Karlsruhe Institute of Technology

# Design validation of the CVD diamond window unit for the ITER EC H&CD Upper Launcher

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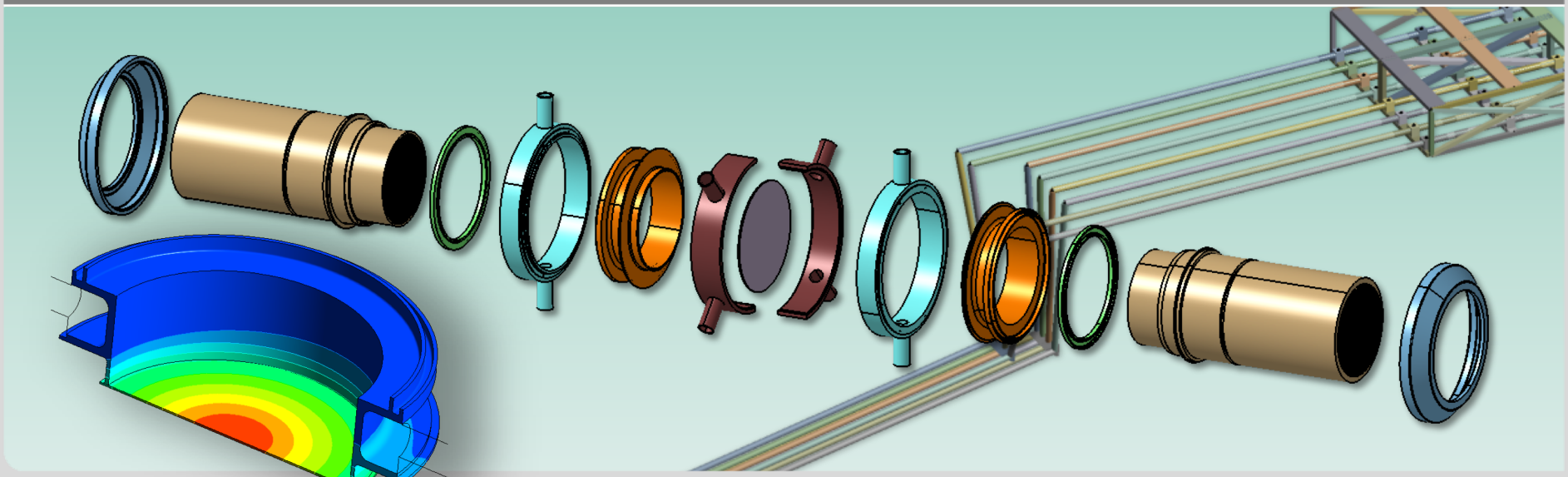
Institute for Applied Materials – Applied Materials Physics

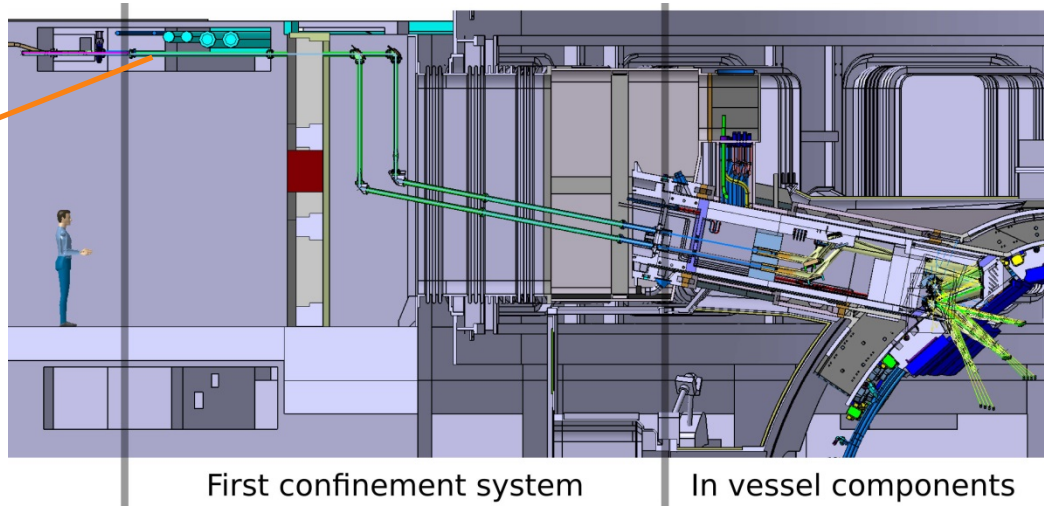


# Outline

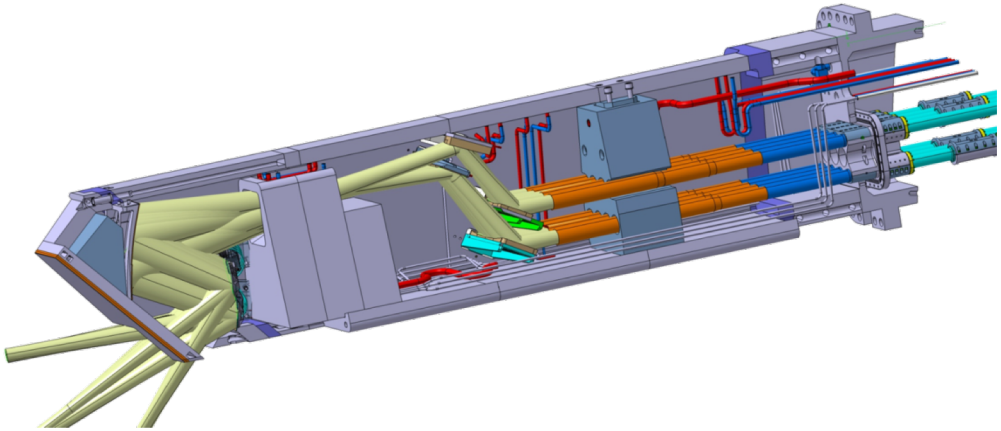
- The ITER EC H&CD Upper Launcher
- Design philosophy of the window unit
- Design aspects improved by FEM analyses
- Optimum design solution
- Design aspects checked by FEM analyses
- Manufacturing and assembling
- Conclusions and outlook

# The ITER EC H&CD Upper Launcher

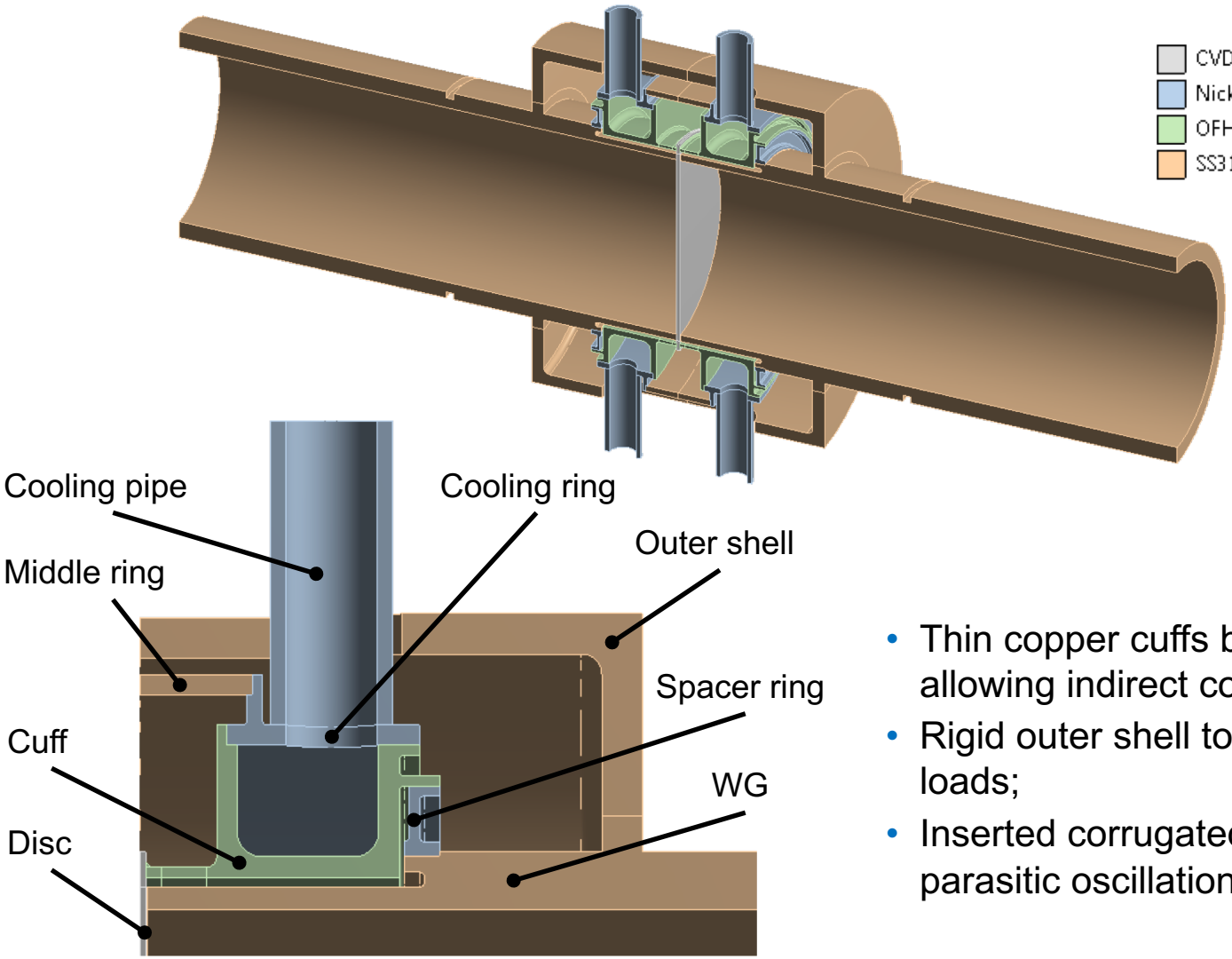
The window units are here located.




