79.73
88.48
97.23
105.9



Von Mise [MPa]

.03
13.0
26.1
39.2
52.2
65.3
78.3
91.4
104.
117.

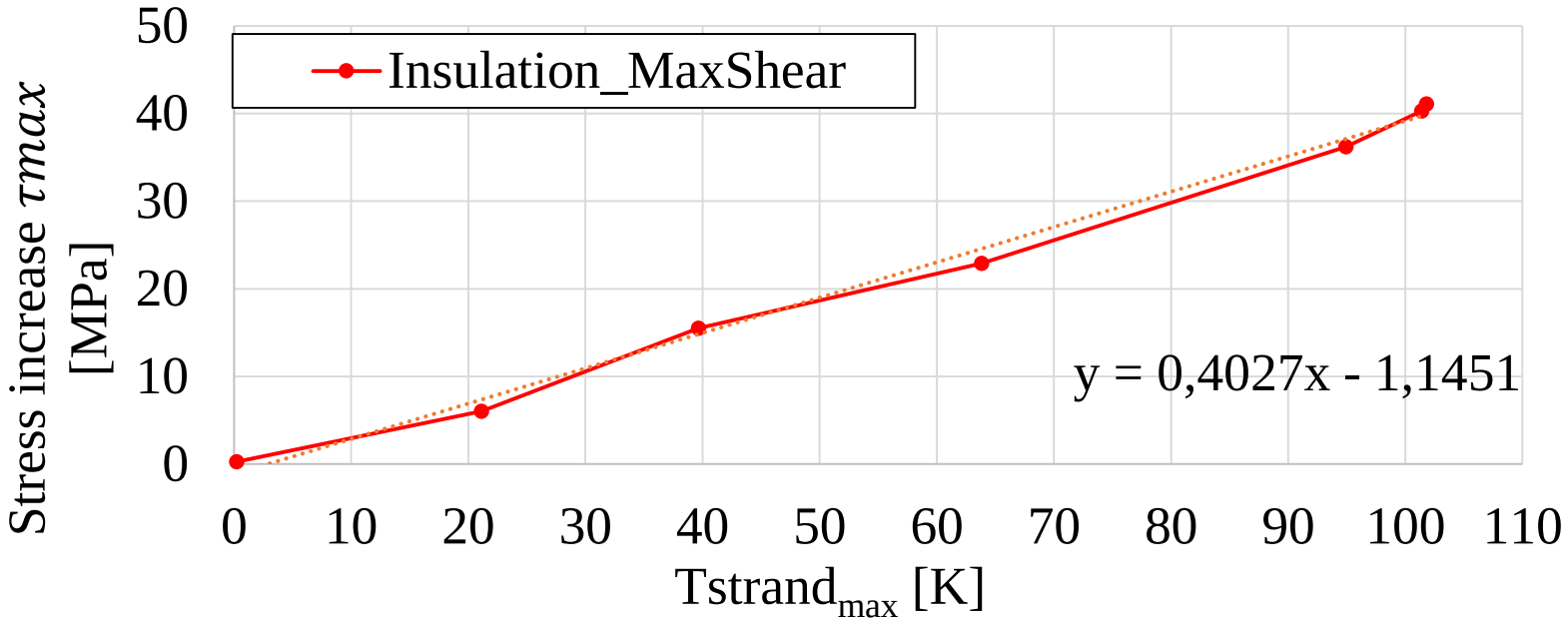


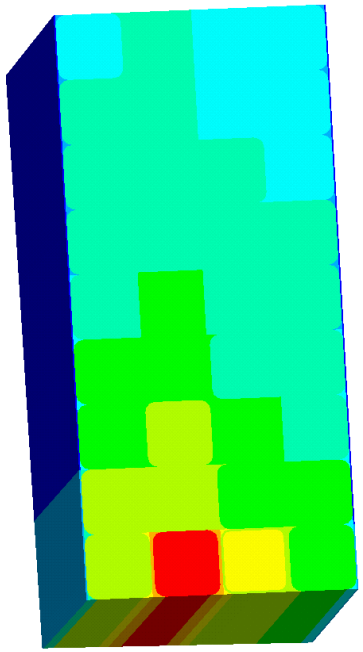
$$\tau_{max} = \frac{\sigma_I - \sigma_{III}}{2}$$

[MPa]

.62
5.13
9.64
14.1
18.6
23.1
27.6
32.1
36.6
41.1

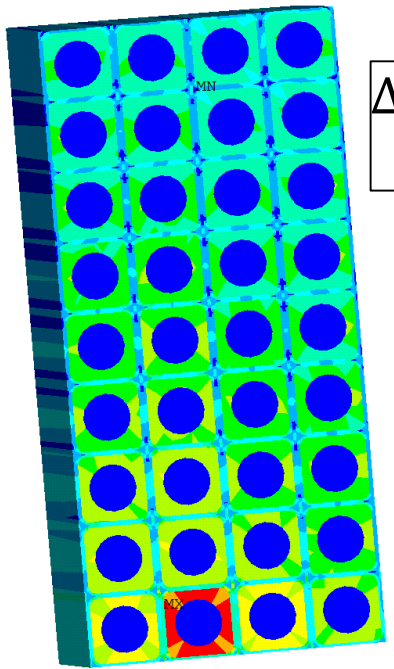
5. Solution and results (3D mechanical + 1D) (14/14)





