The Integrated Engineering Design Concept of the Upper Limiter within the EU-DEMO LIMITER System

M.L. Richiusa

With the contribution of: A. Cardella, A. Čufar, A. Froio, P. Ireland, I. Maione, I. Pagani, G. Pautasso, A. Martin Ramos, G.A. Spagnuolo, F. Viganò, Z. Vizvary.

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Outline

- The EU-DEMO First Wall Protection Strategy
  - Charged Particle Heat Flux Evaluations
- The LIMITER (LIM) System Baseline
  - The LIM Unit: General Overview
- The integrated Upper Limiter (UL) Design Concept
  - W-Armoured PFW Design
  - EUROFER SB Design
  - The UL SB-VV Attachment System
- Assessment Workflow
- Conclusions and Outlook

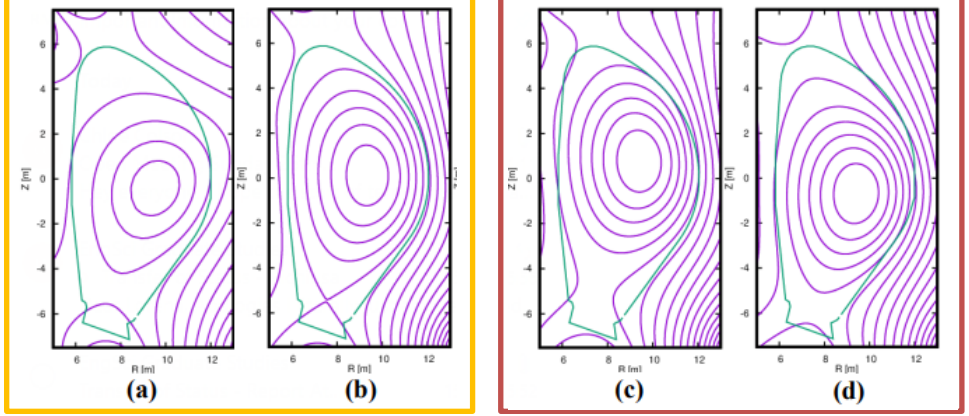
Outline

- The EU-DEMO First Wall Protection Strategy
  - Charged Particle Heat Flux Evaluations
- The LIMITER (LIM) System Baseline
  - The LIM Unit: General Overview
- The integrated Upper Limiter (UL) Design Concept
  - W-Armoured PFW Design
  - EUROFER SB Design
  - The UL SB-VV Attachment System
- Assessment Workflow
- Conclusions and Outlook

The EU-DEMO First Wall Protection Strategy

Normal Operation plasma shape

Off-normal transient plasma shape



(a): Ramp-up phase;

(b): Flat top (Normal Operation);

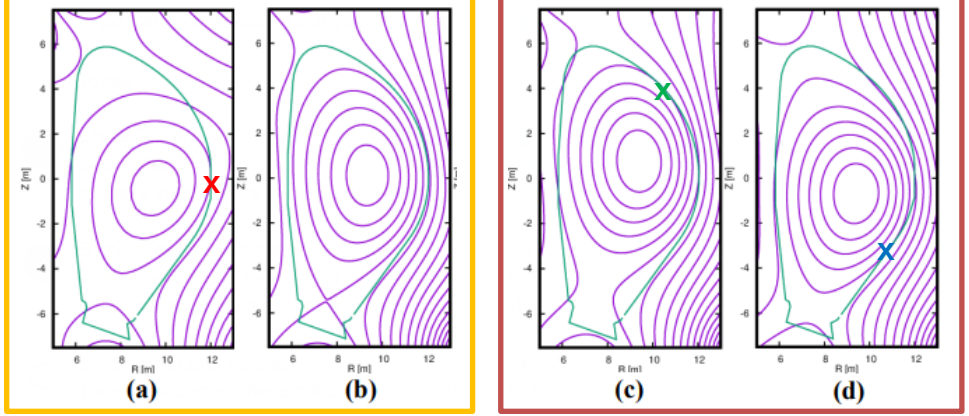
(c): Upward Vertical Displacement Event (UVDE);