The Upper Launcher consists of an assembly of ex-vessel WGs and an in-vessel port plug.

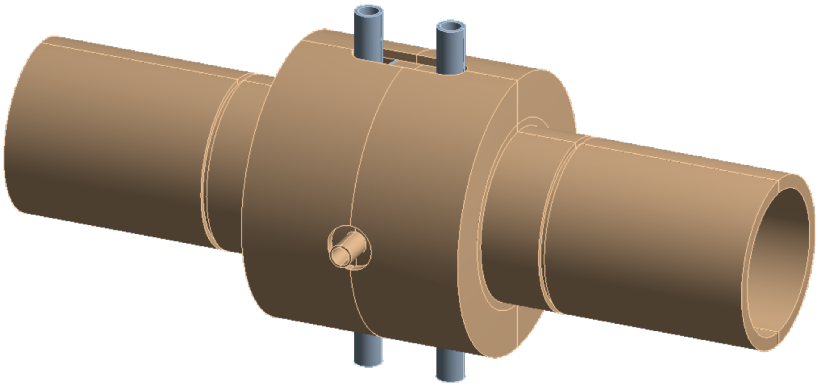


# Design philosophy of the window unit




- Thin copper cuffs brazed to the diamond allowing indirect cooling of the disc;
- Rigid outer shell to withstand the external loads;
- Inserted corrugated WGs to suppress the parasitic oscillations.

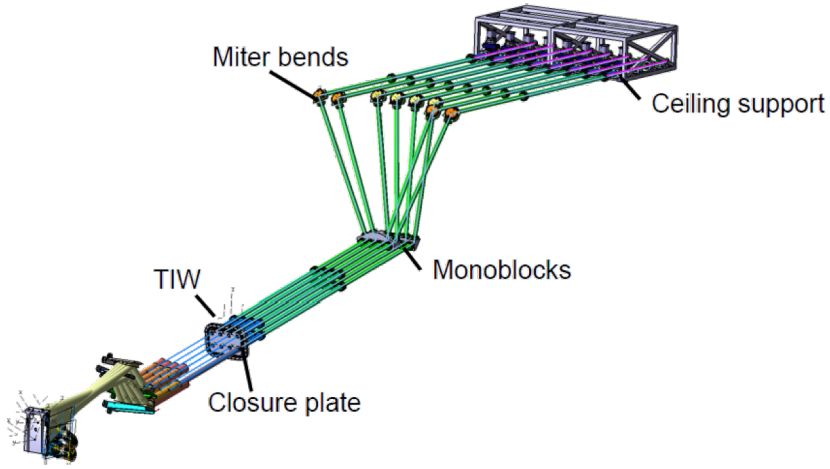
# Need of a new outer shell

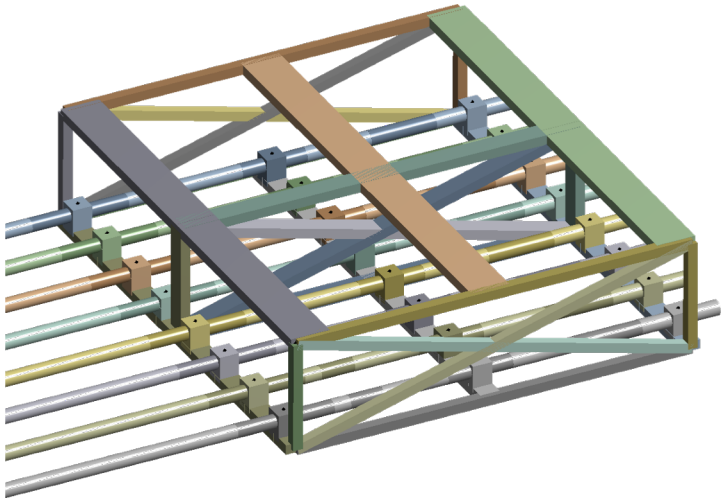


Reasons for a new design of the outer shell:

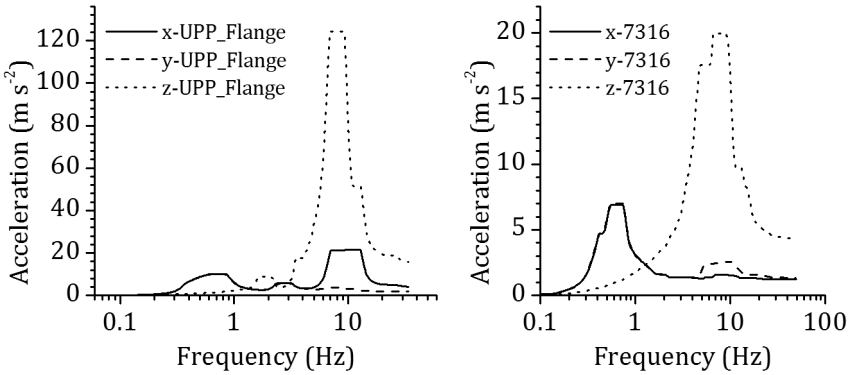
- Provide a second tritium barrier;
- Allow real-time monitoring of all interspaces to detect potential tritium leakages;
- Make the design simpler to manufacture and assemble.

The seismic event SL-2 during the baking of the ITER vacuum vessel is the design driver.



