Numerical analyses of CVD diamond windows in high power microwave applications

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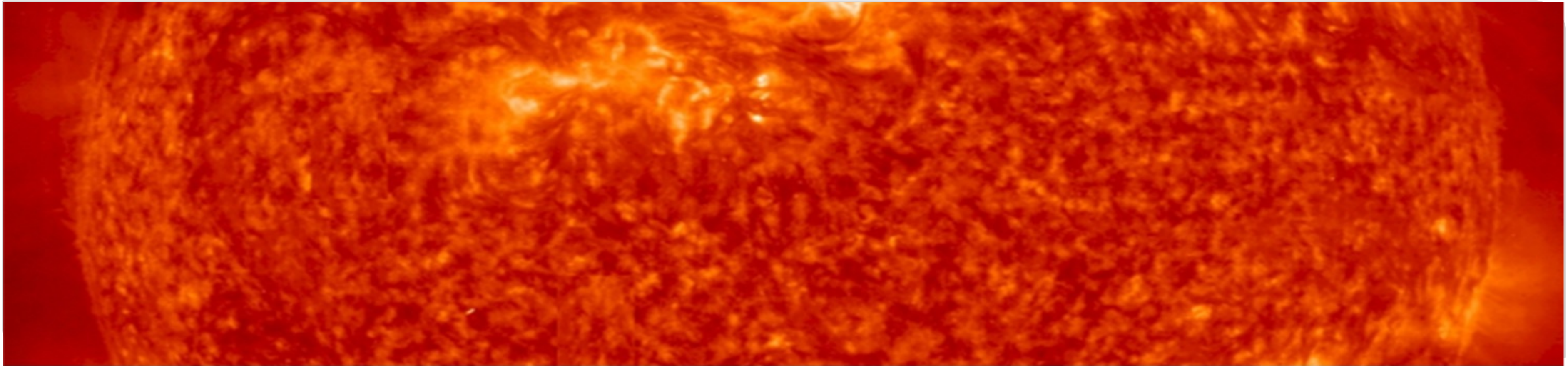
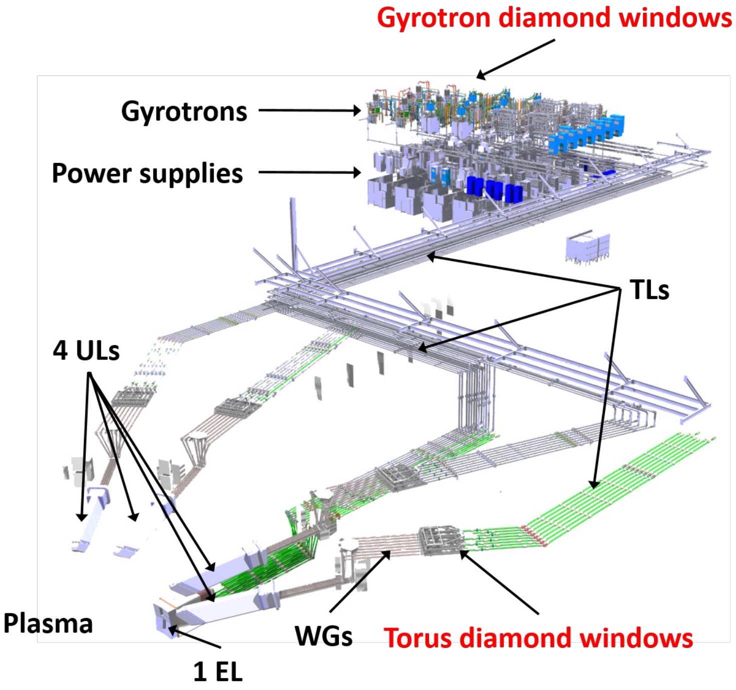
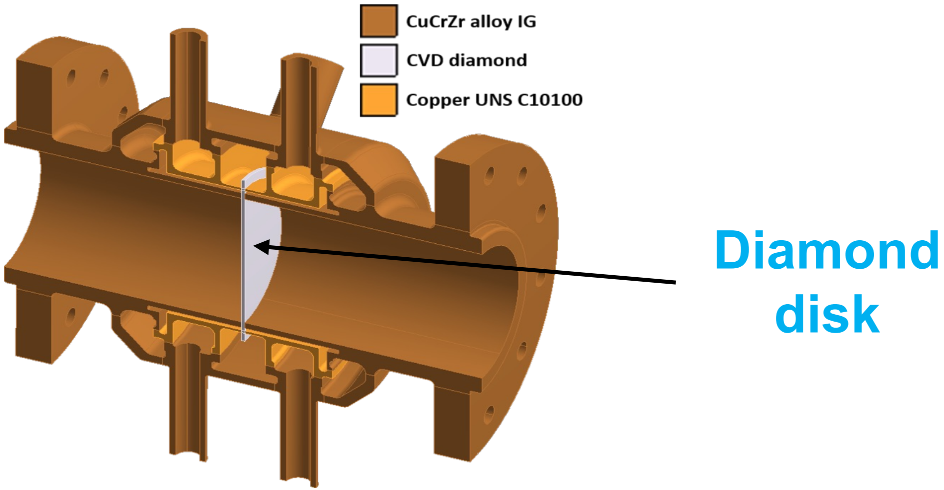