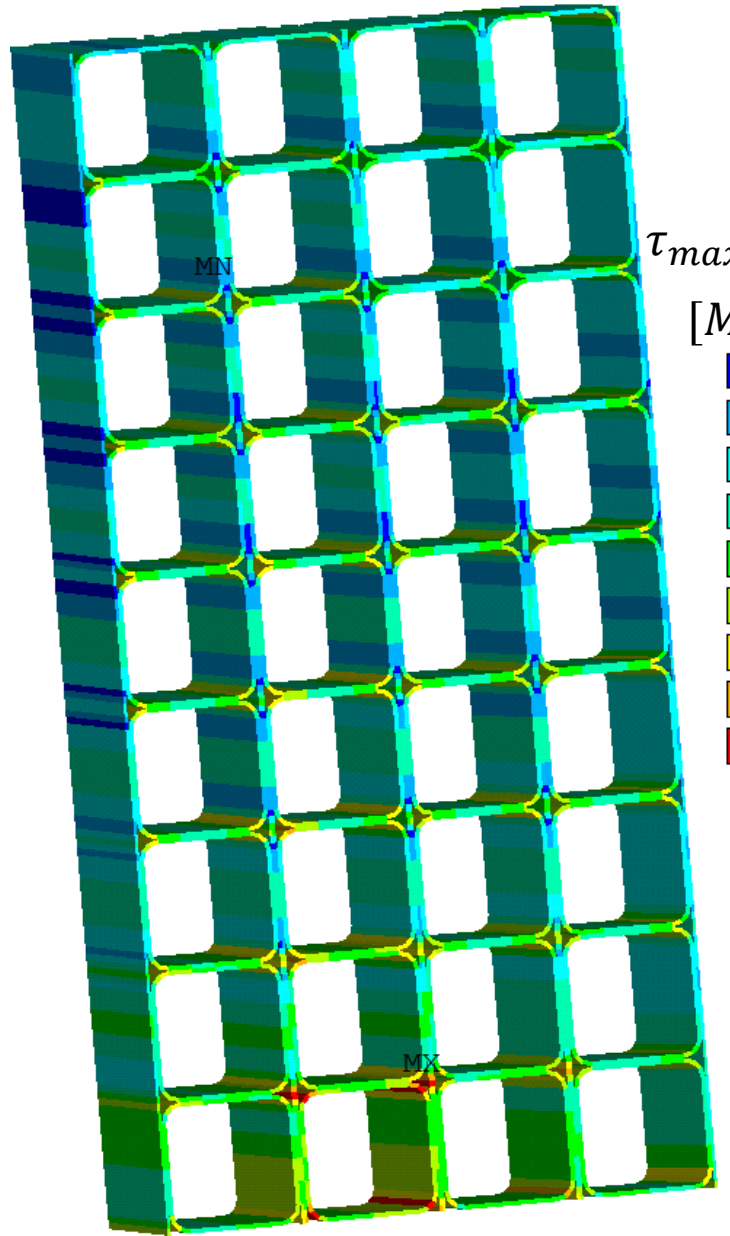
T [K]

27.23
35.98
44.73
53.48
62.23
70.98
79.73
88.48
97.23
105.9



$\Delta(von\ Mises)$ [MPa]

.03
13.09
26.15
39.21
52.27
65.33
78.39
91.44
104.5
117.5



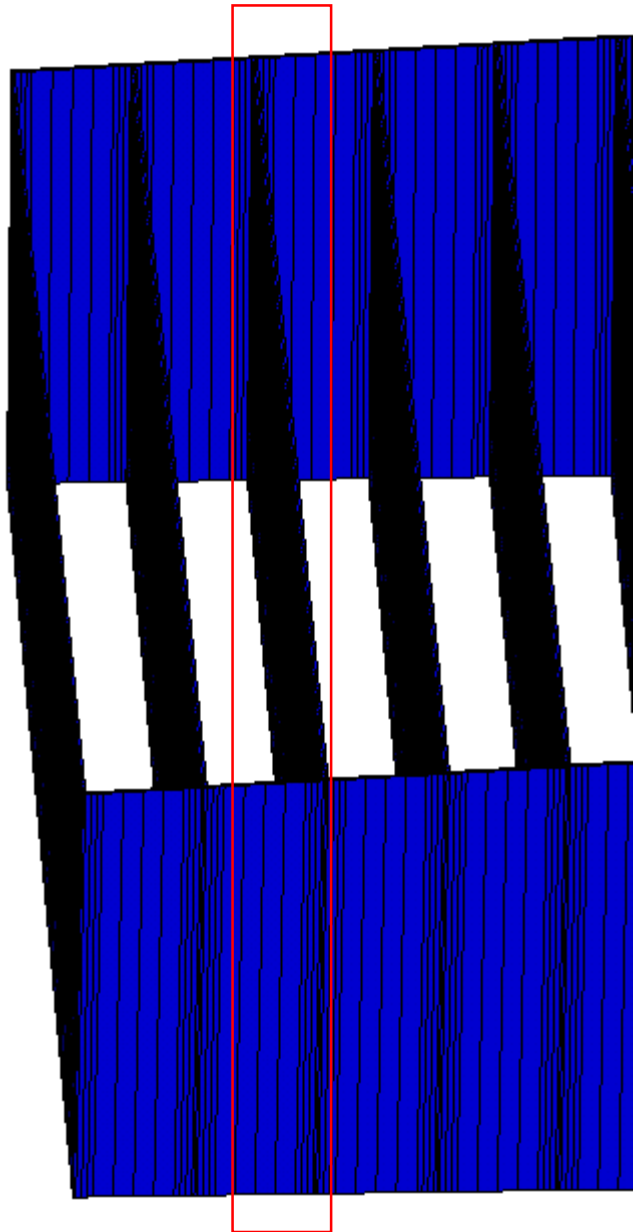
$\tau_{max} = \frac{\sigma_I - \sigma_{III}}{2}$

