POLITECNICO DI TORINO
Dipartimento Energia "Galileo Ferraris"

MAG-2.2-T018
Support to the thermal-hydraulic design and analysis of the DEMO magnet system

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EUROfusion

Deliverable content

1. **Optimize the thermal anchor of the gravity support (GS) and reduce the large conductive load**
   - 3D thermal analysis for three TS temperature
   - 2D thermo-mechanical analysis for the best configuration
   - Parametric (thermal and thermo-mechanical) study for the best configuration

2. **Optimize the casing cooling channels (CCCs)**
   - Redistribute the CCCs to reduce temperature gradients in cold operation
   - Assess effect of optimization during re-cooling

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1. Rationale of the GS analysis

3D thermal analysis to compute the thermal load reaching the TF coil casing for 9 different location of a Thermal Anchor @ 4.5 K across the GS

Optimal configuration

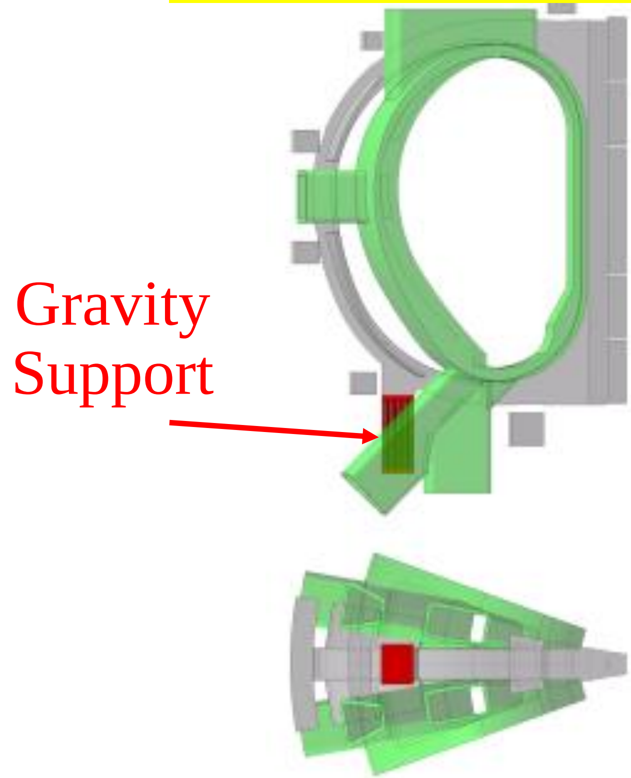
2D themo-mechanical analysis (check secondary stresses < limits)

Application of a second TA on the bottom of the GS at higher temperature (3D)

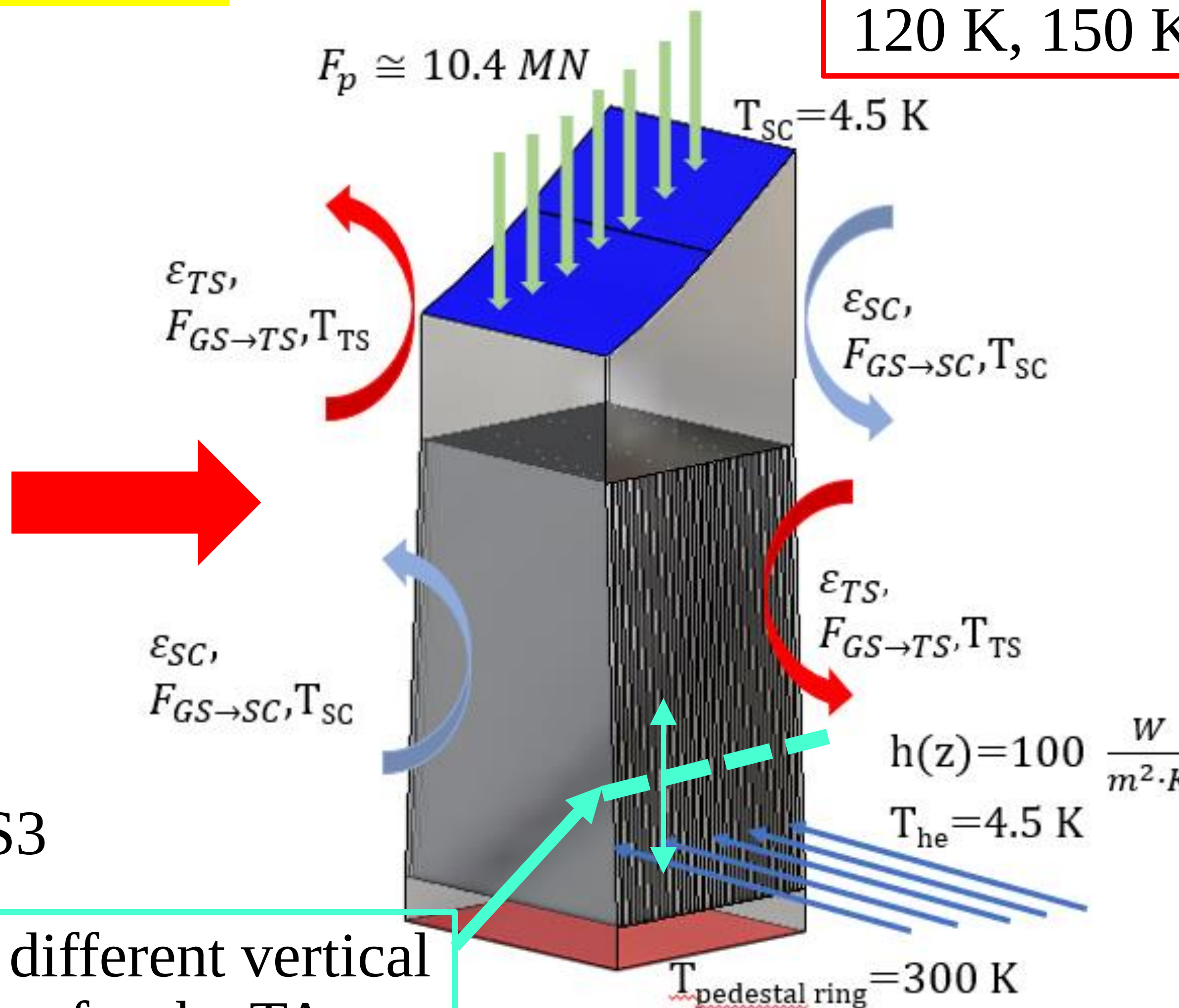
More refine 3D thermo-hydraulic analyses

GS design and Model Setup

[F. Nunio, WPMAG Progress review meeting 2017]