Outline

- Context
- Loss tangent and analyses
- Broadband windows in EU DEMO
- DEMO double-disk window
  - CFD conjugated heat transfer analysis
  - Sensitivity study
  - Structural analysis
- W7-X gyrotron window
- Summary and outlook

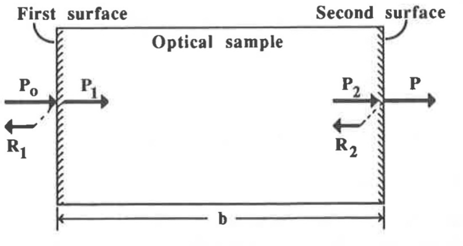
EC H&CD system (example from ITER)





- **1 MW** beam – ITER
- **1.5 MW** beam – W7-X
- **2 MW** beam – EU DEMO

Loss tangent – numerical analyses



$$\frac{P_2}{P_1} = e^{-\alpha b}$$

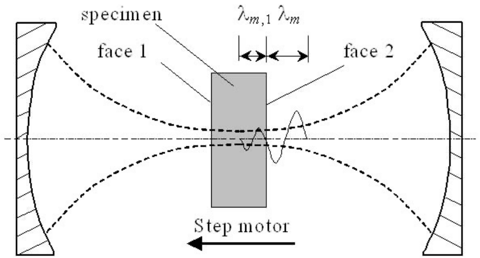
$$\frac{P_2}{P_1} = e^{-\left[\left(\frac{2\pi}{\lambda}\right)tan\delta\right]b}$$

$$P_{abs} = P_{beam} \cdot \frac{f}{c} \cdot \pi \cdot (1+\varepsilon_r) \cdot \tan\delta \cdot t$$

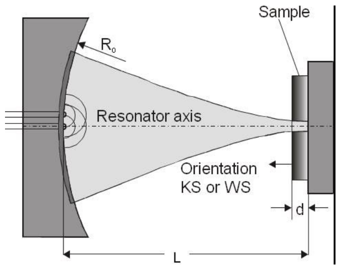
$\varepsilon_r = 5.67$, $tan\delta = 3.5 \times 10^{-5}$, $t = 1.85$ mm

DEMO scenarios	P_{abs} [W]
2 MW @170 GHz	1539
2 MW @204 GHz	1847

Spherical setup



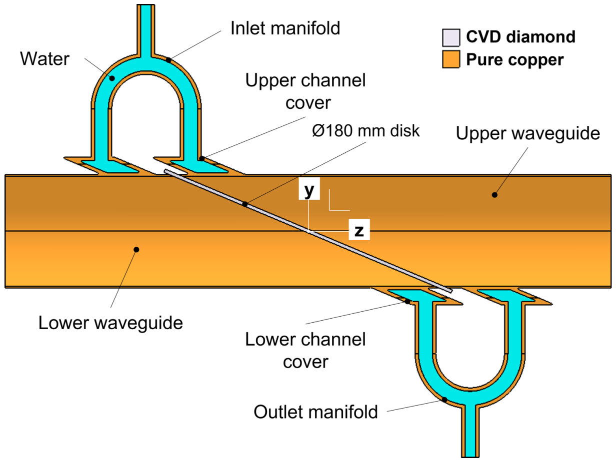
Hemispherical setup



- Fabry-Perot resonators to measure the tanδ of the diamond disks
- Input to numerical analyses to model power absorption in disks