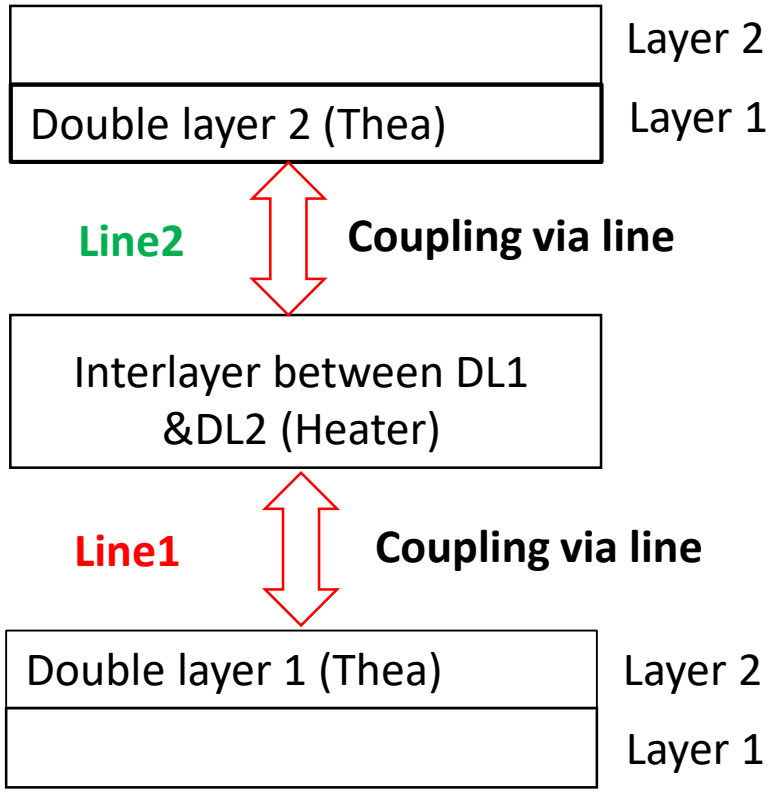
[MPa]

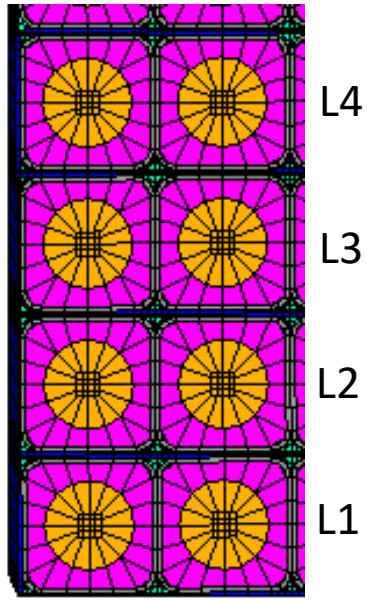
.62
5.13
9.64
14.1
18.6
23.1
27.6
32.1
36.6
41.1