(d): Downward Vertical Displacement Event (UVDE);

The EU-DEMO First Wall Protection Strategy

Normal Operation plasma shape

Off-normal transient plasma shape



(a): Outboard Midplane Limiter (OML);

(b): Flat top (Normal Operation);

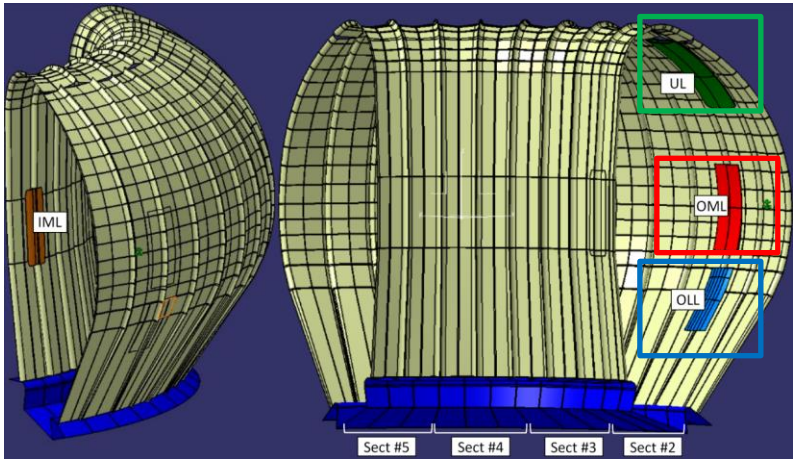
(c): Upper Limiter (UL);

(d): Outboard Lower Limiter (OLL);

F. Maviglia et al., Integrated design strategy for EU-DEMO first wall protection from plasma transients, FED, 2022.

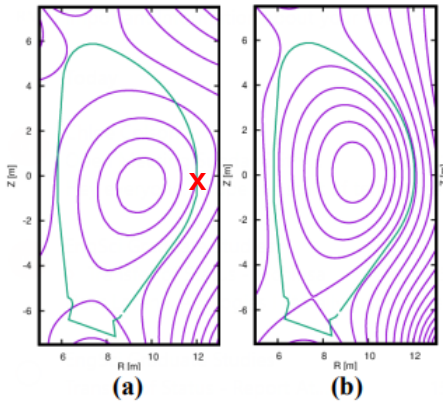
M.L. Richiusa et al., Bare and limiter DEMO single module segment concept first Wall misalignment study by 3D field line tracing, FED, 2020.

DEMO 90º FW sector.