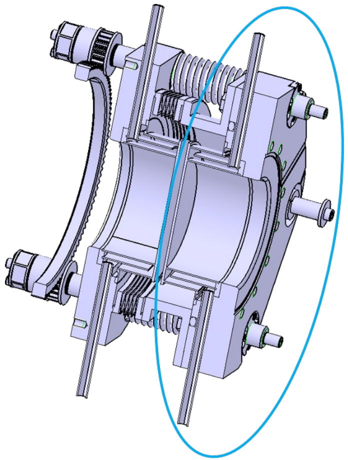
DEMO: EC broadband window solutions

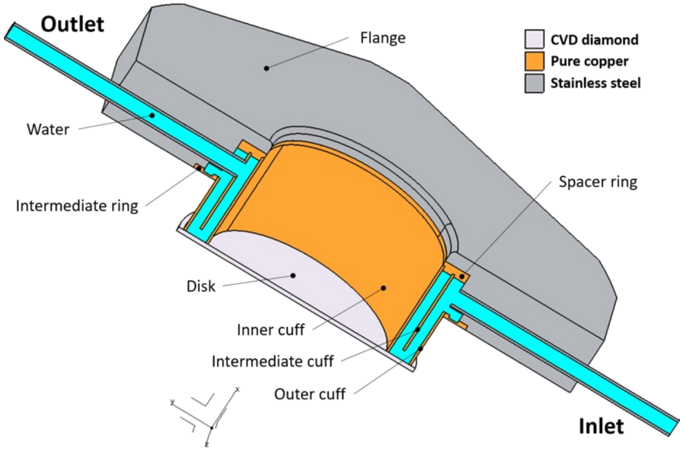
Primary choice



Brewster window: frequency tuning in steps of 2-3 GHz over a range of ±10 GHz around two main frequencies (136, 170, 204 GHz)

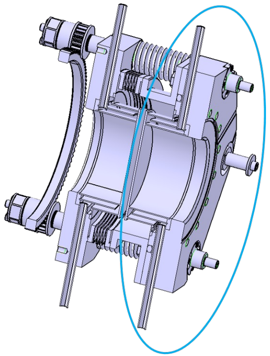
Backup solution

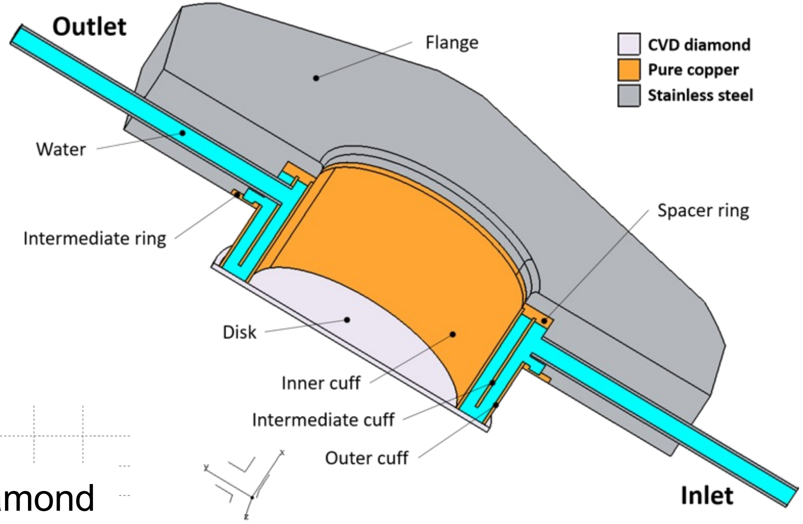


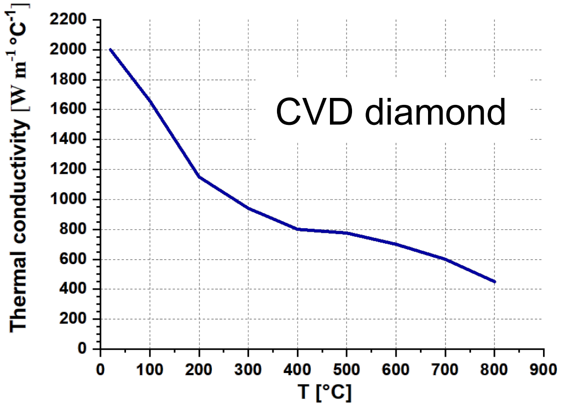


Double-disk window (DDW): used in the ASDEX Upgrade - ECRH system for injection up to 1 MW at 4 selected frequencies between 105-140 GHz