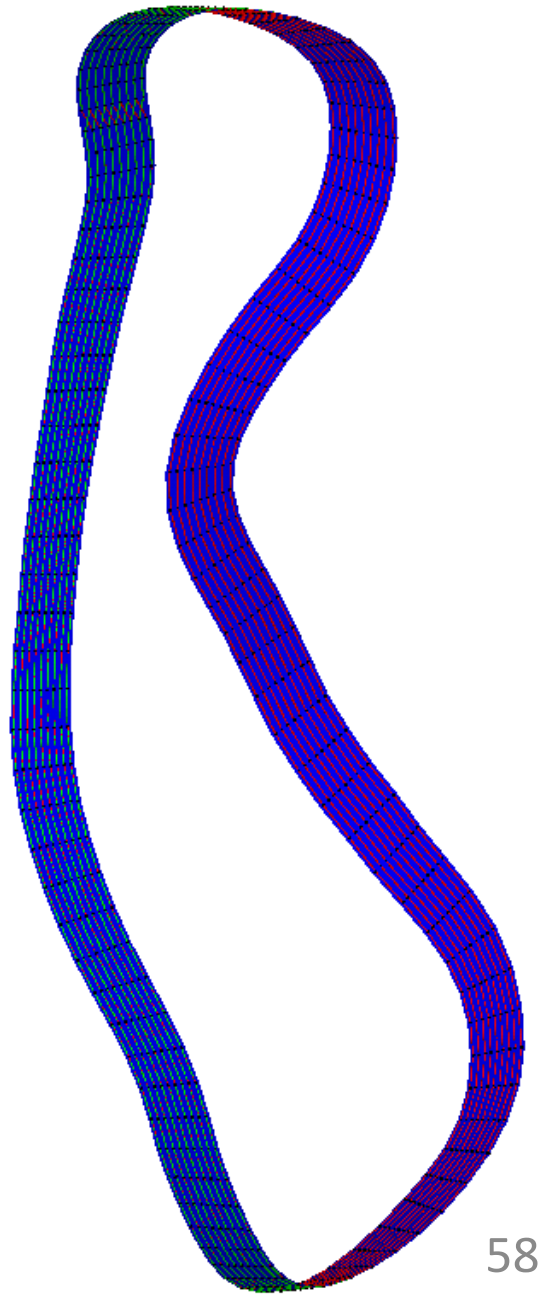
Time:
t=10 s

6. Enhances thermo-hydraulic model (1D+3D) (1/5)





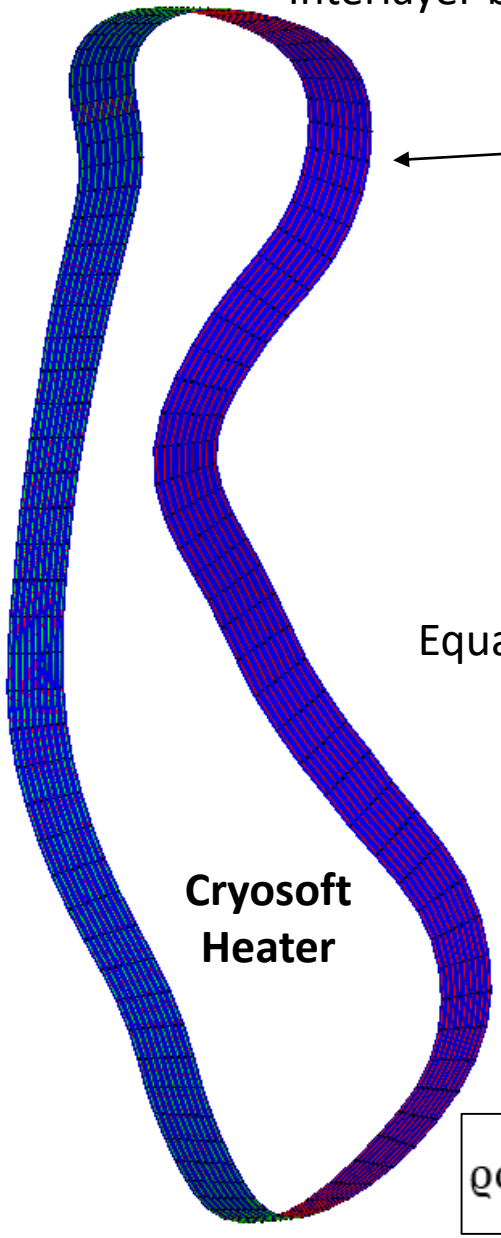


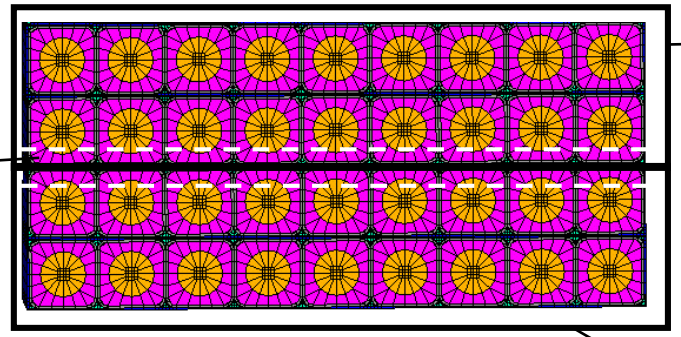


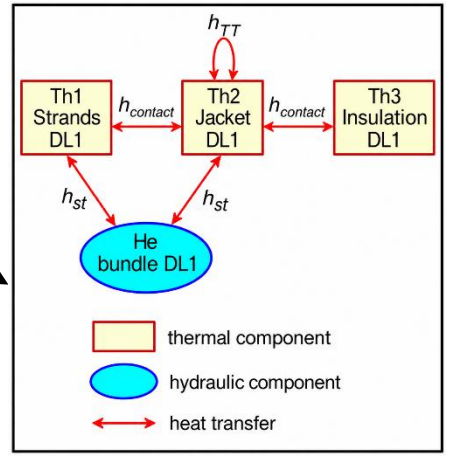
To create the interface from Heater to Theas we need to create lines along nodes in the Heater mesh

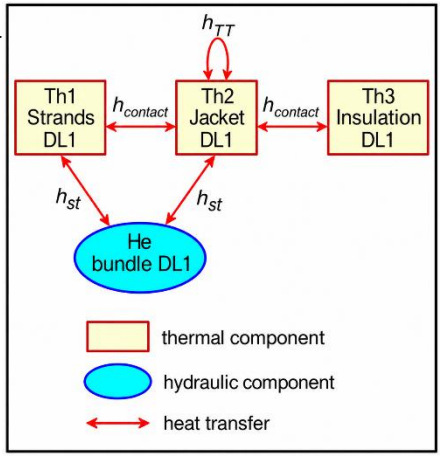
6. Enhances thermo-hydraulic model (1D+3D) (2/5)

Interlayer between DL1 & DL2









Equations solved by Thea (temperature in thermal and volumetric flow, pressure, temperature for hydraulic)

$$A_i\rho_i C_i\frac{\partial T_i}{\partial t}-\frac{\partial\left(A_i k_i\frac{\partial T_i}{\partial x}\right)}{\partial x}=\dot{q}_i'+\dot{q}_{\mathrm{Joule},i}'+\sum_{\substack{j=1\\ j\neq i}}^{N}\frac{T_j-T_i}{H_{ij}}+\sum_{h=1}^{H}p_{ih}h_{ih}(T_h-T_i)$$

$$\rho_h\frac{\partial V_h}{\partial t}+\frac{\rho_h V_h}{A_h}\frac{\partial V_h}{\partial x}+A_h\frac{\partial p_h}{\partial x}-\frac{\rho_h V_h^2}{A_h^2}\frac{\partial A_h}{\partial x}=-A_h F_h-\sum_{\substack{k=1\\ k\neq h}}^{H}\left(\Gamma_{hk}^{v}-v_h\Gamma_{hk}^{\rho}\right)$$