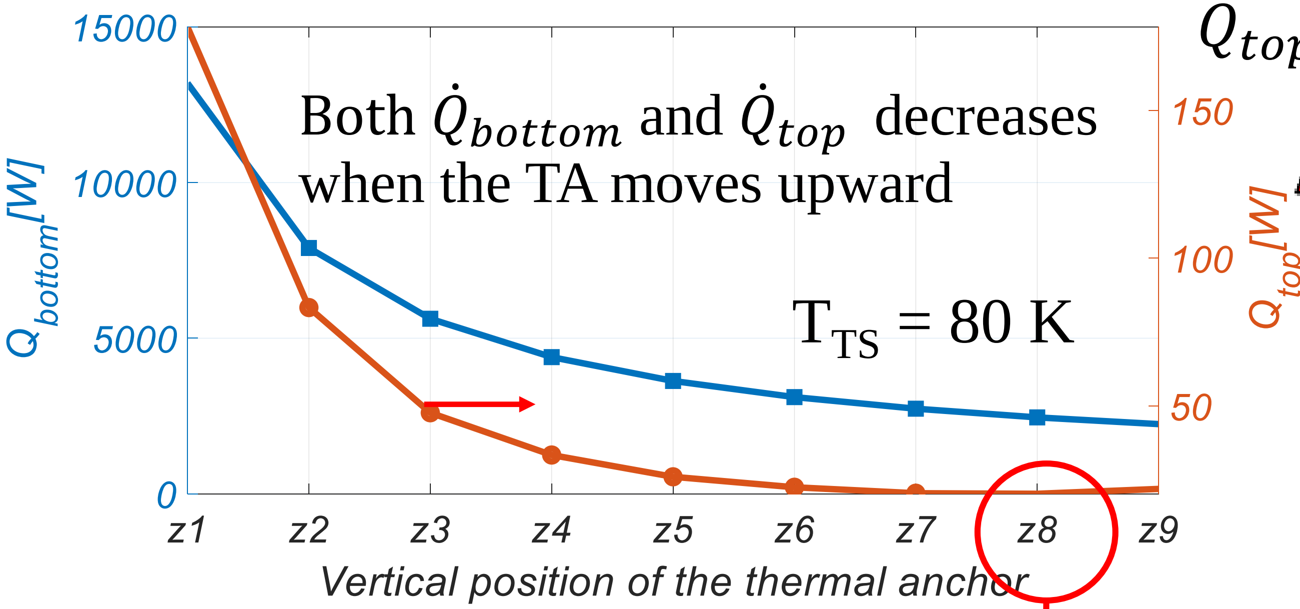
Configuration GS3



TS @ 80 K, 120 K, 150 K

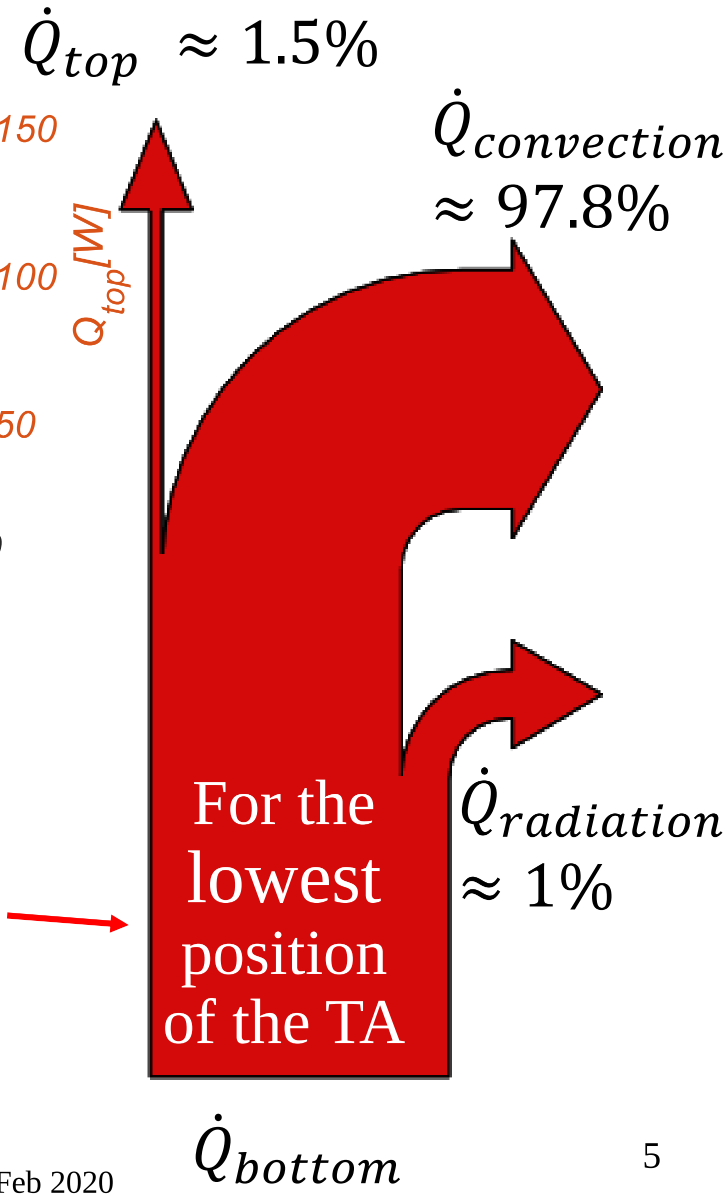
Consider 9 different vertical positions for the TA
(z1 = bottom, z9 = top)

Thermal results



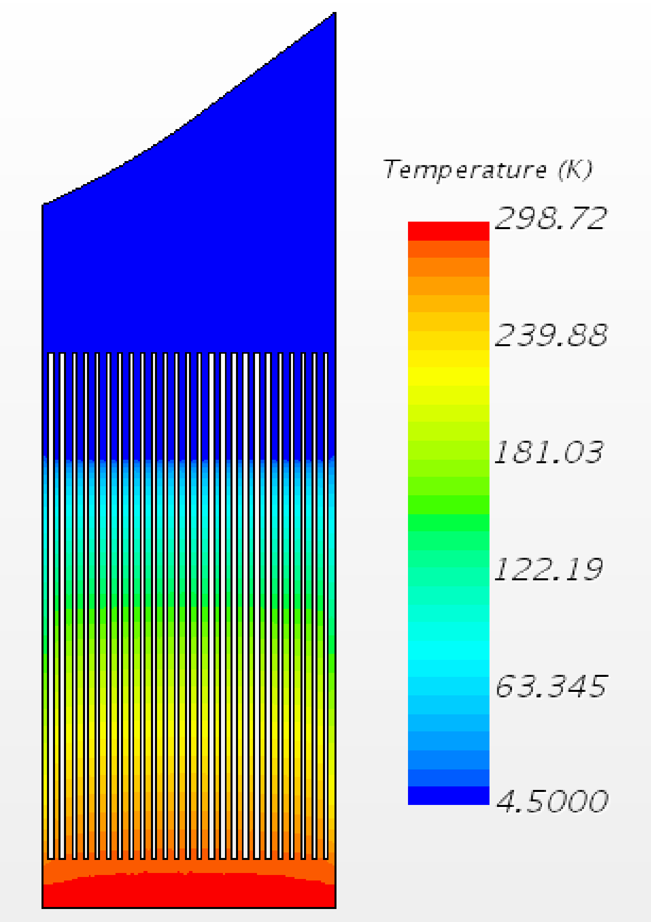
T_{TS} [K]	$\dot{Q}_{top}$ [W]
80	20.3
120	23.54
150	29.35