DDW: CFD conjugated analysis – reference case







$$q'''(r) = \frac{2\,P_{abs}}{\pi\,w_0^{\,2}\,t}\,e^{-2\frac{r^2}{w_0^{\,2}}}$$

- 2 MW @ 204 GHz (worst case)
- Gaussian mm-wave beam
- Symmetry
- T – dependent properties
- 10 l/min and 20°C at inlet (half flow rate in symmetric model)
- 0 Pa at outlet
- Disk *tanδ* = 3.5E-5
- Disk thickness *t* = 1.85 mm
- P_{abs} = 1847 W
- Beam radius w_0 = 20 mm

DDW: CFD conjugated analysis – reference case

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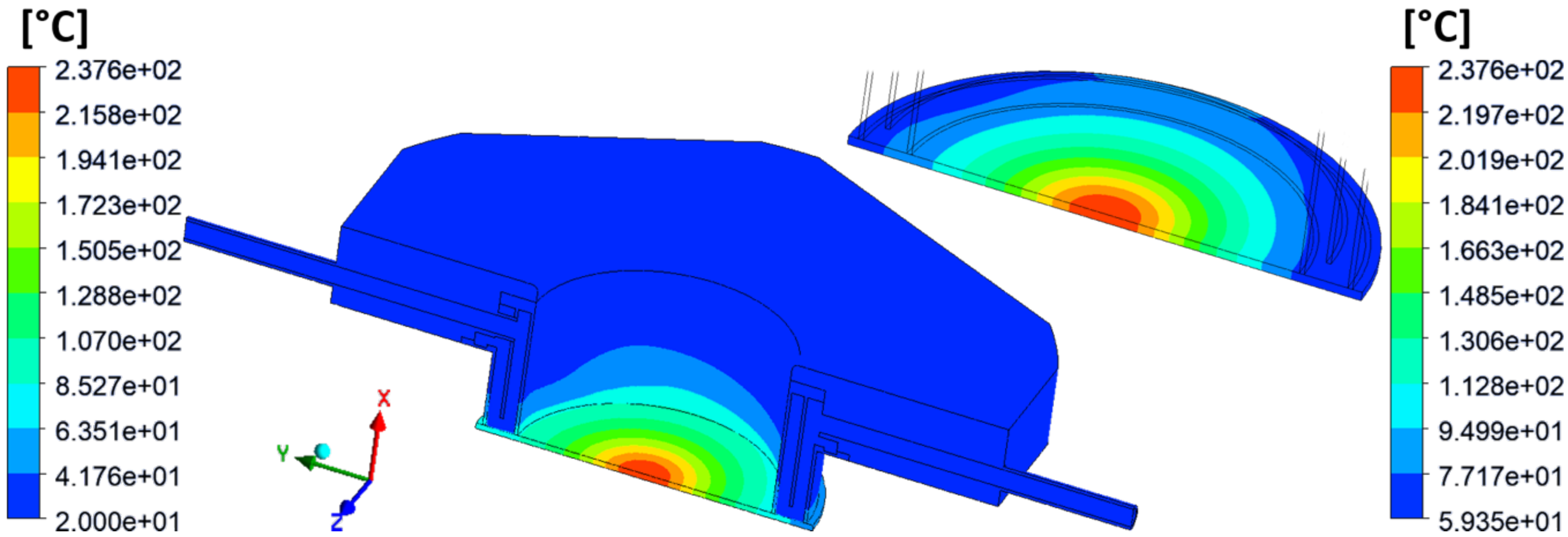
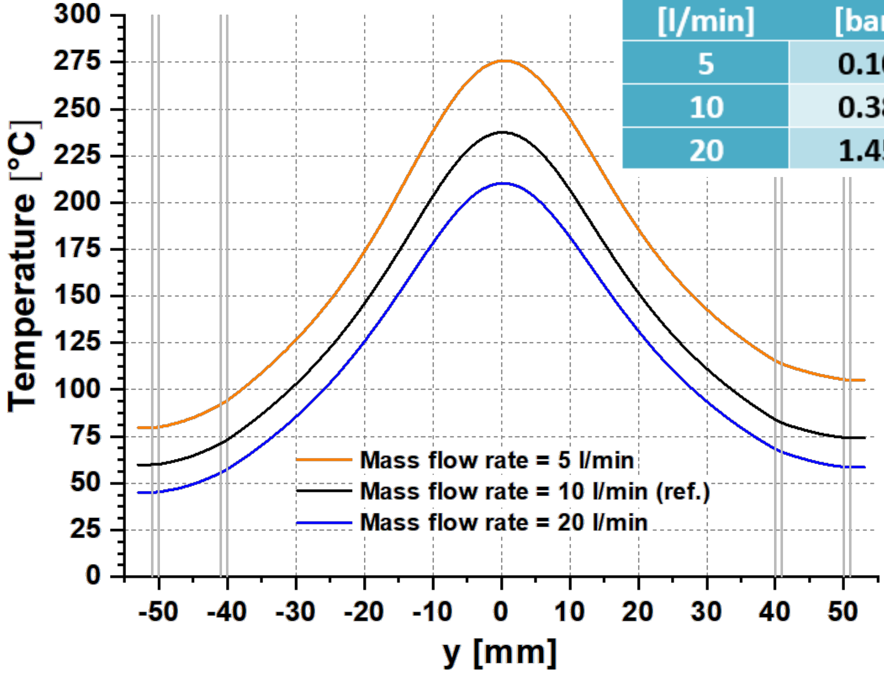