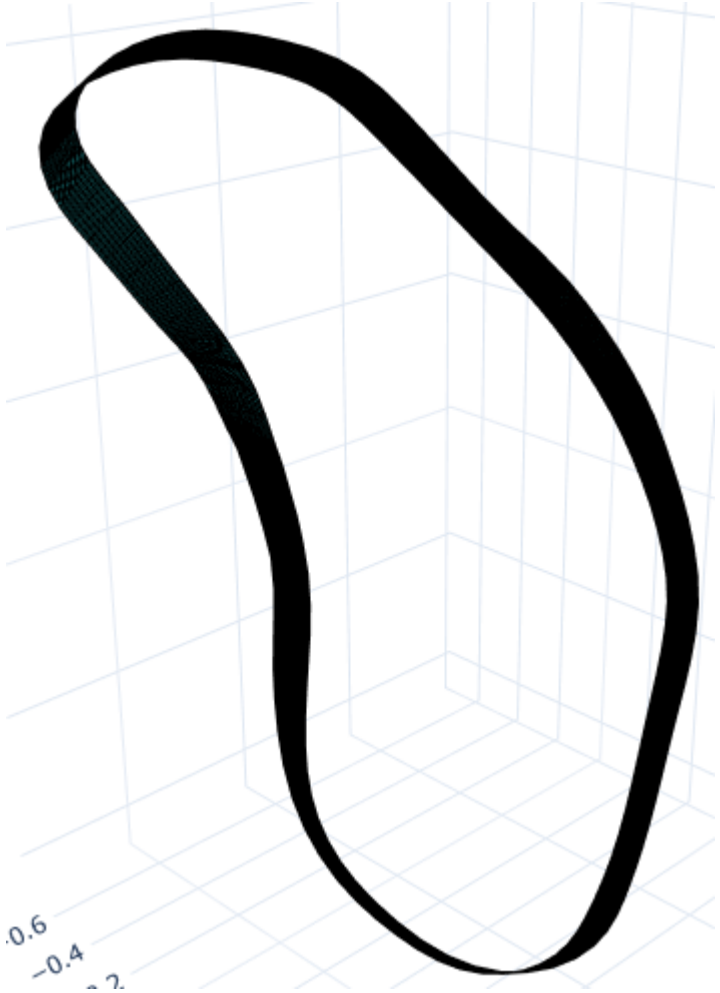
$$A_h\frac{\partial p_h}{\partial t}+V_h\frac{\partial p_h}{\partial x}+\rho_h c_h^2\frac{\partial V_h}{\partial x}=-\sum_{\substack{k=1\\ k\neq h}}^{H}\left\{c_h^2\Gamma_{hk}^{\rho}+\varphi_h\left[\Gamma_{hk}^{e}-v_h\Gamma_{hk}^{v}-\left(h_h-\frac{v_h^2}{2}\right)\Gamma_{hk}^{\rho}\right]\right\}+\varphi_h V_h F_h+\varphi_h\dot{q}_h'+\varphi_h\dot{q}_{\mathrm{cf},h}'$$

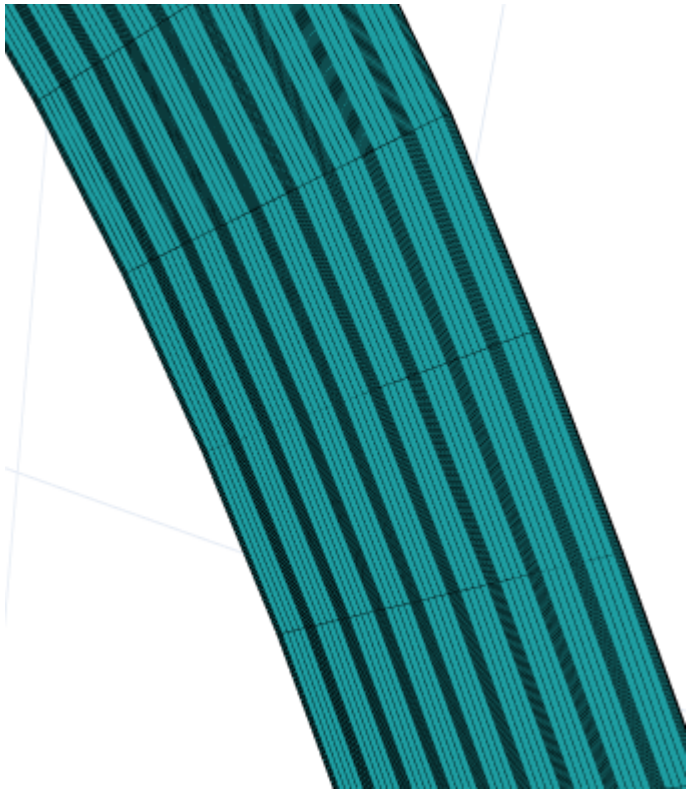
$$A_h\rho_h C_h\frac{\partial T_h}{\partial t}+\rho_h V_h C_h\frac{\partial T_h}{\partial x}+\rho_h\varphi_h C_h T_h\frac{\partial V_h}{\partial x}=V_h F_h-\sum_{\substack{k=1\\ k\neq h}}^{H}\left[\Gamma_{hk}^{e}-v_h\Gamma_{hk}^{v}-\left(h_h-\frac{v_h^2}{2}-\varphi_h C_h T_h\right)\Gamma_{hk}^{\rho}+\dot{q}_h'+\dot{q}_{\mathrm{cf},h}'\right]$$