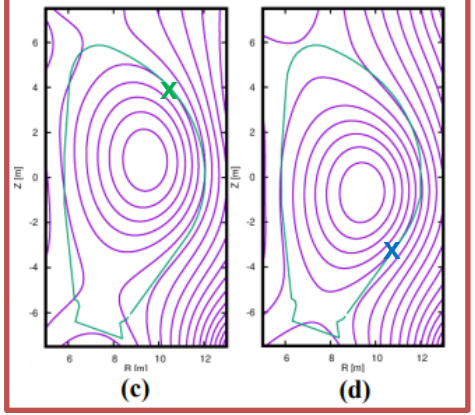


The EU-DEMO First Wall Protection Strategy

Normal Operation plasma shape



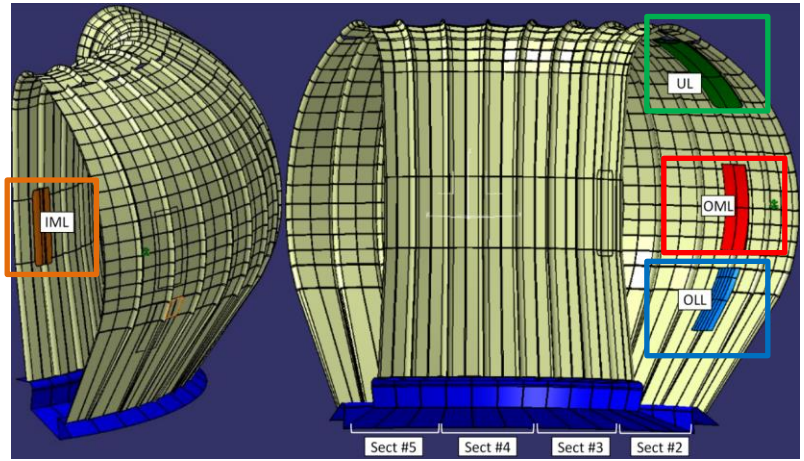
Off-normal transient plasma shape



F. Maviglia et al., Integrated design strategy for EU-DEMO first wall protection from plasma transients, FED, 2022.

M.L. Richiusa et al., Bare and limiter DEMO single module segment concept first Wall misalignment study by 3D field line tracing, FED, 2020.

DEMO 90º FW sector.



(a): Outboard Midplane Limiter (OML);

(b): Flat top (Normal Operation);

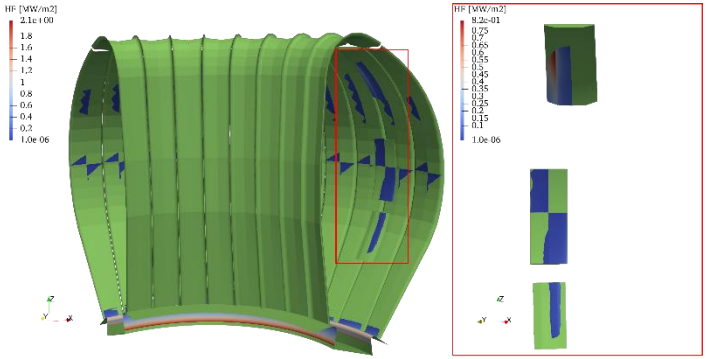
(c): Upper Limiter (UL);

(d): Outboard Lower Limiter (OLL);

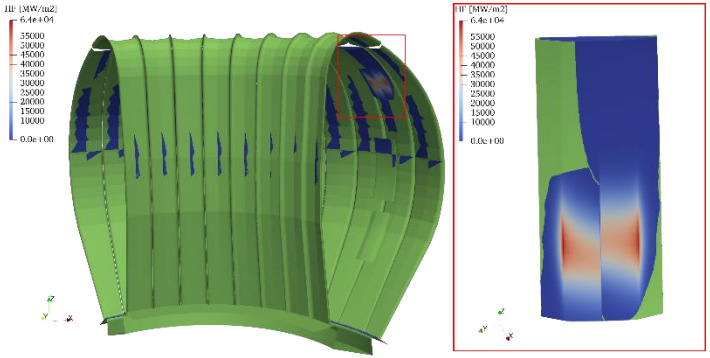
(e): Inboard Midplane Limiter (IML) for H-L transitions