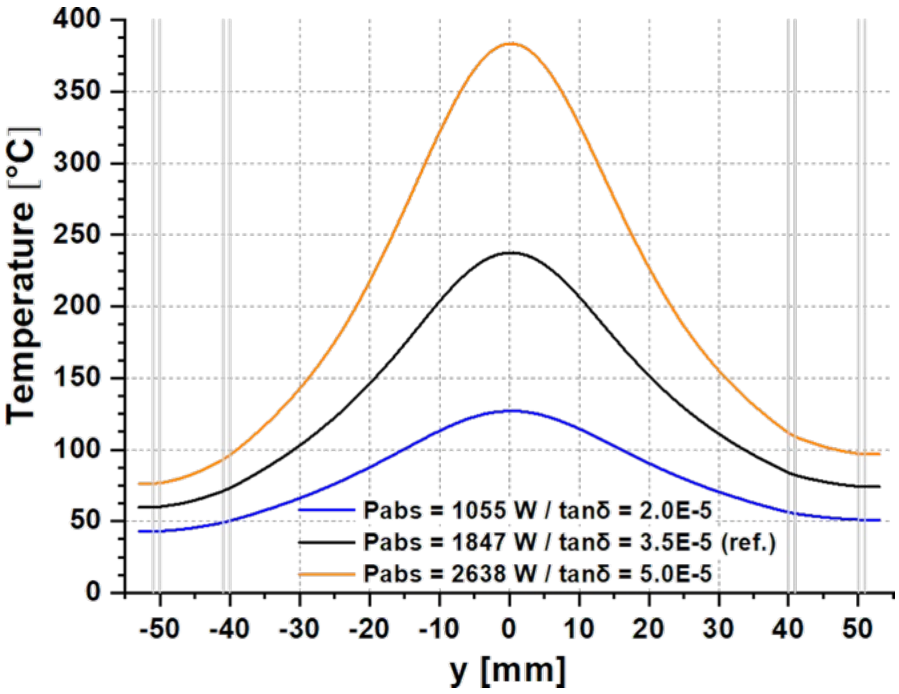
Design safe limit of <u>250 °C for CVD diamond</u>
(decreasing of thermal conductivity, increasing of loss tangent)

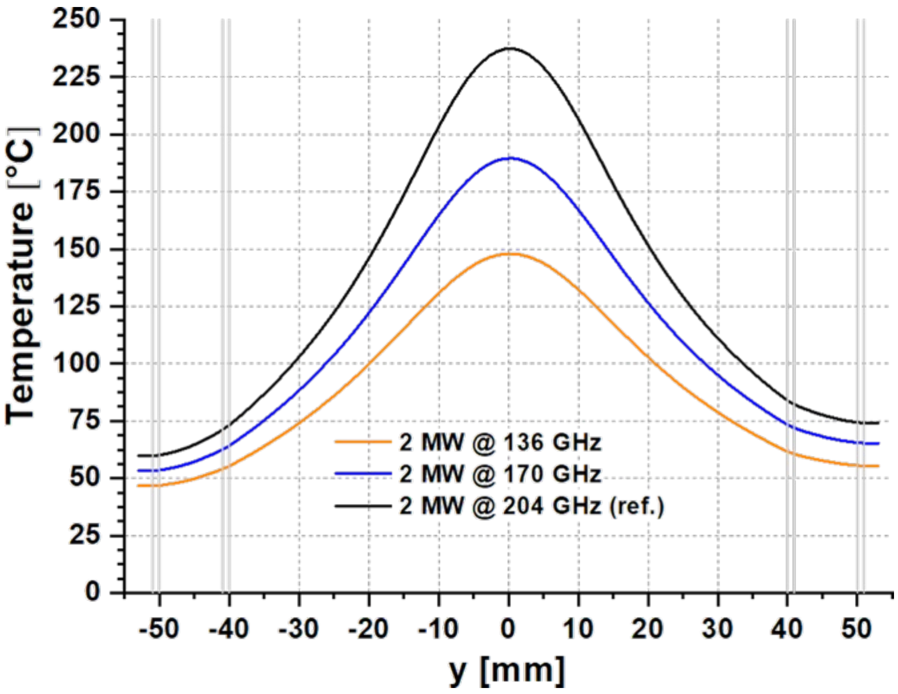
DDW: CFD conjugated analysis – sensitivity