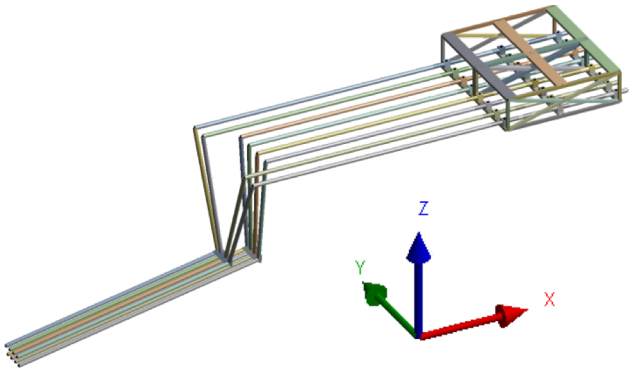



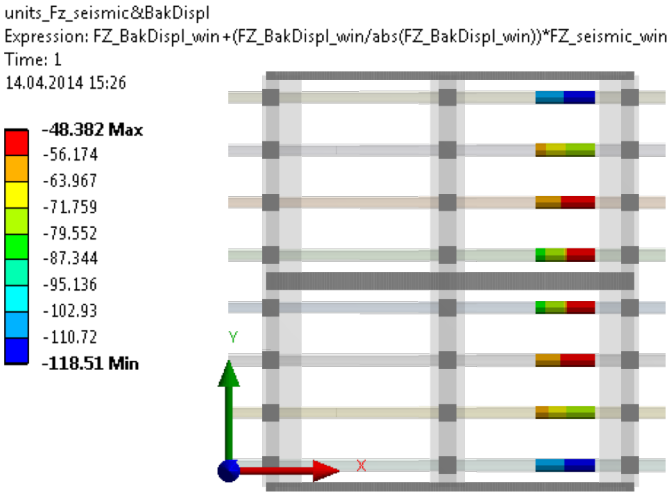
# Forces and moments acting on the units




| VV-to-UL displacements from F4E_D_25QD28 | | | |
|---|---|---|---|
| **Load condition** | **Δx [mm]** | **Δy [mm]** | **Δz [mm]** |
| VV Operation (100°C) | 14.9 | -0.8 | 19.2 |
| VV baking (200°C) | 34.7 | -1.8 | 44.9 |
| Displacements to be applied in the analysis | **19.8** | **-1** | **25.7** |

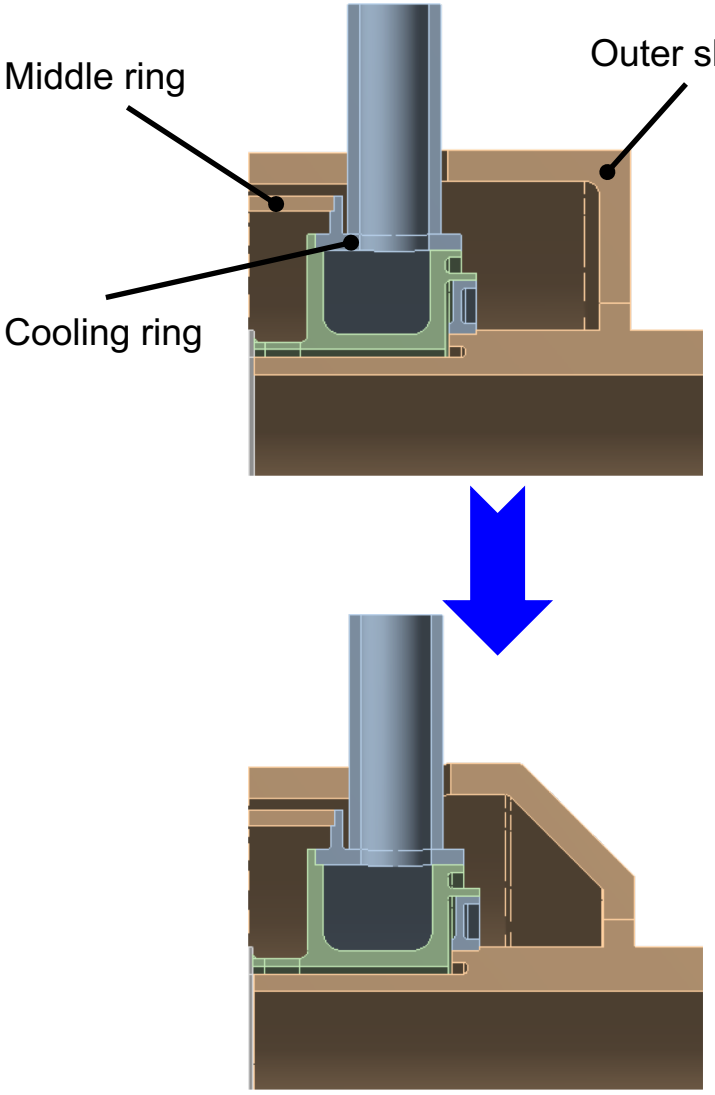
| VV-to-UL displacements from F4E_D_25QD28 | | | |
|---|---|---|---|
| **Load condition** | **Δx [mm]** | **Δy [mm]** | **Δz [mm]** |
| SL-2 | -0.5 | -3.7 | -5.3 |

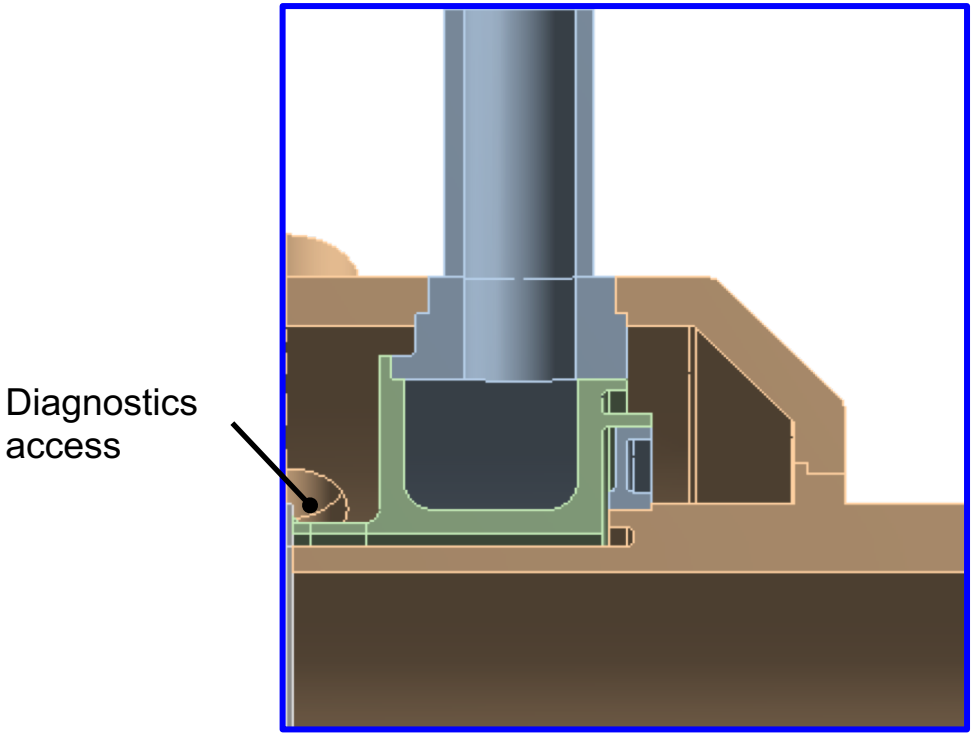


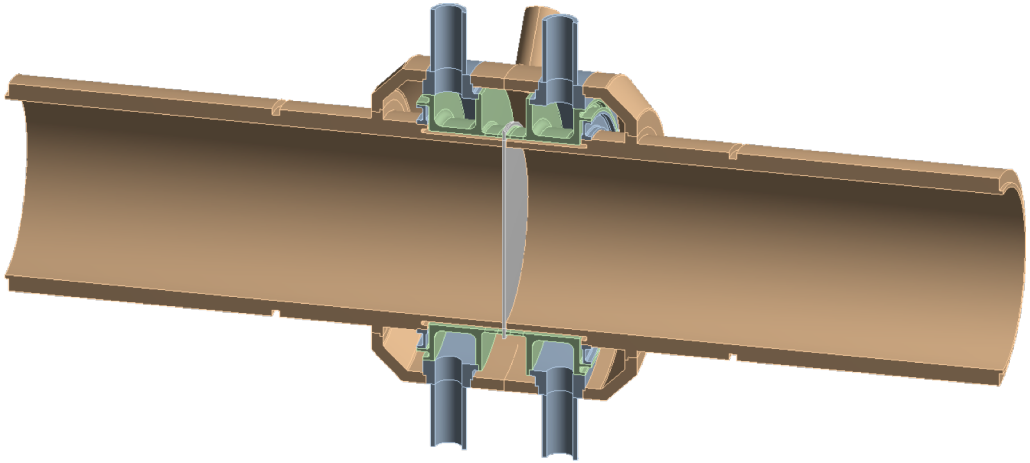

| | Max values | SL-2 (FRS) | SL-2 (Displ.) | SL-2 (FRS & Displ.) | Baking (Displ.) | SL-2 & Baking |
|---|---|---|---|---|---|---|
| Window units | Fx [N] | 12.287 | 3.47E-09 | 12.287 | 3.91E-08 | 12.287 |
| | Fy [N] | 16.659 | 0.46748 | 16.842 | 2.9843 | -19.499 |
| | Fz [N] | 61.959 | 6.1504 | 63.865 | -55.366 | -118.510 |
| | Mx [N m] | 14.544 | 0.38969 | 14.783 | -2.6252 | 16.147 |
| | My [N m] | 18.165 | 2.1686 | 18.29 | 19.111 | 33.444 |
| | Mz [N m] | 6.123 | 0.13673 | 6.1864 | 0.76442 | 6.286 |