Charged Particle Heat Flux Evaluations

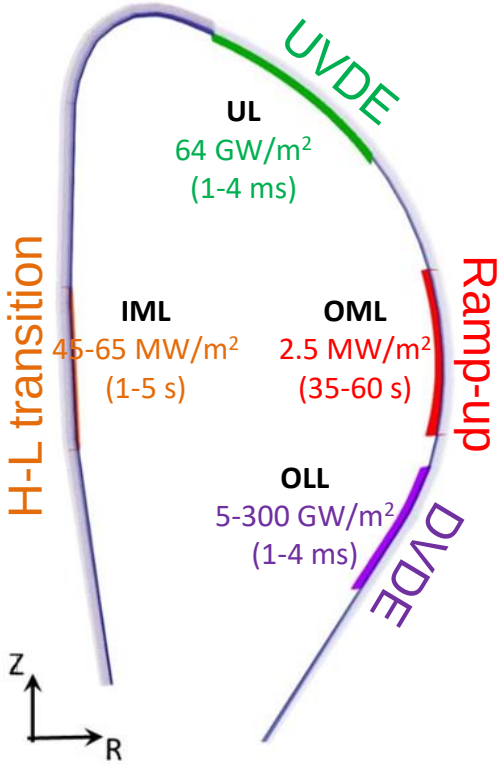
HF pattern during Normal Operation



HF pattern during UVDE

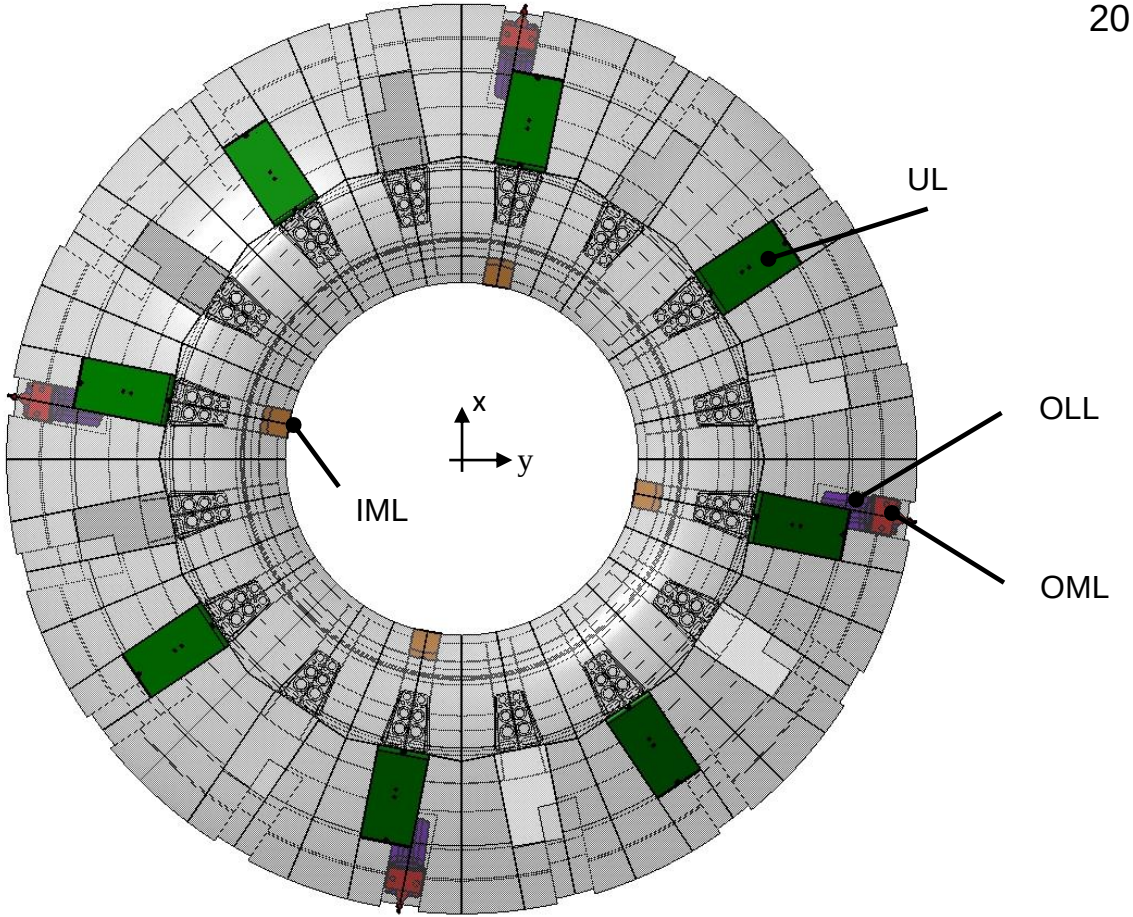