Mass flow rate [l/min]	Pressure drop [bar]	ΔT fluid inlet-outlet [°C]	Max T in disk [°C]	Max T in cuffs [°C]	ΔT disk edges [°C]
5	0.10	5.2	275.9	114.1	25.4
10	0.38	2.6	237.6	88.9	14.3
20	1.45	1.3	210.3	71.4	13.4

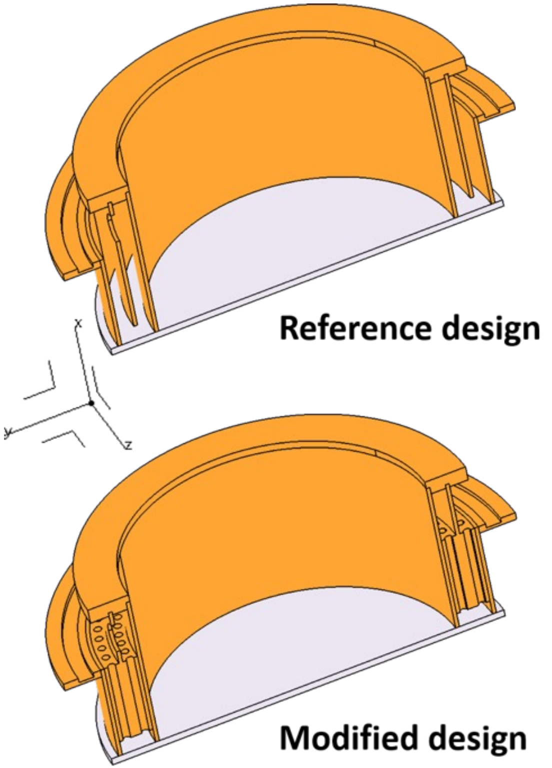


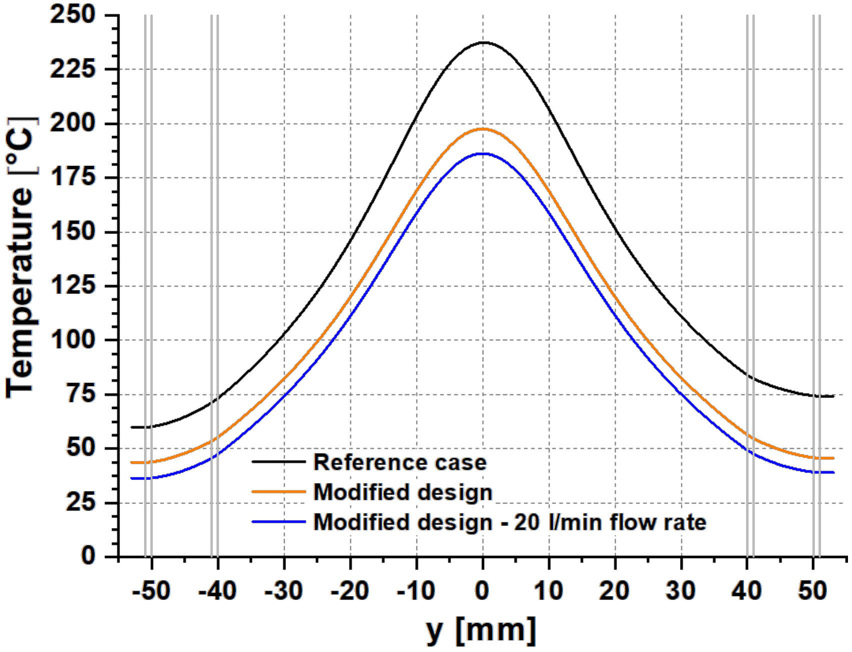
DDW: CFD conjugated analysis – sensitivity