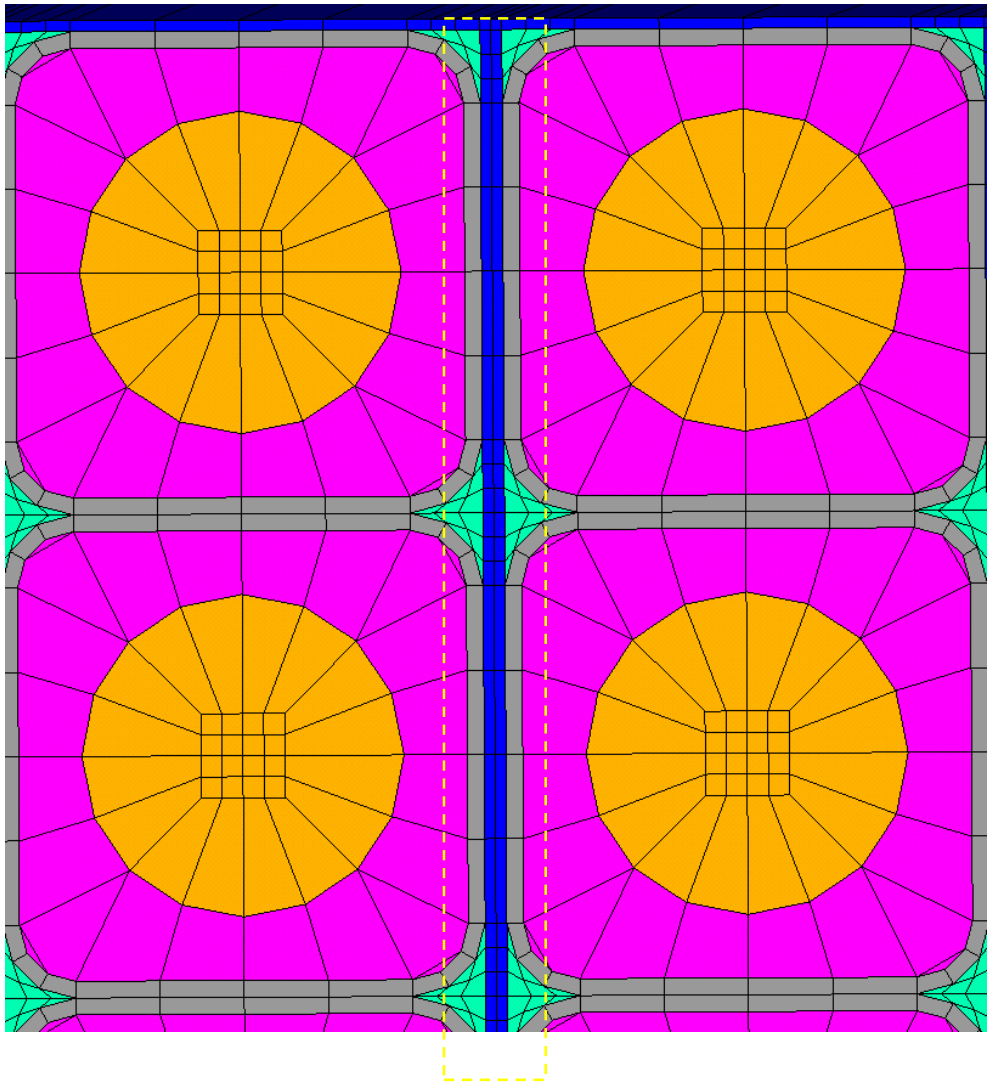
Equations solved by Heater

$$\varrho c\frac{\partial T}{\partial t}-\nabla(k\nabla T)=\dot{q}'''$$

6. Enhances thermo-hydraulic model (1D+3D) (3/5)