HF_{max} during plasma transients



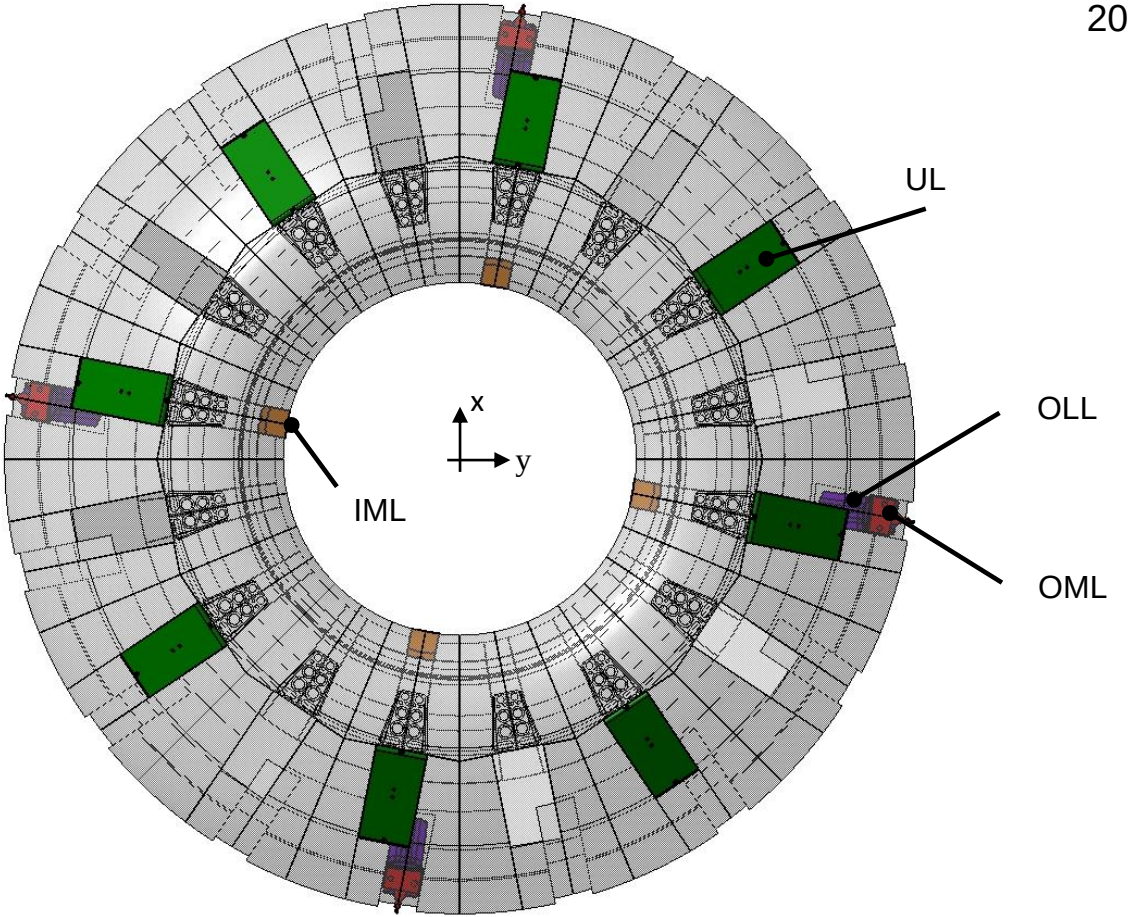
The LIMITER (LIM) System Baseline

20 Limiters: 8 UL; 4 OML; 4 OLL; 4 IML.



The LIM Unit: General Overview