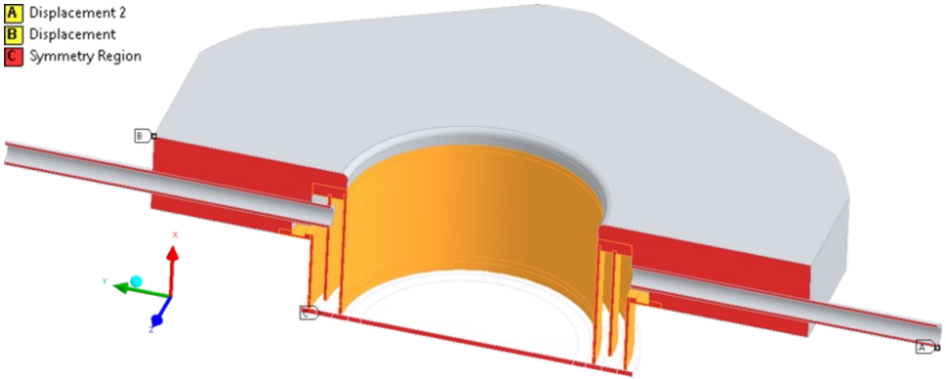
Conceptual proposal for DDW design change

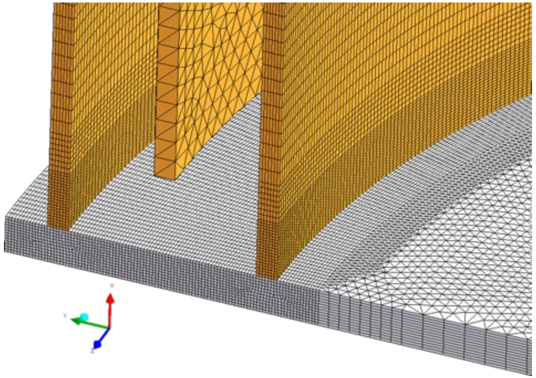


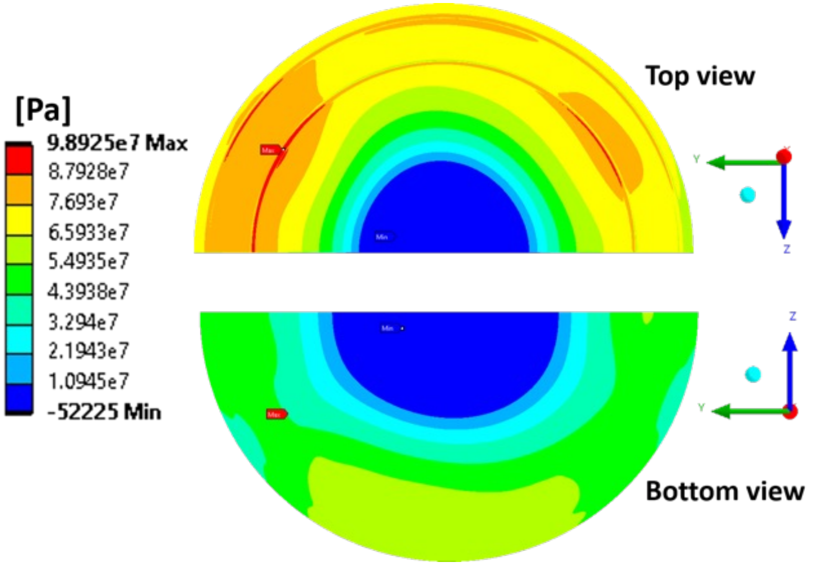


It is possible to achieve a **maximum temperature of 186 °C** (design safe limit of 250 °C for CVD diamond)