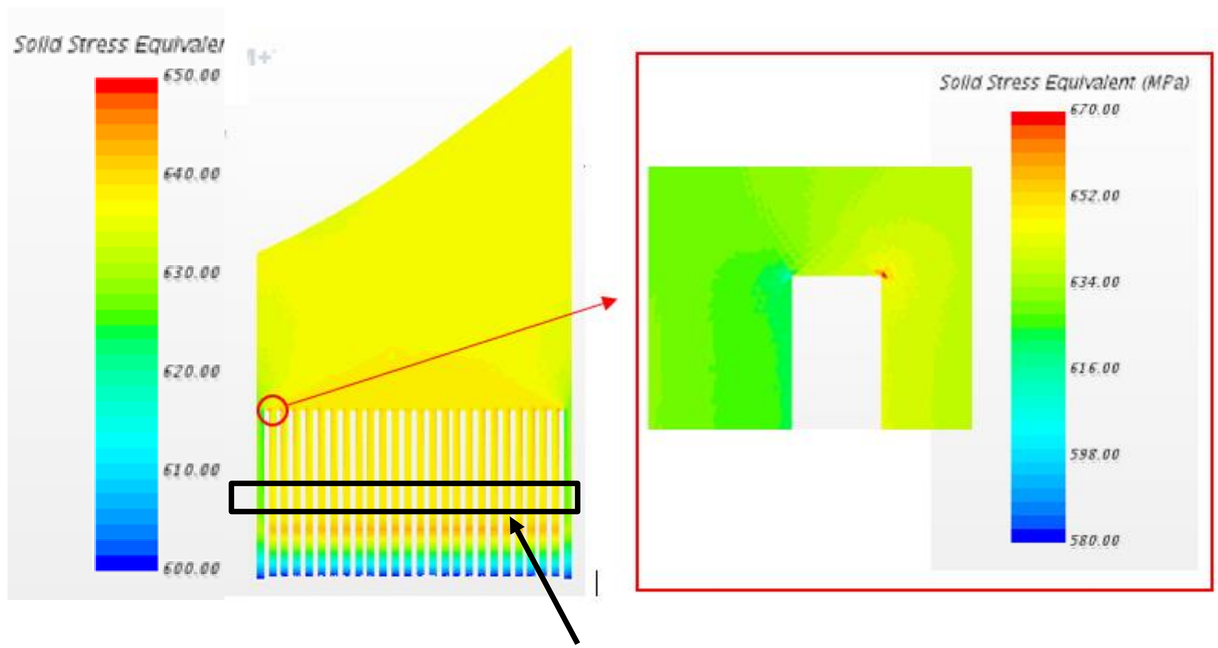
$for\ z8$



Thermo-mechanical results

- Stress computed on a single cell at the end of the plates.
- Peak value < limit everywhere





Location of the TA

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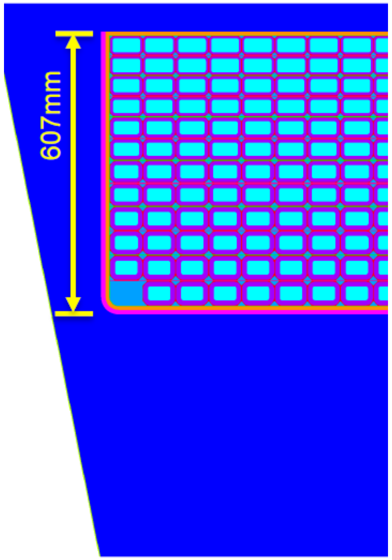
2. Optimization of the casing cooling channels: new ingredients

Conductor/WP layout (ENEA):

[L. Muzzi, ENEA TF Winding Pack Design and Analysis (EFDA_D_2NGZ2G), 2may2019]

- 3 holes in the conductor



- **Layer-wound** option analyzed here

Coil layout/drivers:

- 16 (vs 18) TF coils
- "New" casing design (ENEA)
- Heat loads:
  - "New" version of the nuclear heat load
  - Static heat load

[M. Colemann, Advanced definition of neutronic heat load density map on DEMO TF coils (EFDA_D_2MFVCA v2.0), 15jul2016]

[M. Colemann, Definition of the static heat load on the DEMO TF coils (EFDA_D_2N6VWA v1.0) 20sep2016]

BUT still computed for 18 TF coils (old baseline)!

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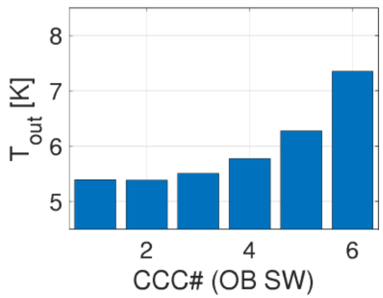
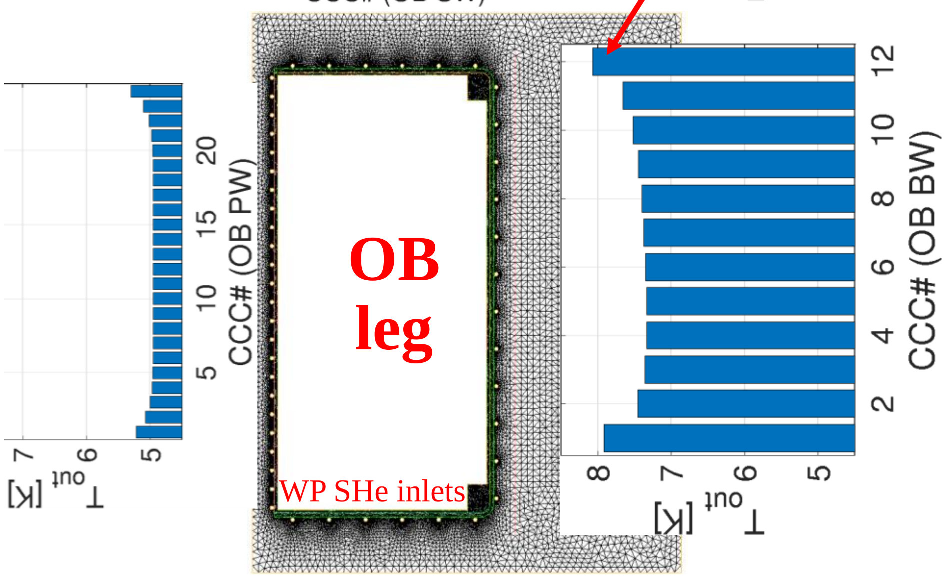
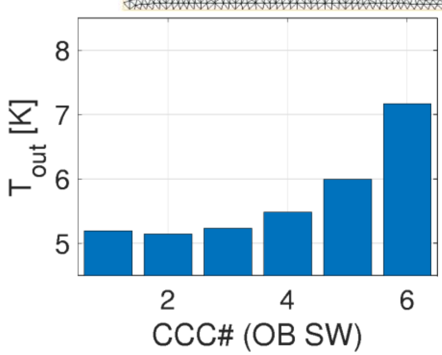
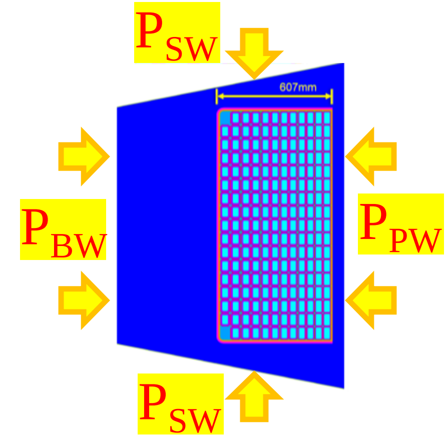
ITER-like CCCs design: Tout