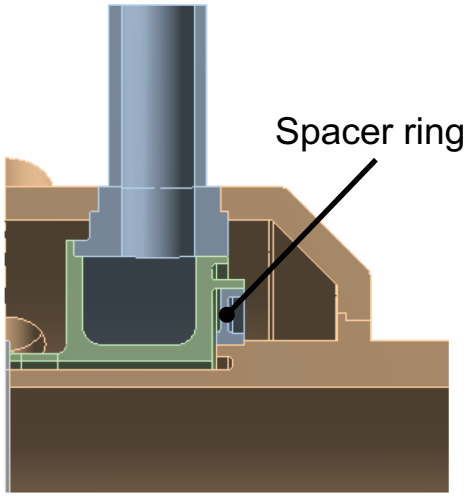
# Different design variants



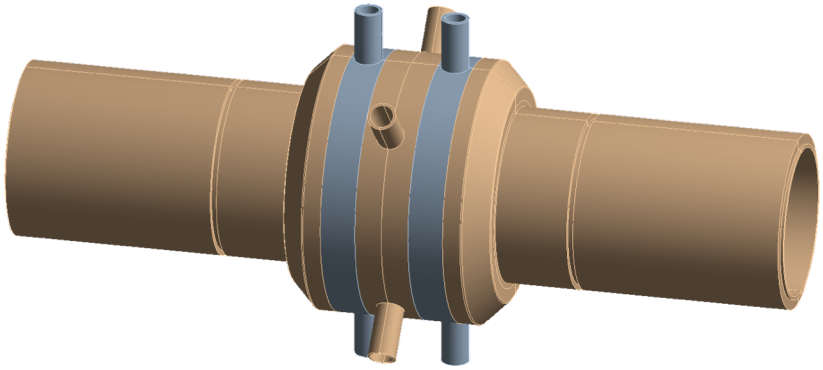



# Optimum design solution



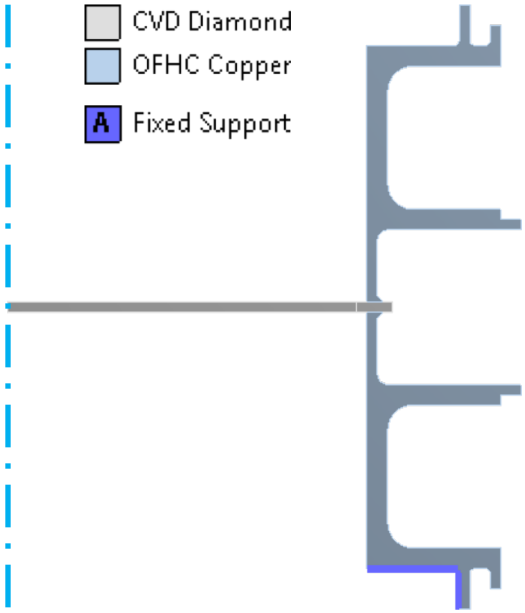



- Design is more compact and simpler to manufacture.
- Second tritium barrier with monitored interspaces is incorporated.
- The stiff outer frame reduces the stress in the nickel spacer rings to about **30 MPa** (it was ~ 70 MPa).



# Brazing with cuffs only (1st opt)

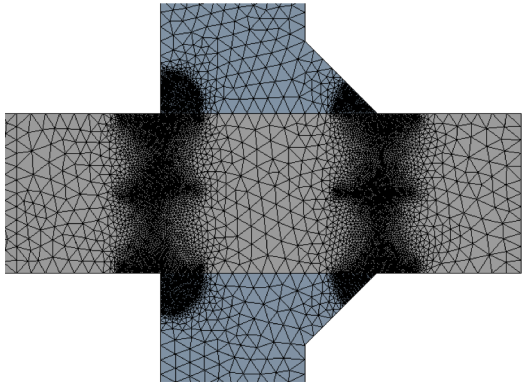
$\alpha_{Cu}/\alpha_{Diam} \sim 16$




- The model includes the diamond disc (1.111 mm thick, Ø 75 mm) and the copper cuffs.
- 2-D axial-symmetric model.
- Temperature from 800°C down to 20°C.
- Stresses in the disc sampled at 51 μm away from the singularities.

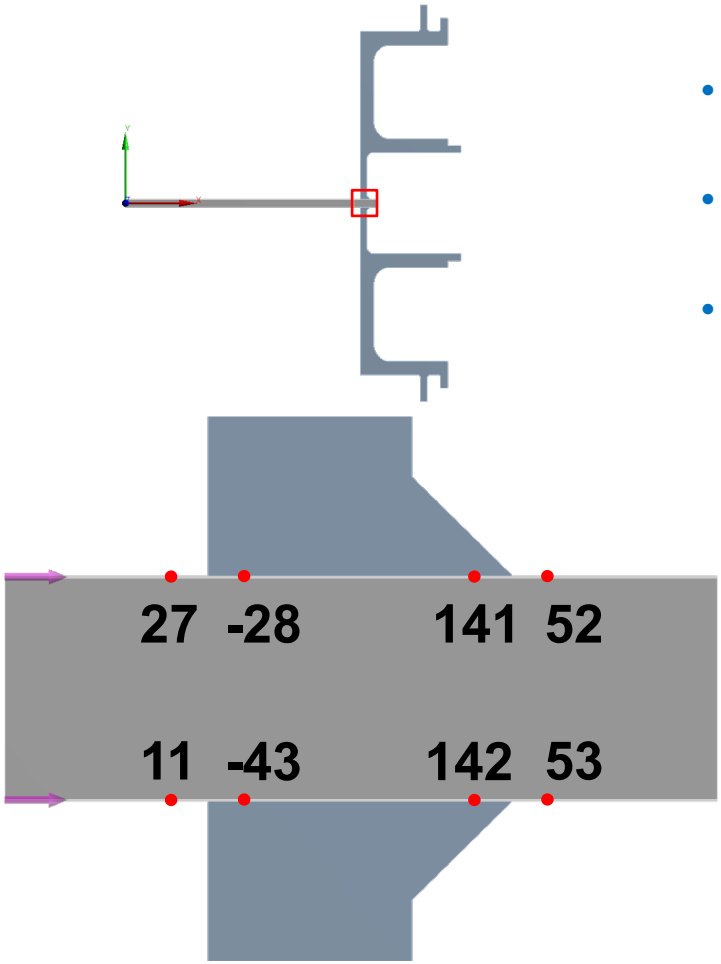
$$\sigma_r = \frac{K_{Ic}}{1.24\sqrt{r}} \Rightarrow r = 51\ \mu m$$

$\sigma_r$ = ultimate stress of CVD diamond (450 MPa)
$K_{IC}$ = fracture toughness of CVD diamond (4 MPa $m^{1/2}$)
$r$ = radius of the critical flaw that gives rise to fracture



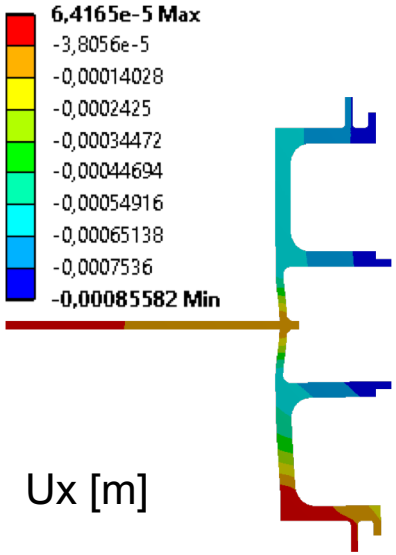
Sphere of influence with element size of ~ **10 μm**.