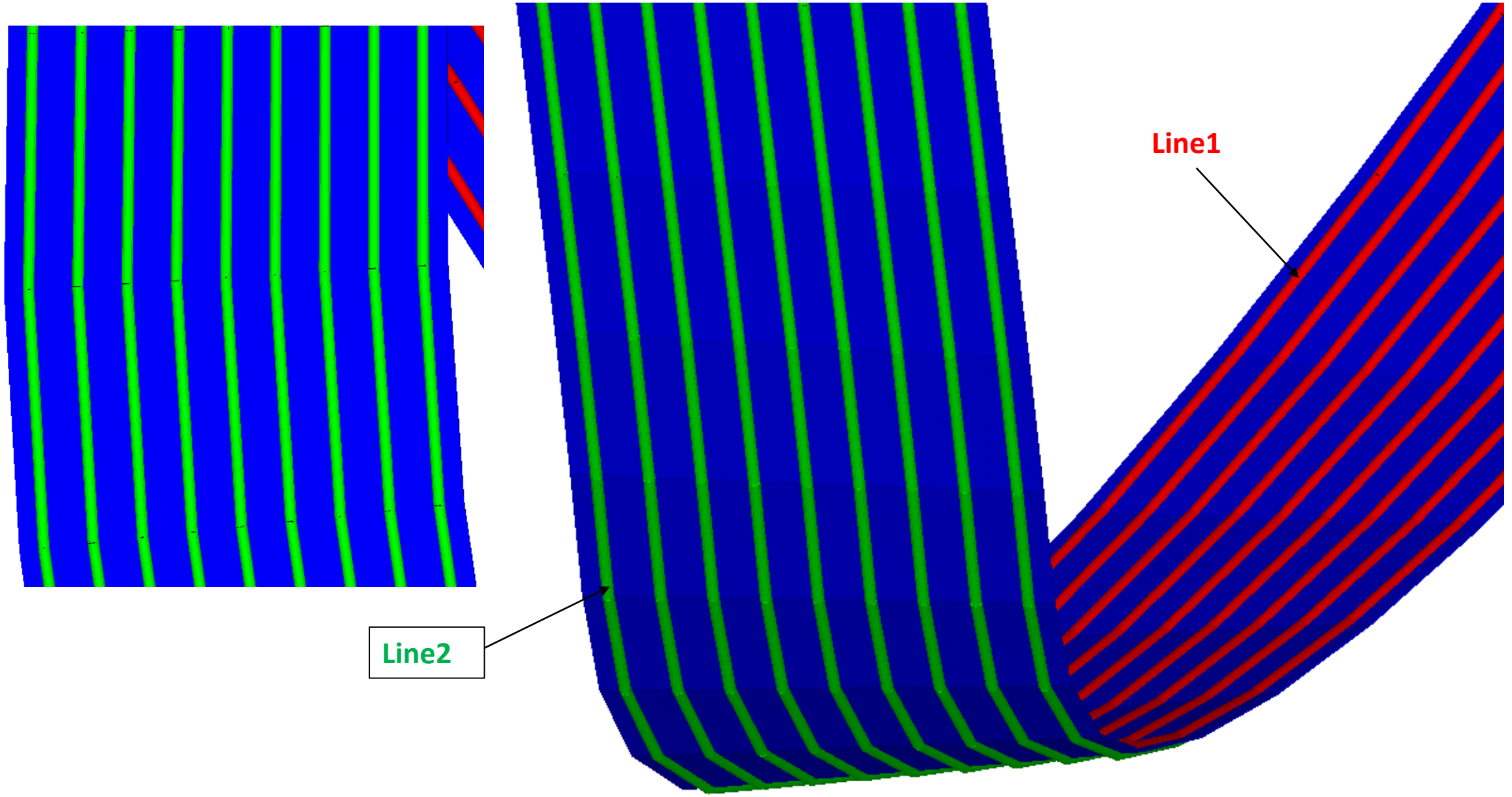


Heter mesh size: **24192 elements**

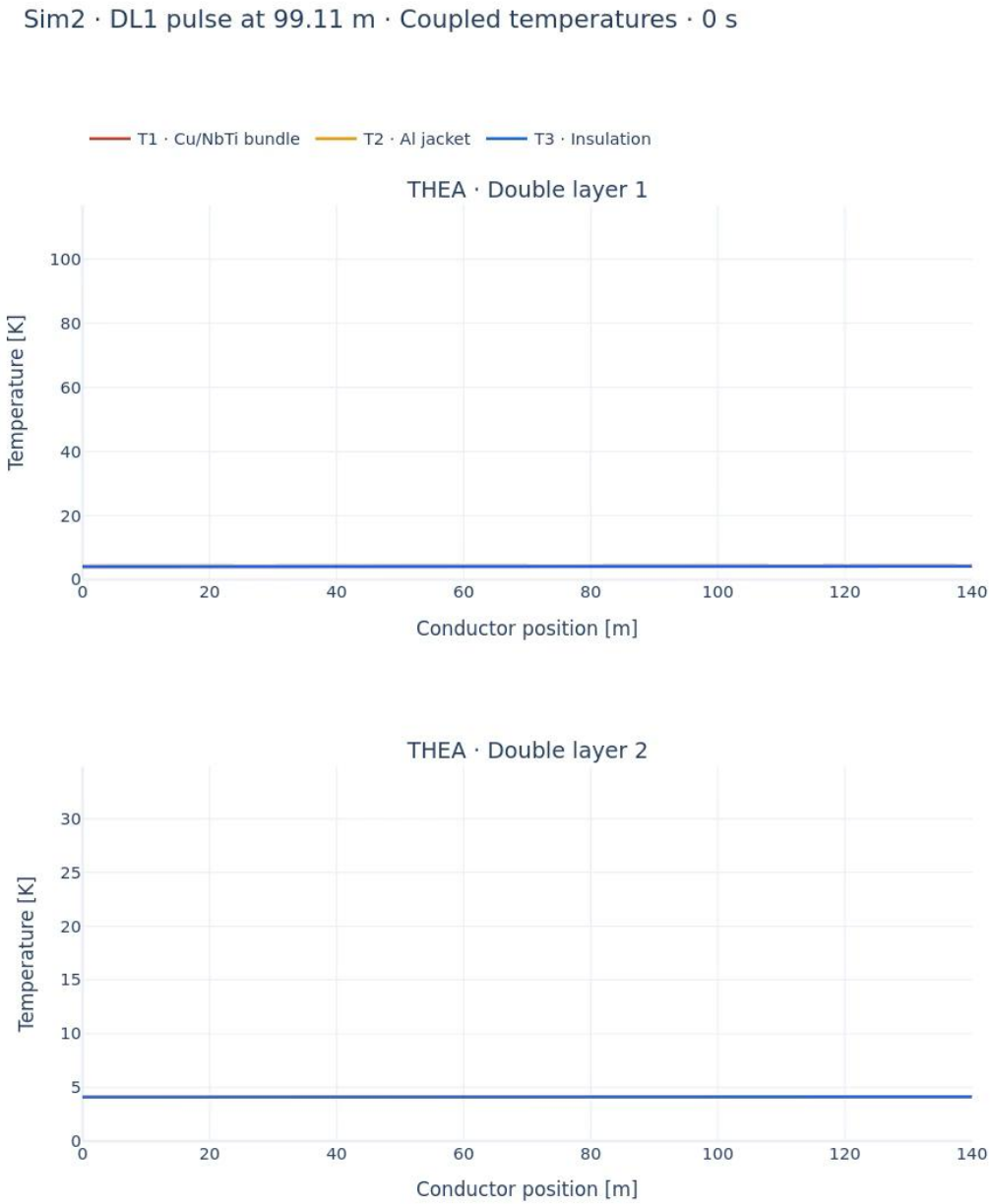
Heater mesh (as in Ansys mechanical model):
96 divisions along the circumference