Large temperature increase at BW OB **(up to ~3.5 K)**

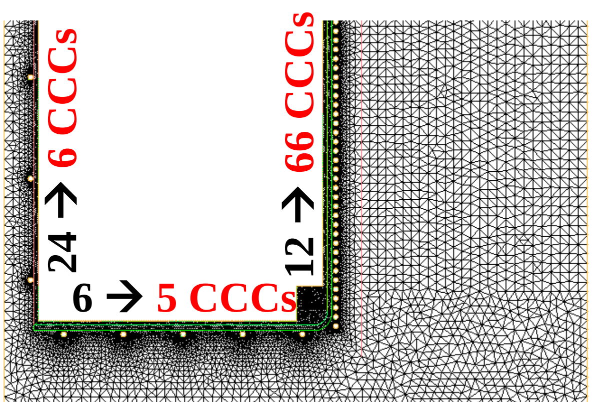






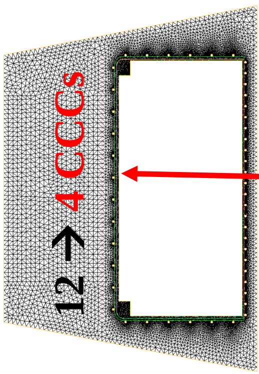
OPTIMIZED design

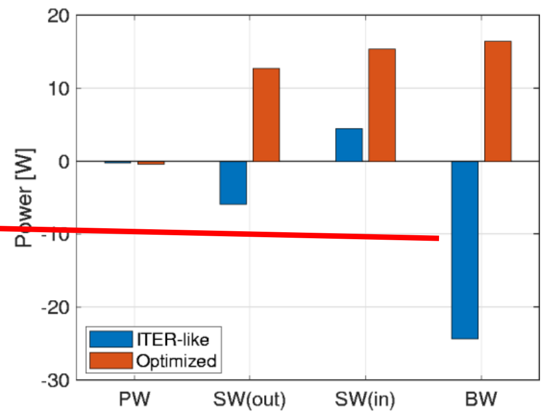
- **Keep same total # of CCCs**
- Split them proportionally to the static heat load on each side



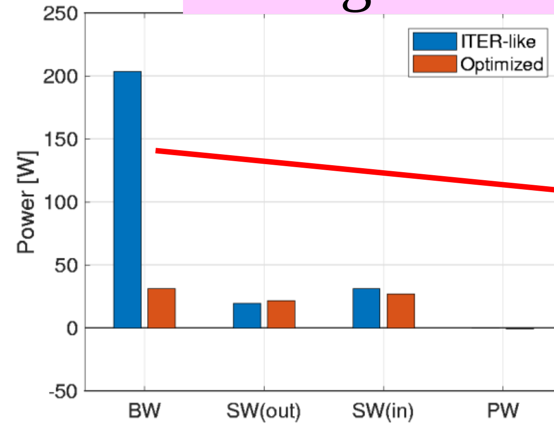
Optimized CCCs design: power to the WP

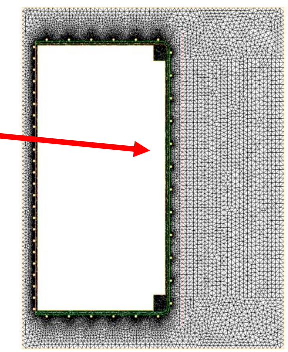
BW IB: Overcooling cancelled





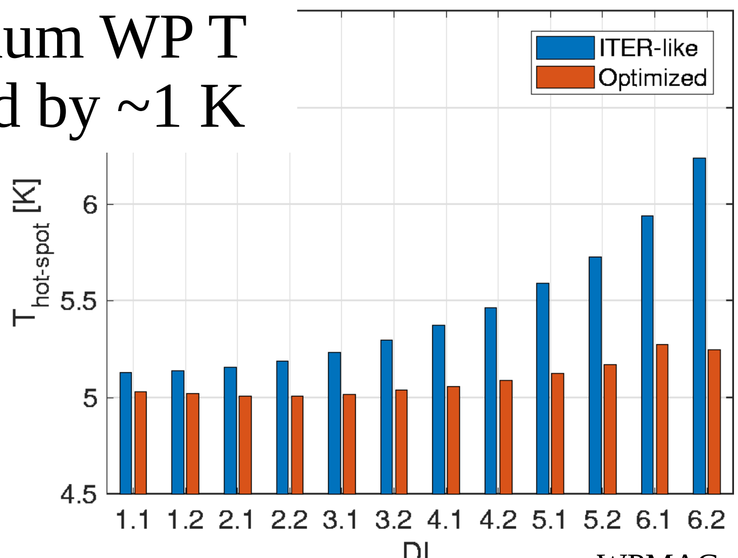
BW OB: Casing → WP heating reduced by 85%





WP SHe inlets

- Maximum WP T reduced by ~1 K



- First results show that the recooling time after FD is unaltered by the optimized CCCs configuration
- *The optimization can benefit of the thermal anchor on the GS*

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Conclusions / 2020 activity proposal

To sum up:

- Minimum thermal load to the TF casing considering TS temperature equal to 80 K and constant coolant temperature
- No issues from thermal stresses
- Additional TA @ T_{TS} beneficial (not shown)
- Optimization strategy of casing cooling channels distribution analyzed → Temperature peak in the WP during cold operation reduced by ~1 K

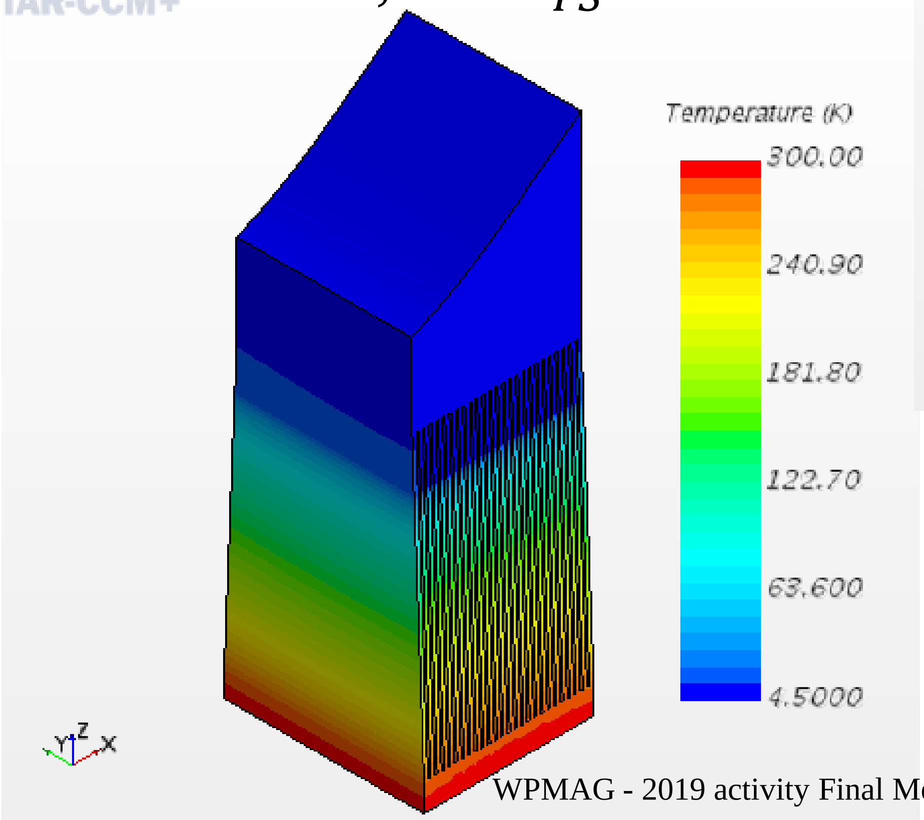
2020 activity:

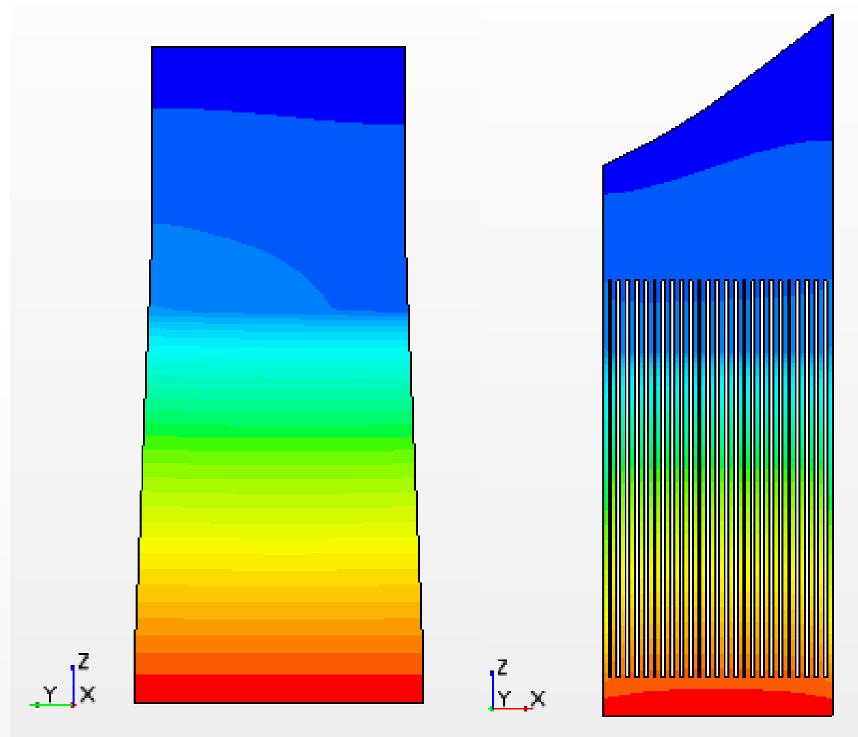
- Coupling GS thermal analysis with the analysis of temperature distribution in the coil
- Analysis of pancake-wound ENEA TF WP (+Setup of model for the SPC CS proposal)

Thank you for your attention!

Thermo-hydraulic analysis

Temperature map considering the minimum helium mass flow rate (re-routing of only BW IB CCC), thus maximum gradient between inlet and outlet, and $T_{TS} = 80\ K$



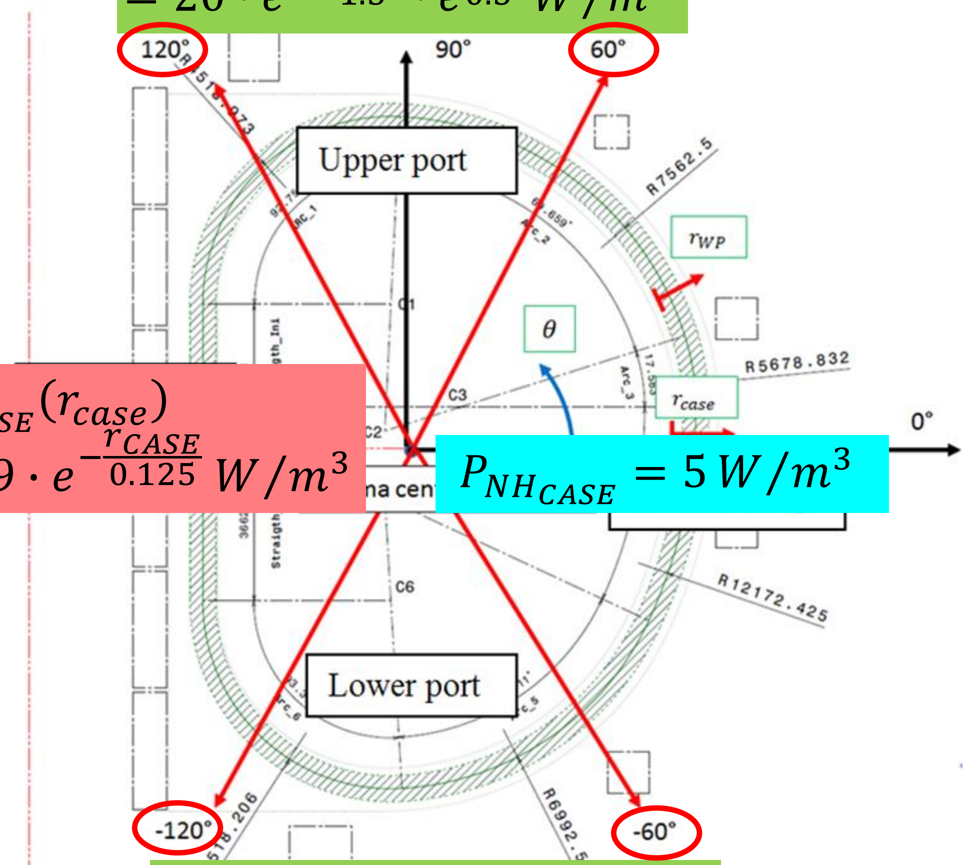


$$\boxed{\dot{Q}_{top} \sim 44\ W}$$

"New" version of the nuclear heat load

- Poloidal variation:

$$P_{NH_{CASE}}(r_{case}, z) = 20 \cdot e^{-\frac{r_{CASE}}{1.5}} \cdot e^{\frac{|z|}{0.5}}\ W/m^3$$



$$P_{NH_{CASE}}(r_{case}) = 68.9 \cdot e^{-\frac{r_{CASE}}{0.125}}\ W/m^3$$

$$P_{NH_{CASE}} = 5\ W/m^3$$

$$P_{NH_{CASE}}(r_{case}, z) = 20 \cdot e^{-\frac{r_{CASE}}{1.5}} \cdot e^{\frac{|z|}{0.5}}\ W/m^3$$

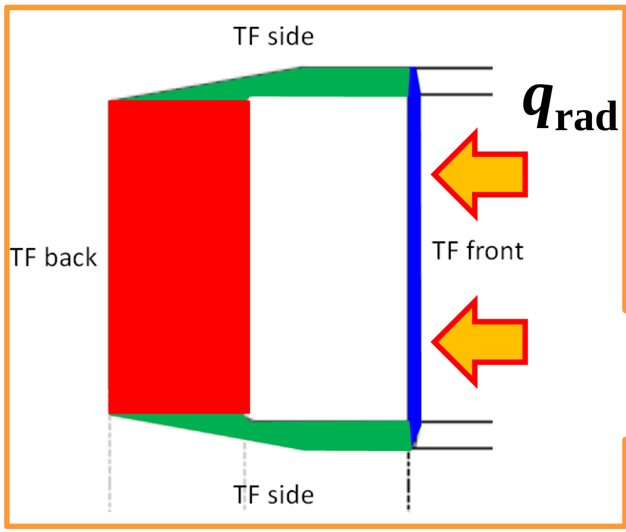
[M. Colemann, Advanced definition of neutronic heat load density map on DEMO TF coils (EFDA_D_2MFVCA v2.0), 15jul2016]

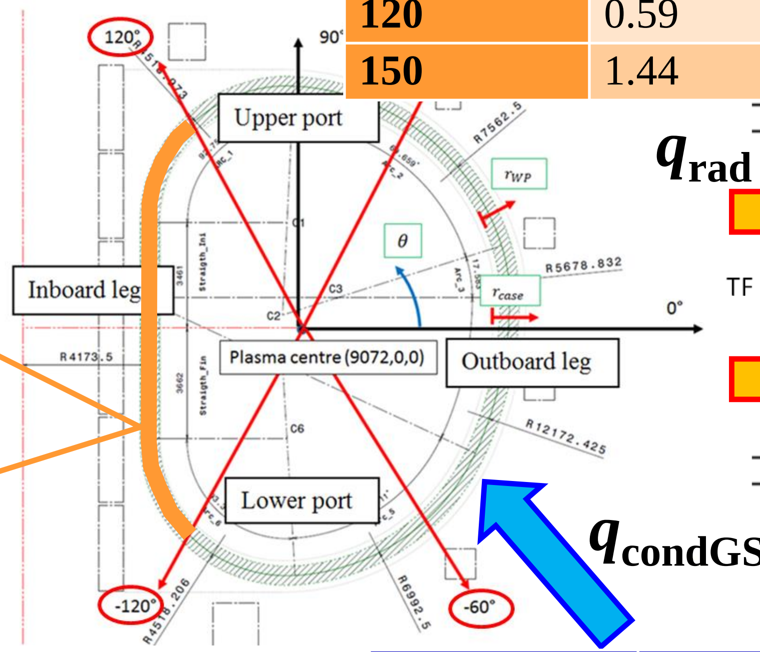
Still not consistent with the 16 coils!