# Results of the brazing analysis

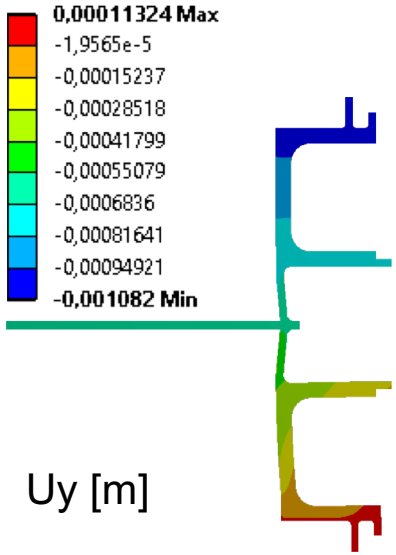



Maximum principal stress [MPa] in the disc.

- The maximum principal stress in the disc is below the **150 MPa safety limit** assumed for diamond.
- The equivalent stress in the cuffs at the interface with diamond is in the range 80-100 MPa for the most part.
- However, EB welding between the cuffs and the cooling rings might be unfeasible due to the deformations.

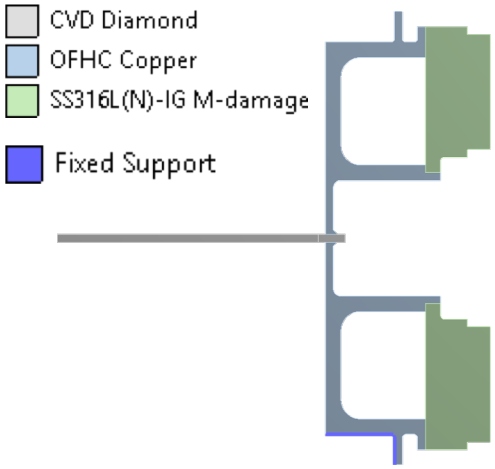


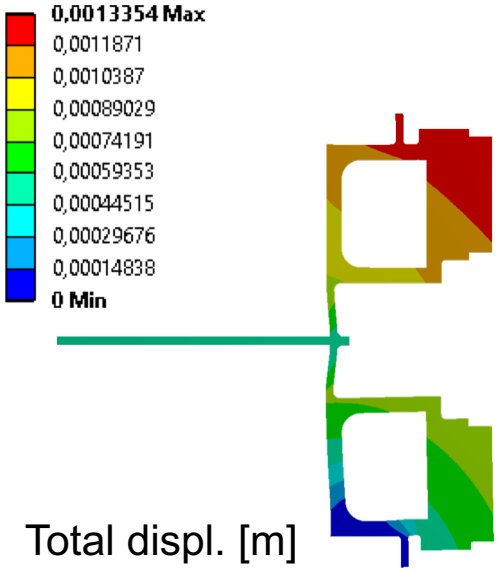

Ux [m]




Uy [m]

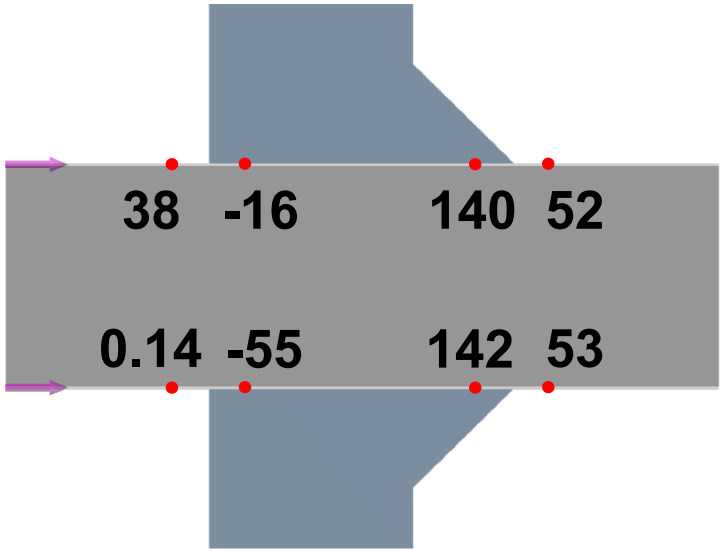
# Brazing with cuffs and cooling rings (2nd opt)



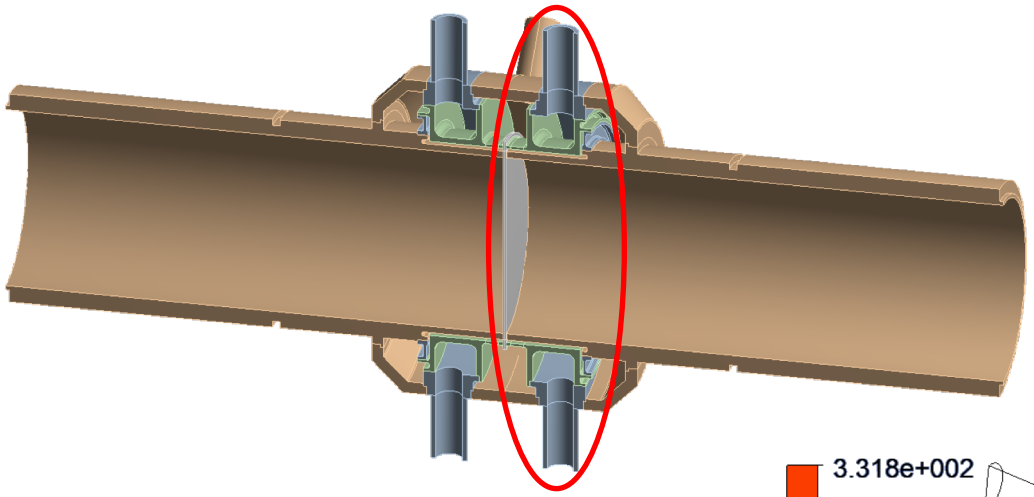

Total displ. [m]

- The maximum principal stress in the disc is still below the 150 MPa safety limit.
- The equivalent stress at the interface with diamond is in the range 80-120 MPa for the most part.
- Assembling of the unit is improved.



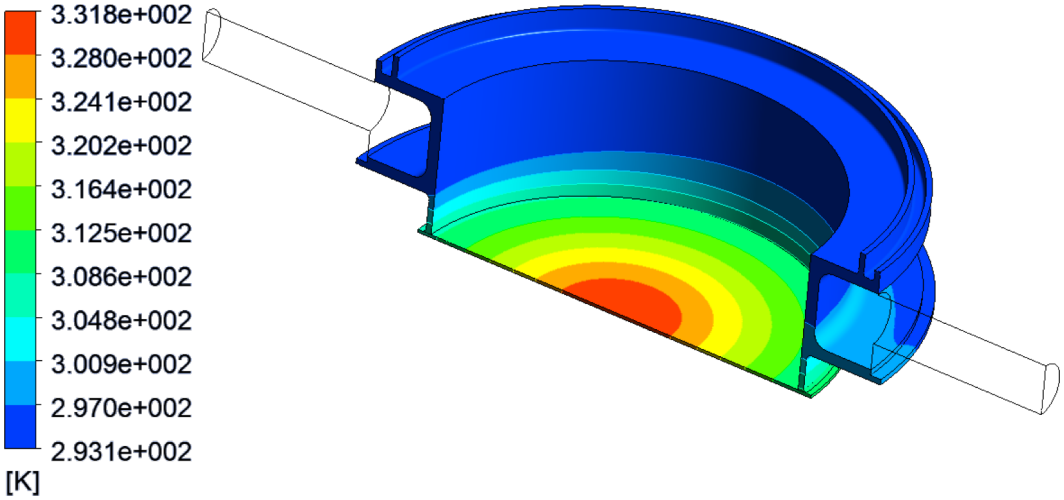

Maximum principal stress [MPa] in the disc.

# Thermal and fluid-dynamic behaviour



CFD conjugated heat transfer analysis on ¼ of the unit.
The structural parts are scarcely heated and are omitted.