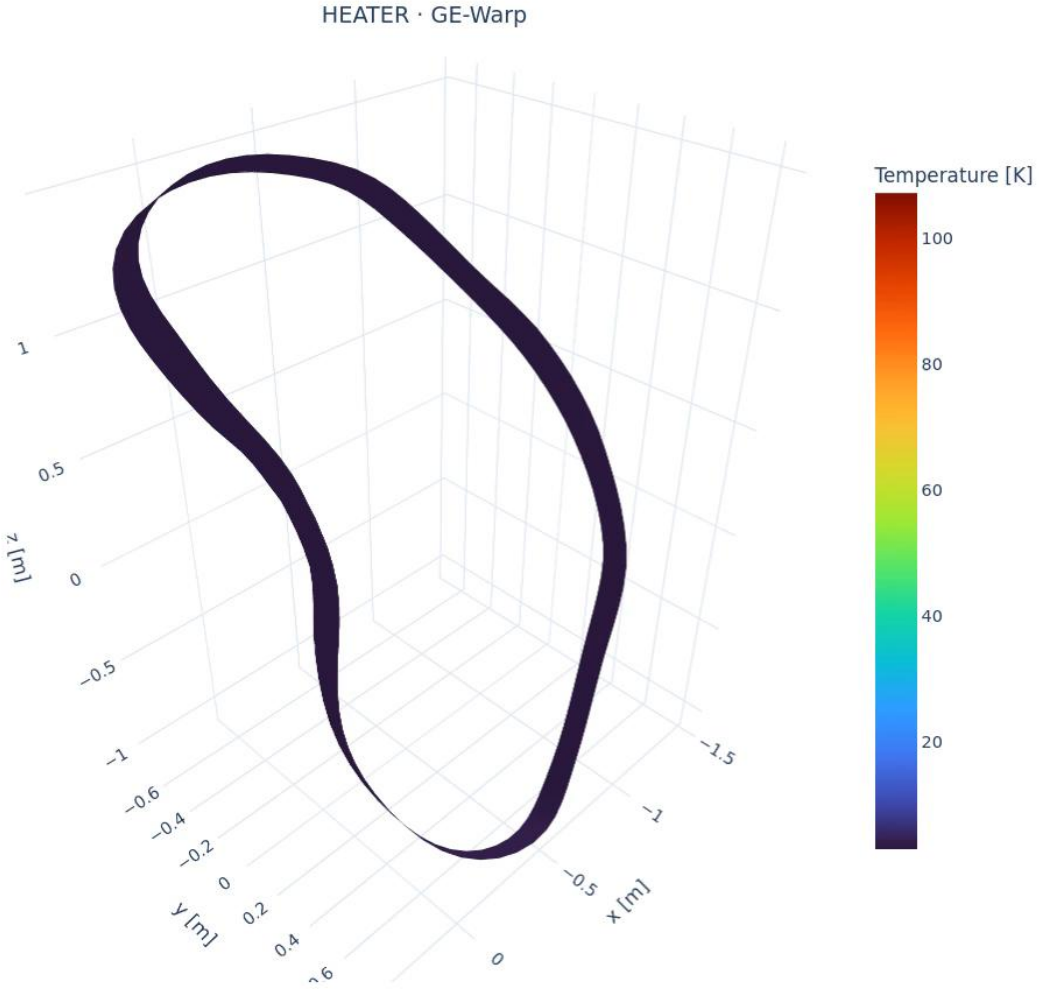
- Heat pulse: **99.06–99.16 m**
- Begin refined: 94.11 m
- End refined : 104.11 m

6. Enhances thermo-hydraulic model (1D+3D) (4/5)



6. Enhances thermo-hydraulic model (1D+3D) (5/5)





7. Conclusions/next steps

1. Several models have been established to analyze quench in W7-X NPC coil from the thermo-hydraulic-mechanic point of view:

- 1D model in Thea of 2 DL
- 3D model in Ansys with detailed Winding pack
- 1D+3D model of the 2DLs with Thea, Heater and Supermagnet

2. In the next step the thermal results from the enhanced model will be used in the mechanical model

3. Ultimately we will extend the model to the full Winding pack (6 double layers)