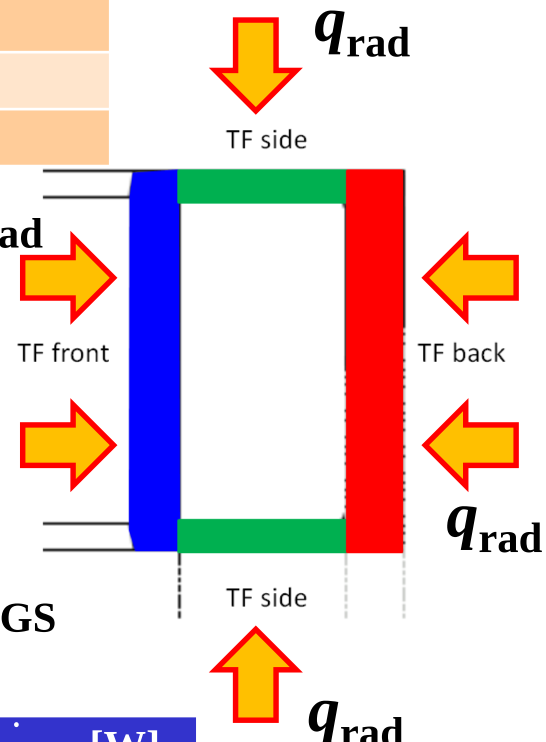
Static heat load

- Poloidal variation:

T_{TS} [K]	$\dot{q}_{rad}$ [W/m²]
80	0.12
120	0.59
150	1.44







T_{TS} [K]	$\dot{Q}_{cond_{GS}}$ [W]
80	244.63
120	374.24
150	471.45

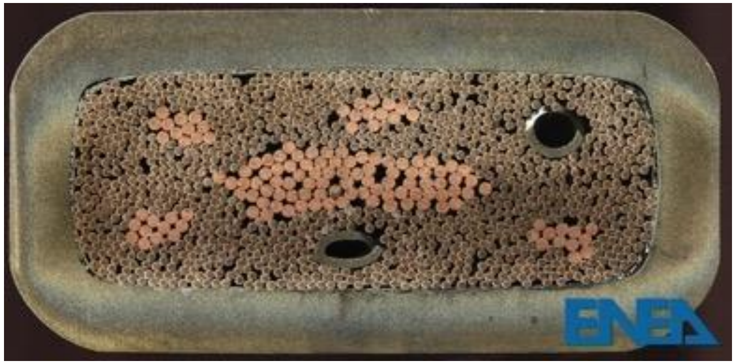
[M. Colemann, Definition of the static heat load on the DEMO TF coils (EFDA_D_2N6VWA v1.0) 20sep2016]

Still not consistent with the 16 coils!

ENEA conductor

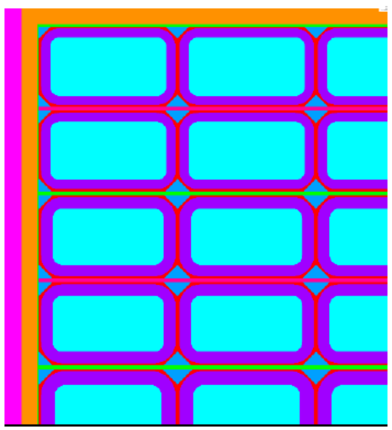
[L. Muzzi, ENEA TF Winding Pack Design and Analysis (EFDA_D_2NGZ2G), 2may2019]

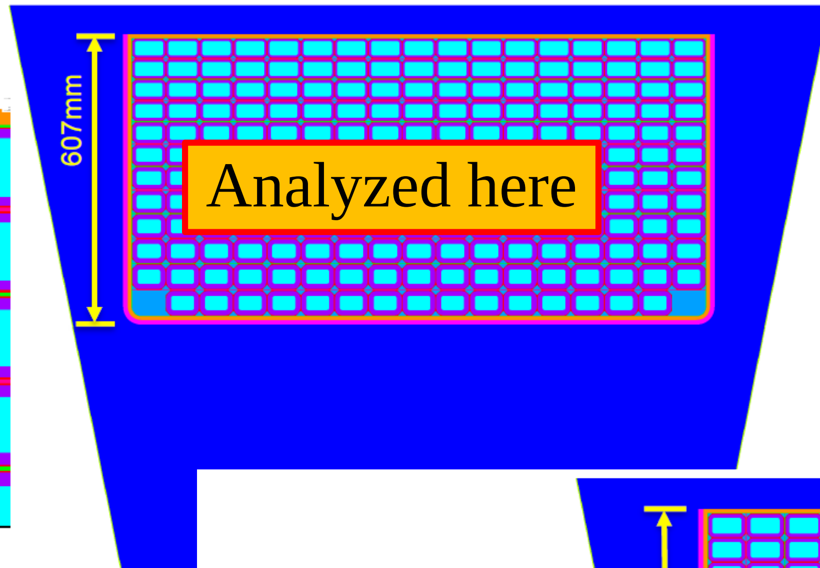
- WP#2, wind-and-react
  - Layer-wound: steel, Cu and SC grading
  - Pancake-wound: no grading
- NEW feature: 3 distributed pressure-relief channels



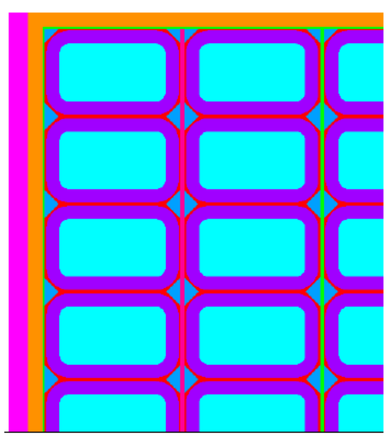
- 3 channels modeled as 3 × 1 channel (all identical)

Layer-wound vs. pancake-wound WP + new casing design (ENEA)