- 1 MW $HE_{11}$ mode beam
- 20 l/min at 20°C for the complete window unit (there are two inlets)
- Loss tangent $2\times10^{-5}$: 264 W absorbed at 170 GHz

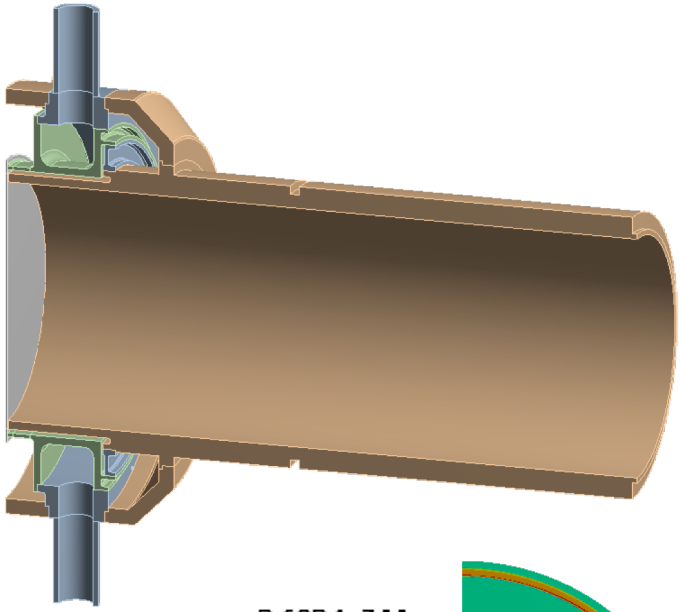


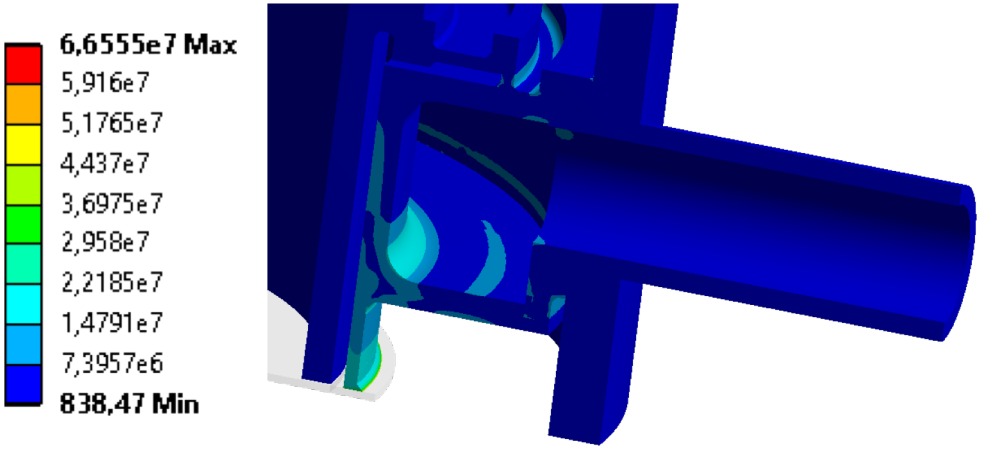

Max temperature in the disc is lower than 60°C and pressure drop is limited to 5.7 kPa.

# Operating conditions

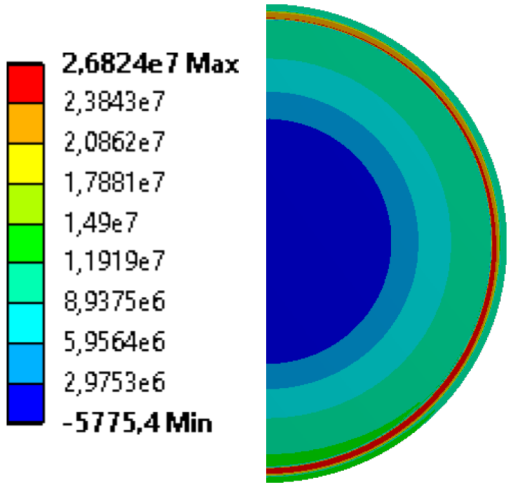
Loads applied to the unit:

- Dead weight
- Temperature distribution in the disc and the copper cuffs
- Fluid pressure (9 bar absolute)
- External atmospheric pressure (1 bar)





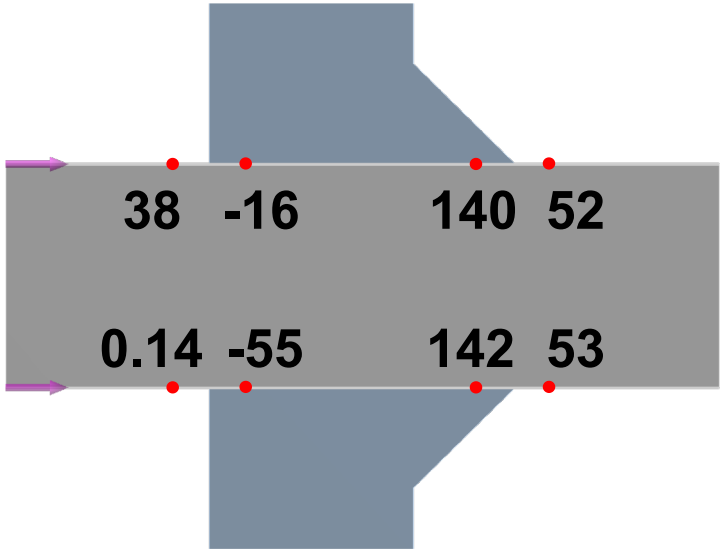

Equivalent stress [MPa]



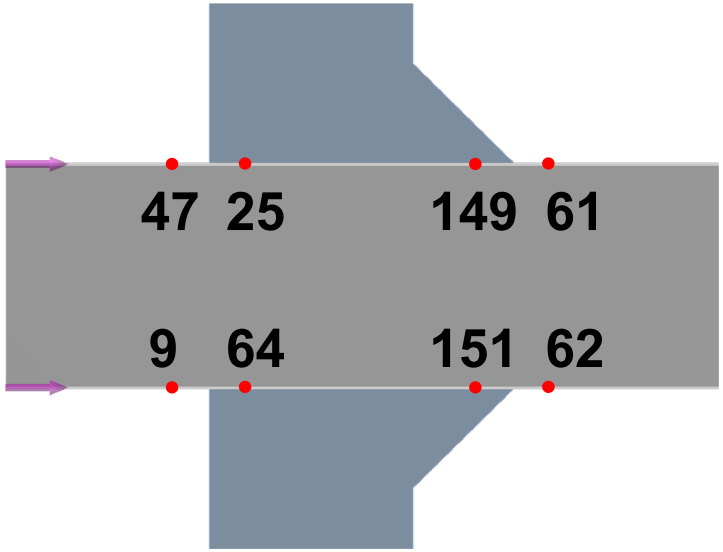

Maximum principal stress [MPa]

# Brazing + Operating conditions for the disc

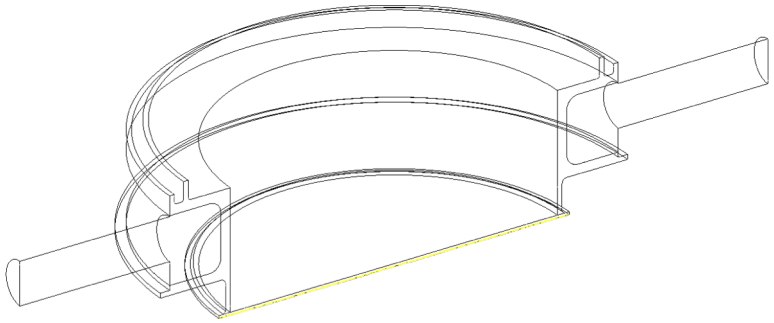
## Brazing only (2nd option)