DDW: structural analysis for power absorption

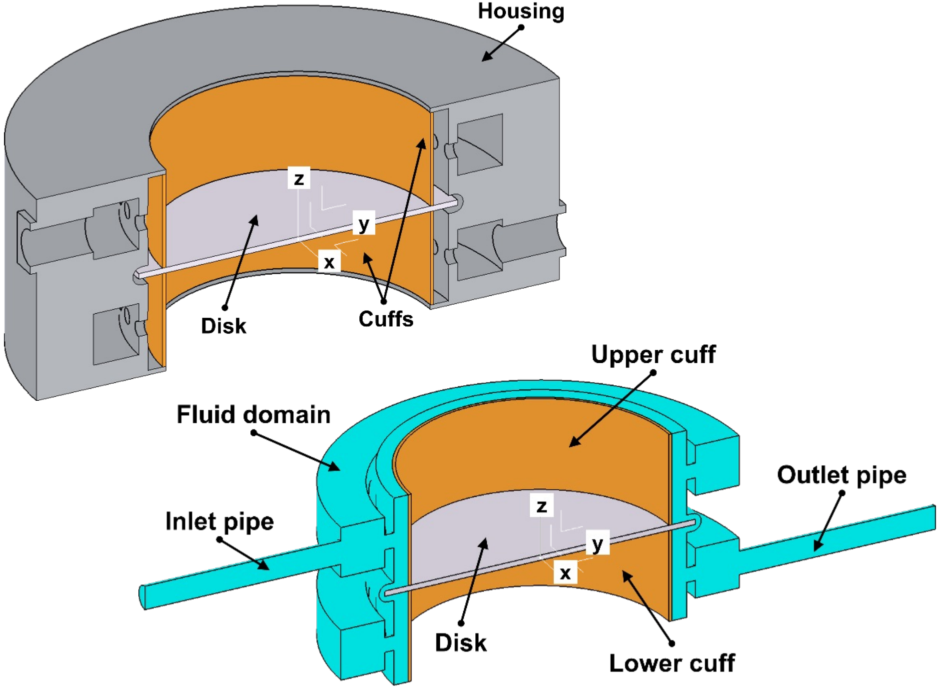


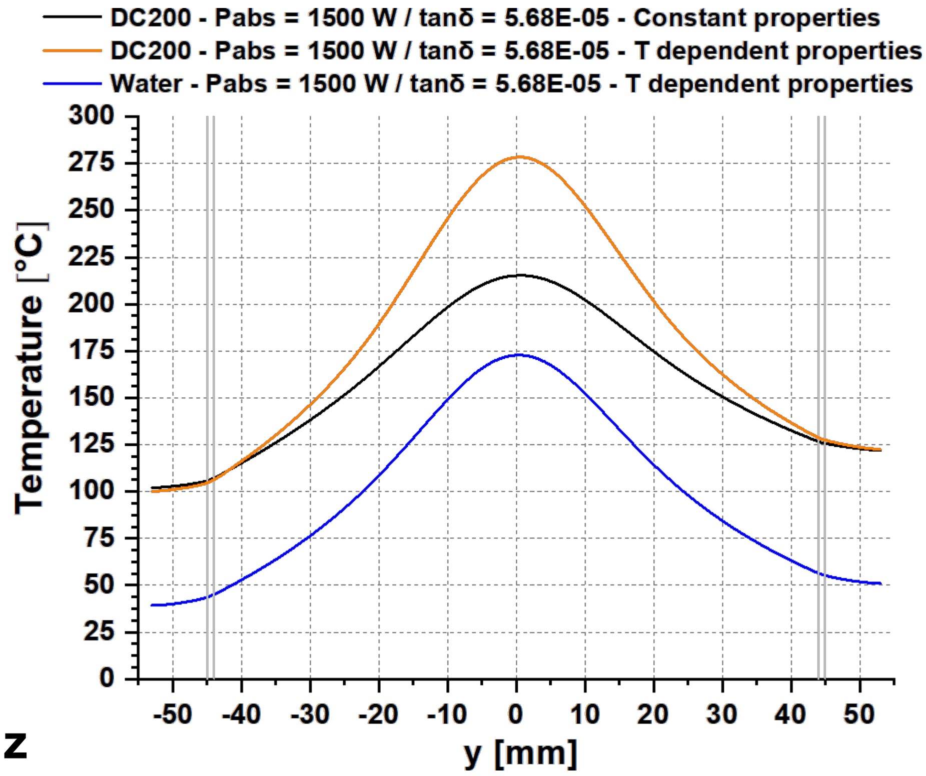




The stress results are below the allowable limit of 150 MPa assumed for CVD diamond

W7-X gyrotron diamond output window





1.5 MW @ 140 GHz

Summary & outlook

- The double disk CVD diamond window - the broadband backup window solution for EU DEMO - was characterized by CFD conjugated heat transfer and structural analyses
- It is a feasible window solution, but safety margins against limits shall be increased by introducing features aiming to make the fluid more turbulent
- The window shall be characterized for DEMO from RF beam transmission perspective to determine the intermediate frequencies at which minimum reflection conditions are met

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