- Layer-wound: steel, Cu and SC grading
- 6 DLs

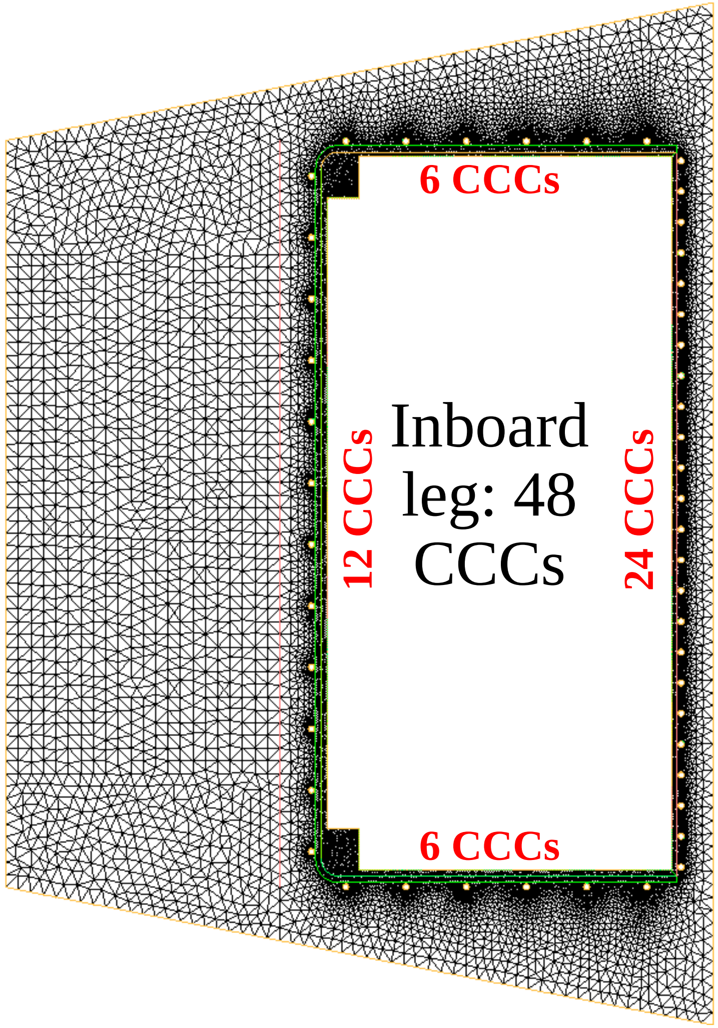


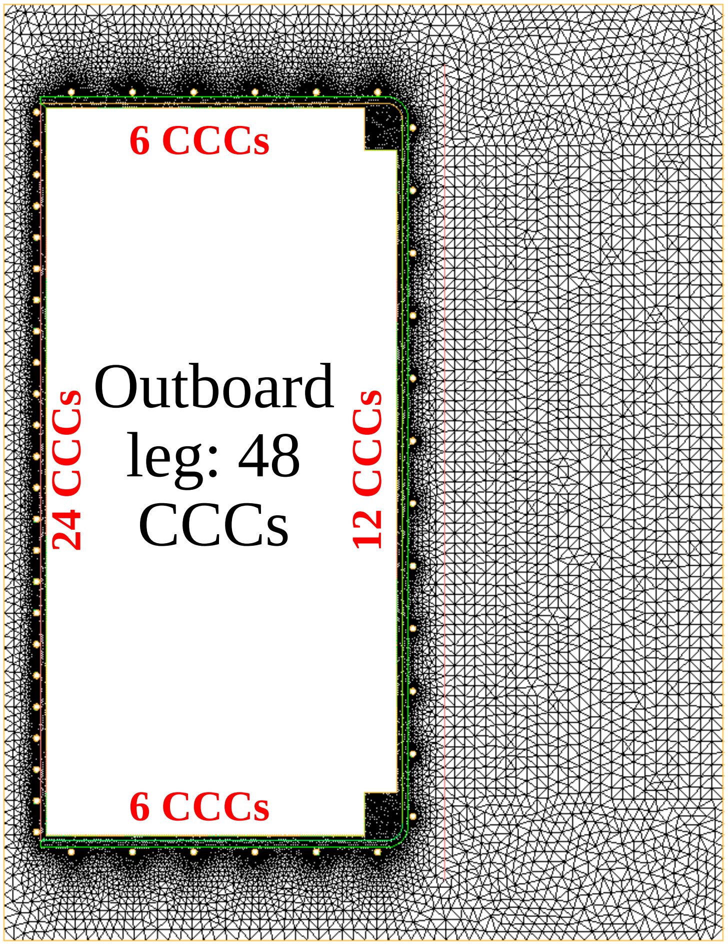
- Pancake-wound: no grading → **increased radial thickness**
- 8 DPs

[L. Muzzi, ENEA TF Winding Pack Design and Analysis (EFDA_D_2NGZ2G), 2may2019]

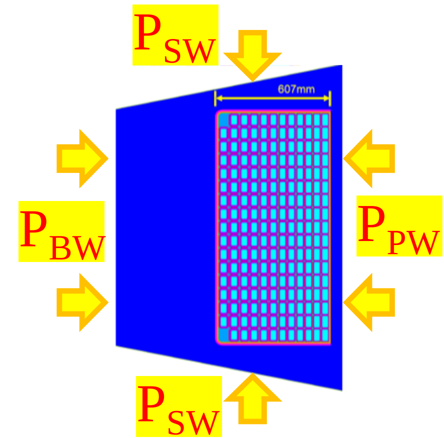
[L. Muzzi, private communication, September 2019]

ITER-like CCCs design





Casing cooling channels (CCCs) design



- Compute the heat load (static, dynamic) in the different walls of the casing (plasma-facing, side, back) in different transients
  - Normal operation
  - Fast discharge (at present, uniform power generation in casing due to eddy currents)
  - Cooldown

- Estimate the power that can be removed by each CCC in normal operation (steady state)

$$Q_{CCC} = A \times h \times (T_{case} - T_{He}) = dm/dt \times (T_{out} - T_{in})$$

Depends on the side → this procedure is not directly applicable

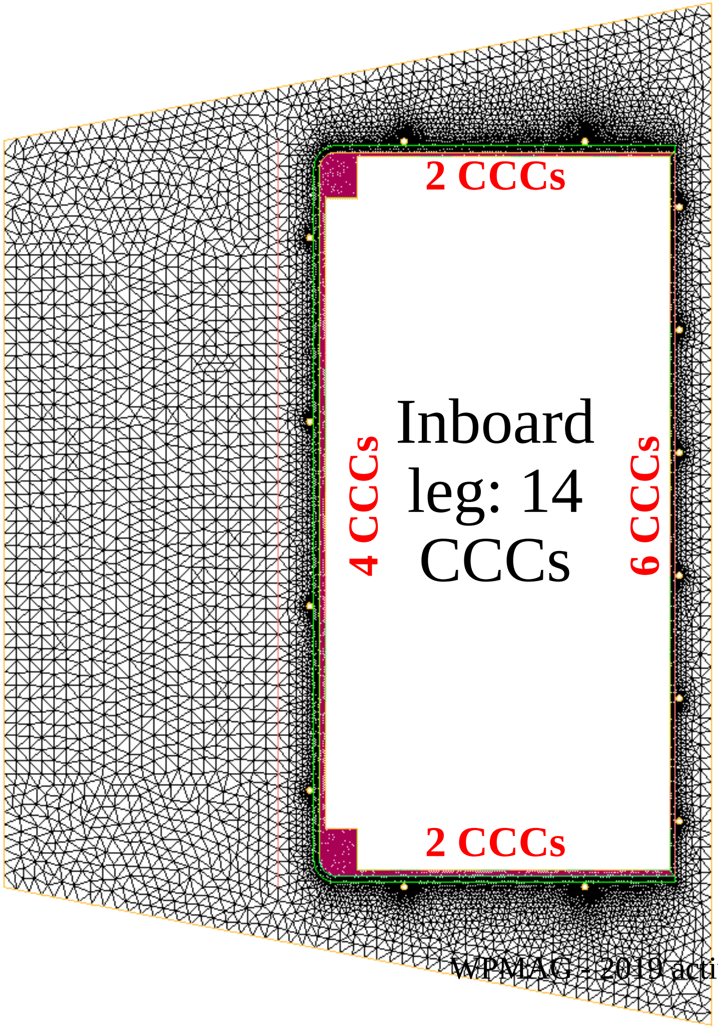
→ Retrieve the number of CCCs on each side, and cross-check for FD and cooldown:

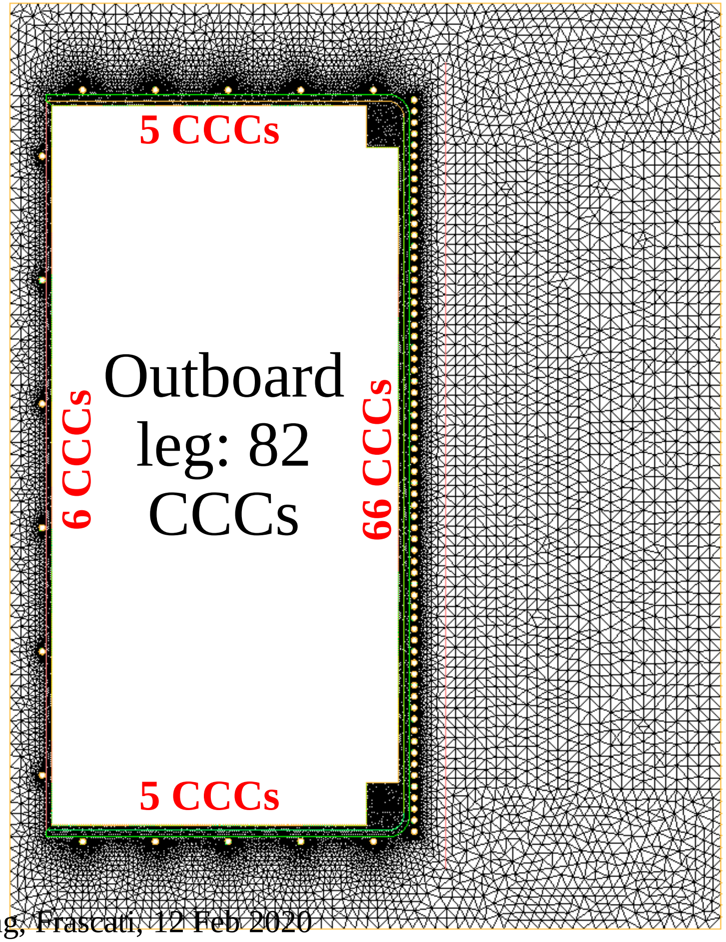
$$\#CCCs_{XW} = P_{XW}/Q_{CCC}$$

→ Start the dimensioning of the structure cooling feeders (*extra-budget activity in collaboration with SPC*)

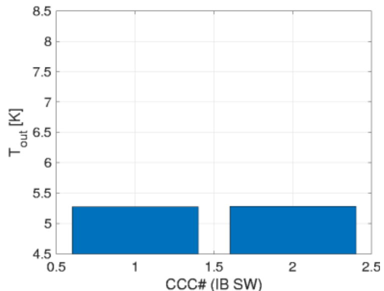
Optimized CCCs design

- **Keep same total number of CCCs**
- Split them proportionally to the static heat load on each side

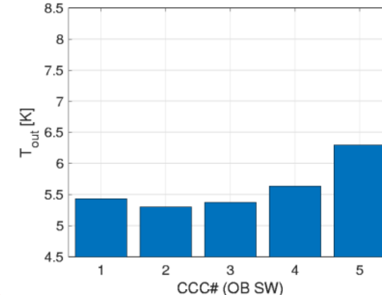


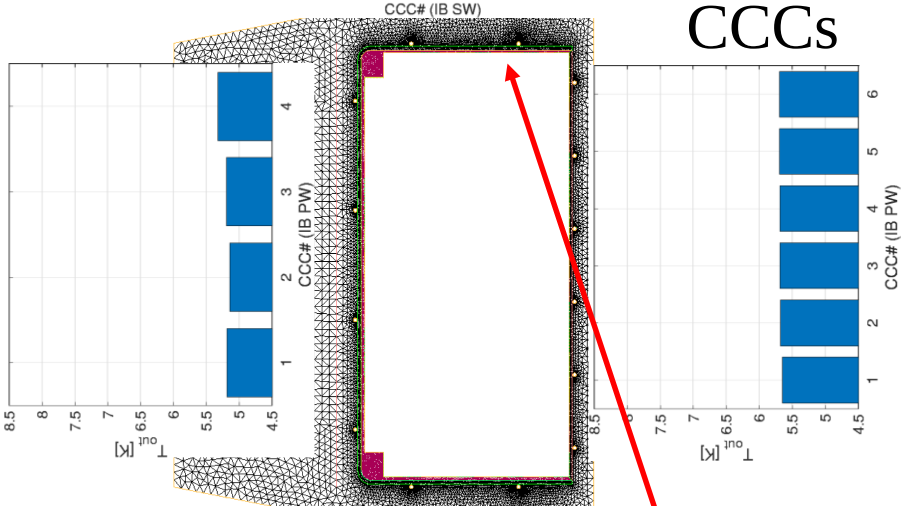


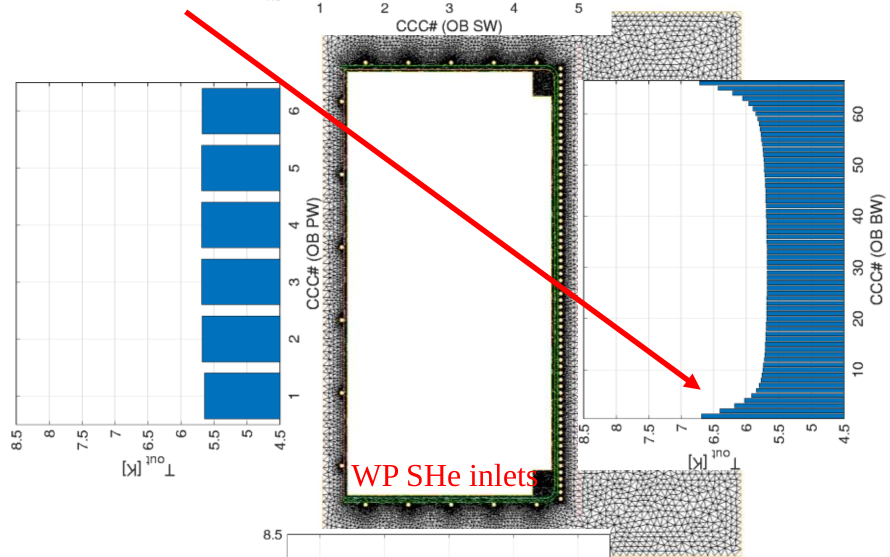
Optimized CCCs design: Tout

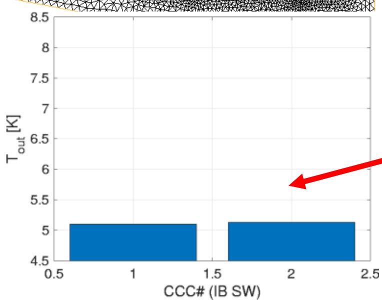


- T increase ~1 K almost everywhere
- T increase up to 2 K in few BW OB CCCs









- Remove all SW IB CCCs?