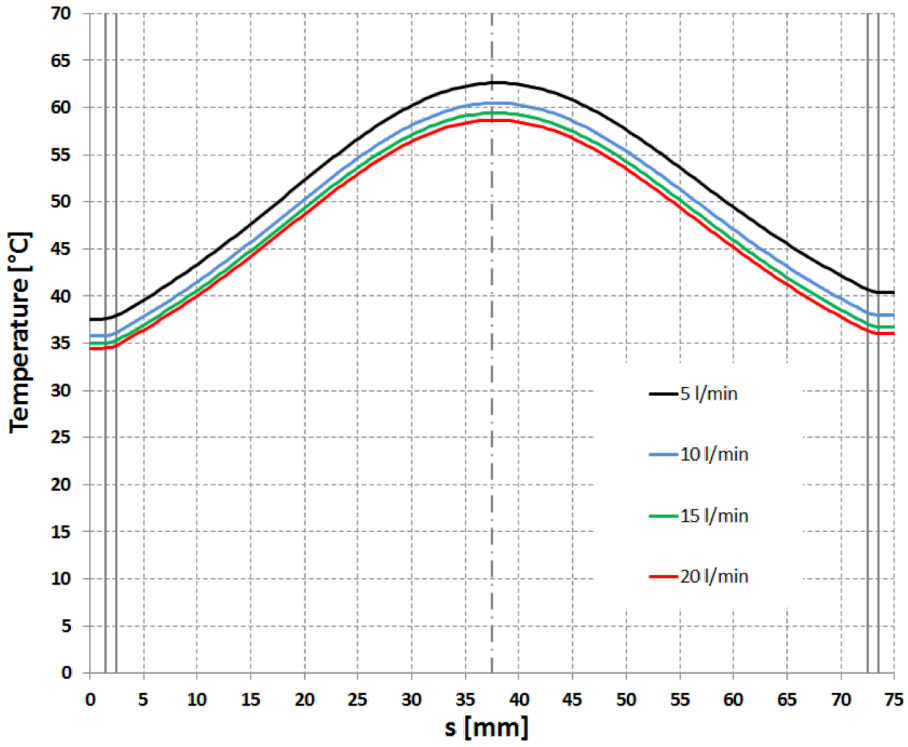



## Brazing + Operating conditions



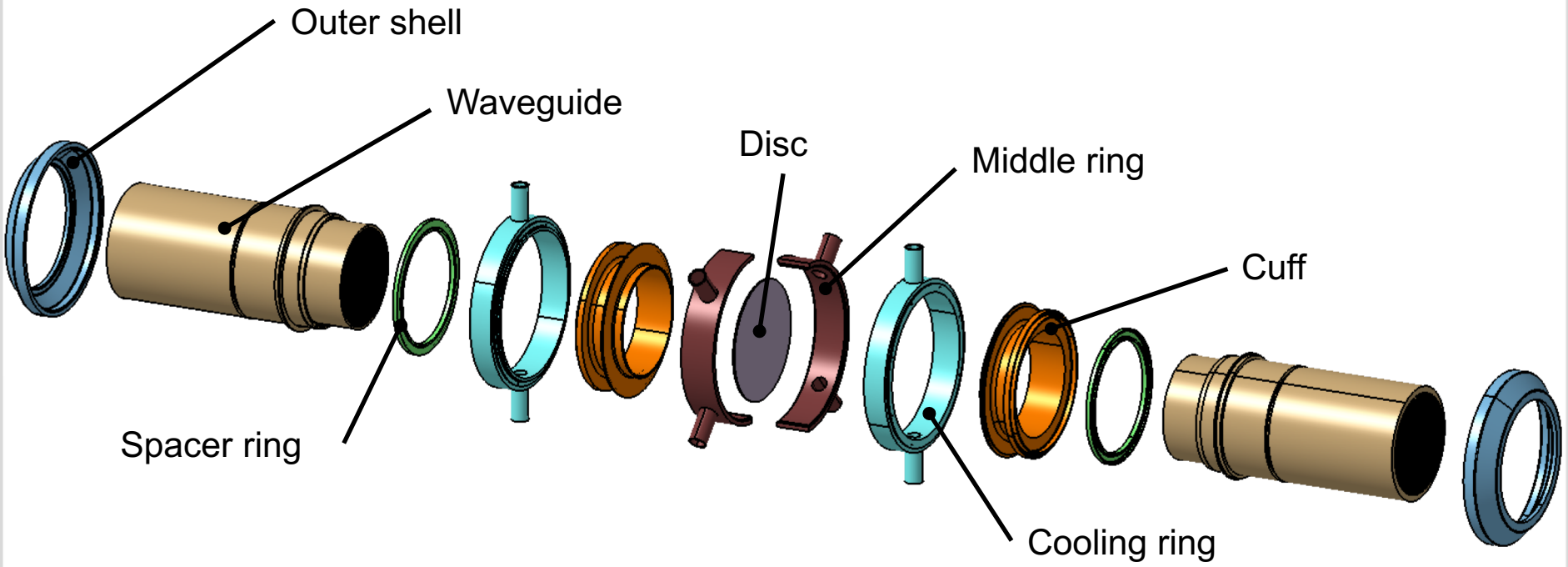
# Sensitivity analysis



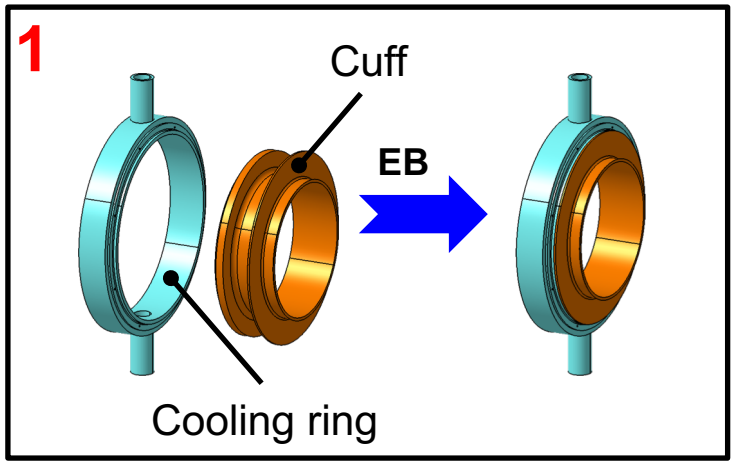



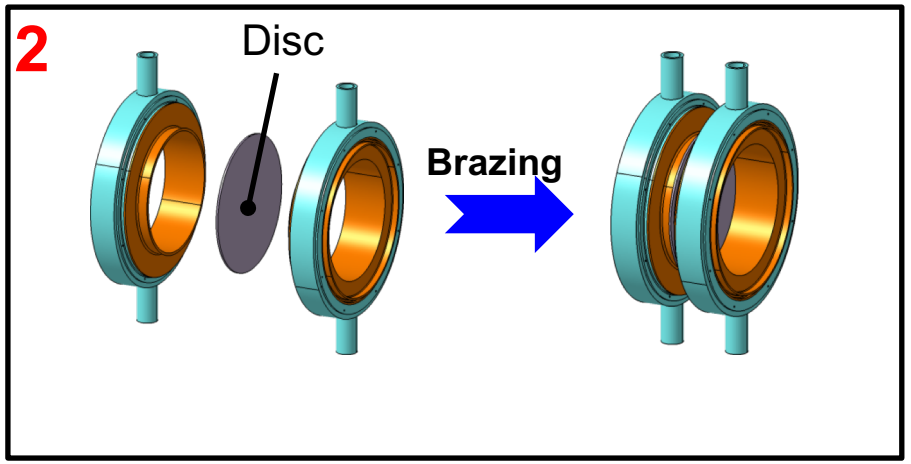

- Very stable thermal performance with regards to variations of the inlet mass flow rate.
- Temperature increased by only 4°C.

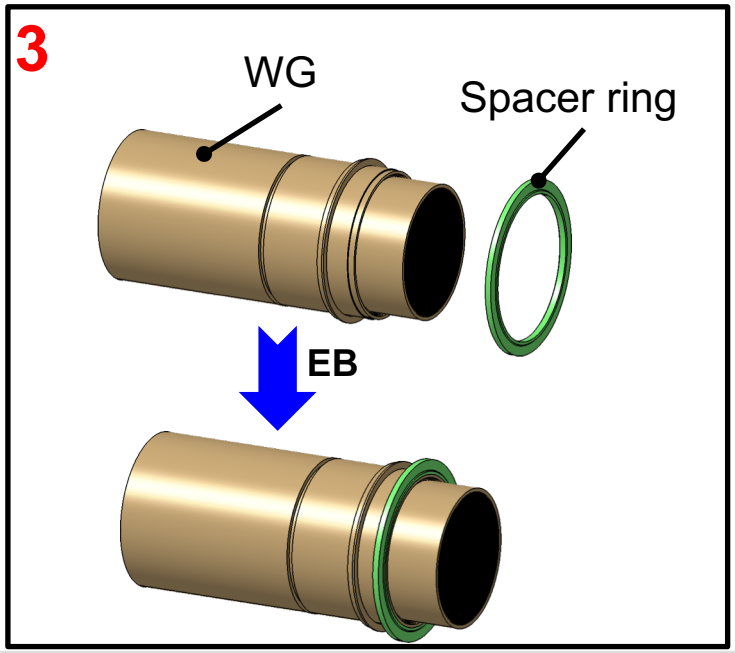
# Exploded view of the unit

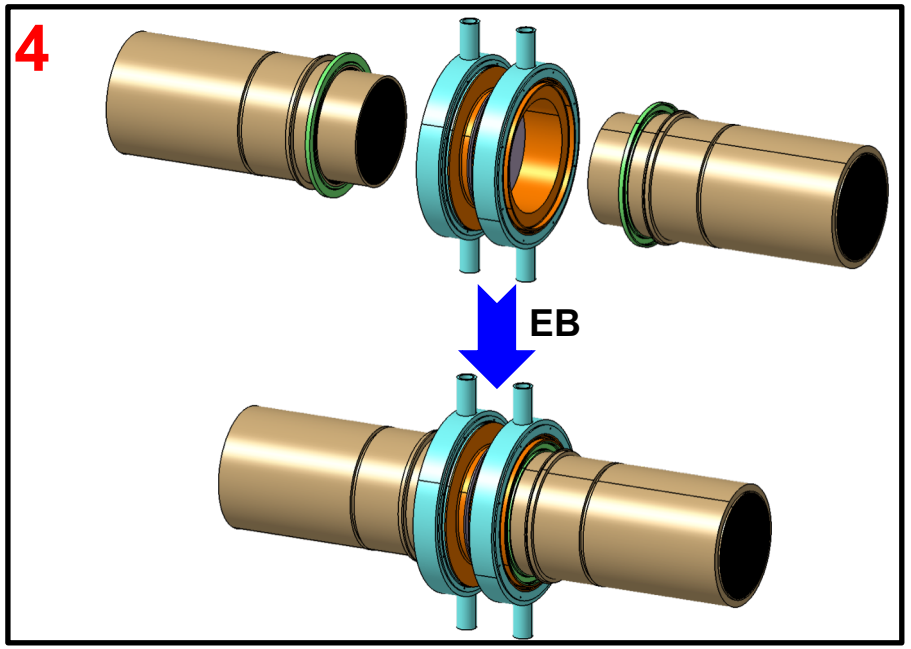


# Assembling sequence of the unit



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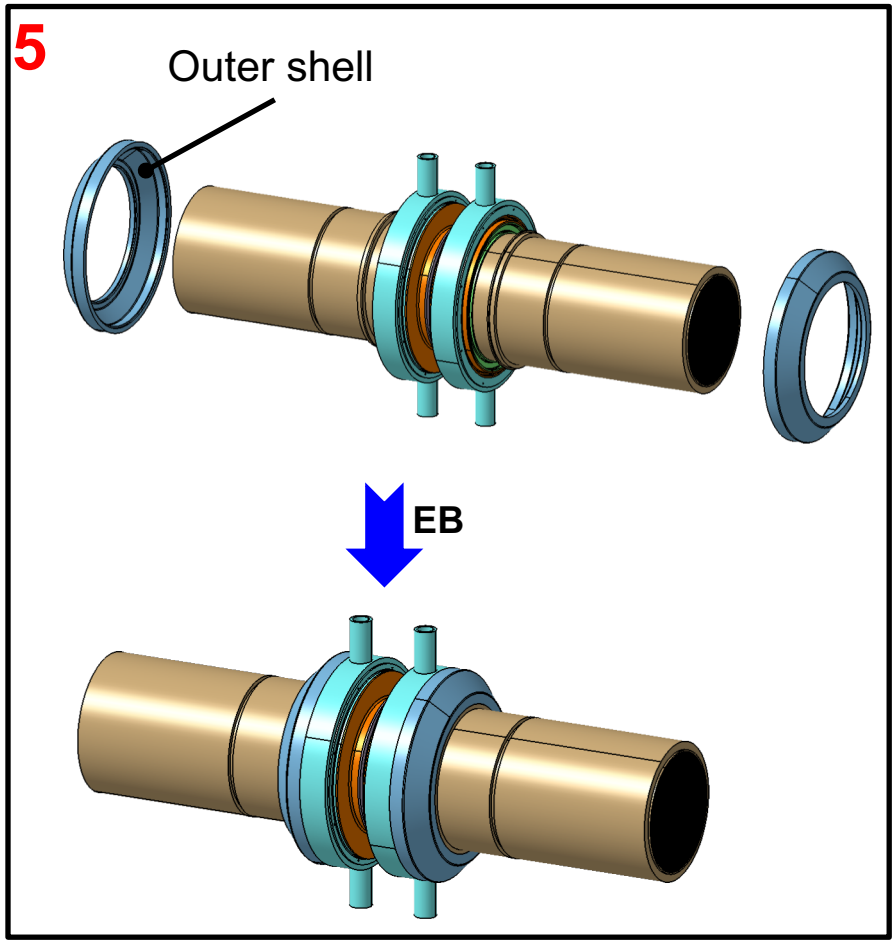


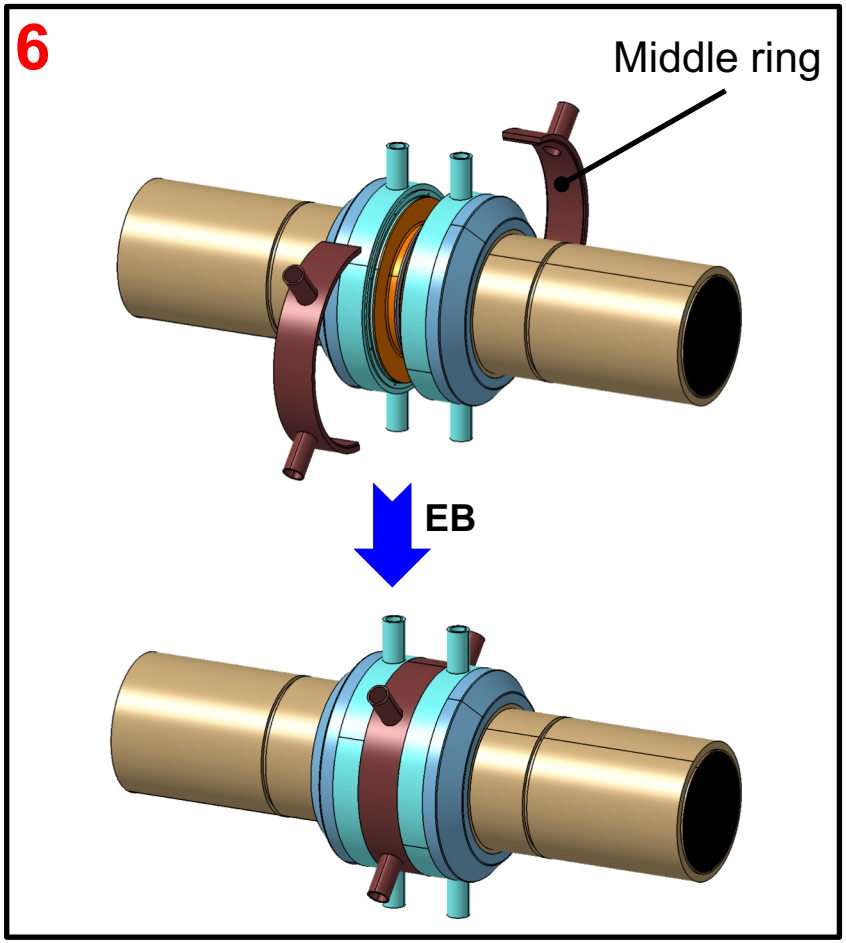

# Conclusions and outlook

- The design of the unit was assessed and optimized by FEM analyses.
- The maximum principal stress in the disc for Brazing + Operating conditions is not above the safety limit assumed for diamond (150 MPa).
- The thermal-hydraulic performance of the unit is adequate.

- After formal approval from F4E, the manufacturing of the unit prototype will start.