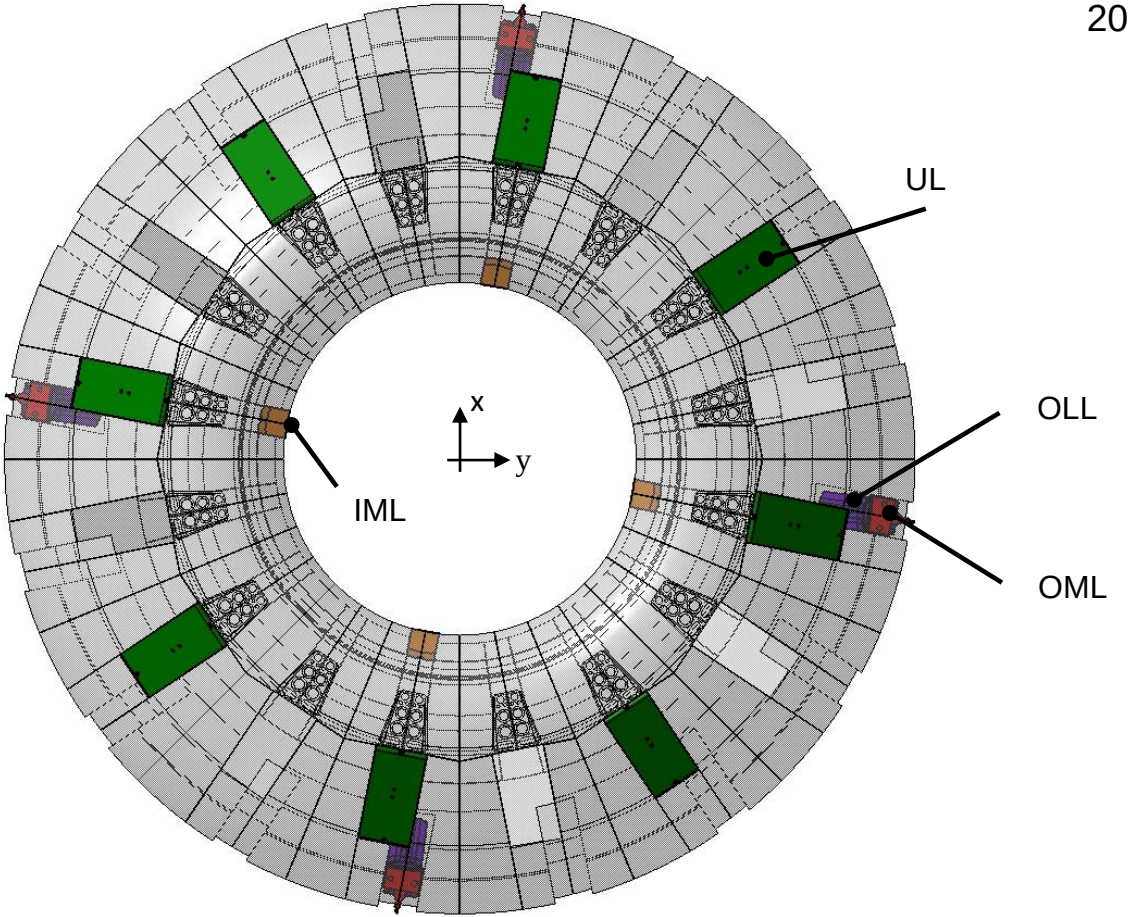
20 Limiters: 8 UL; 4 OML; 4 OLL; 4 IML.

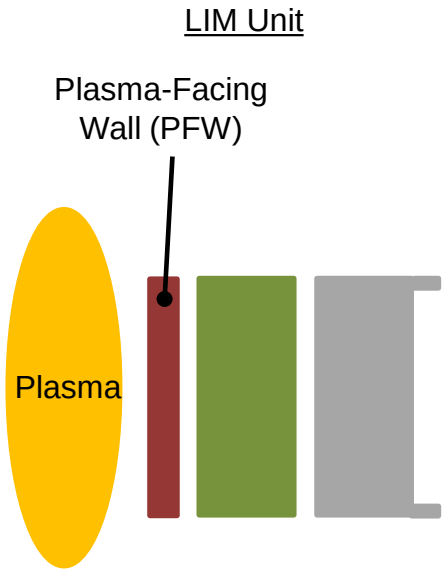


LIM Unit

The LIM Unit: General Overview

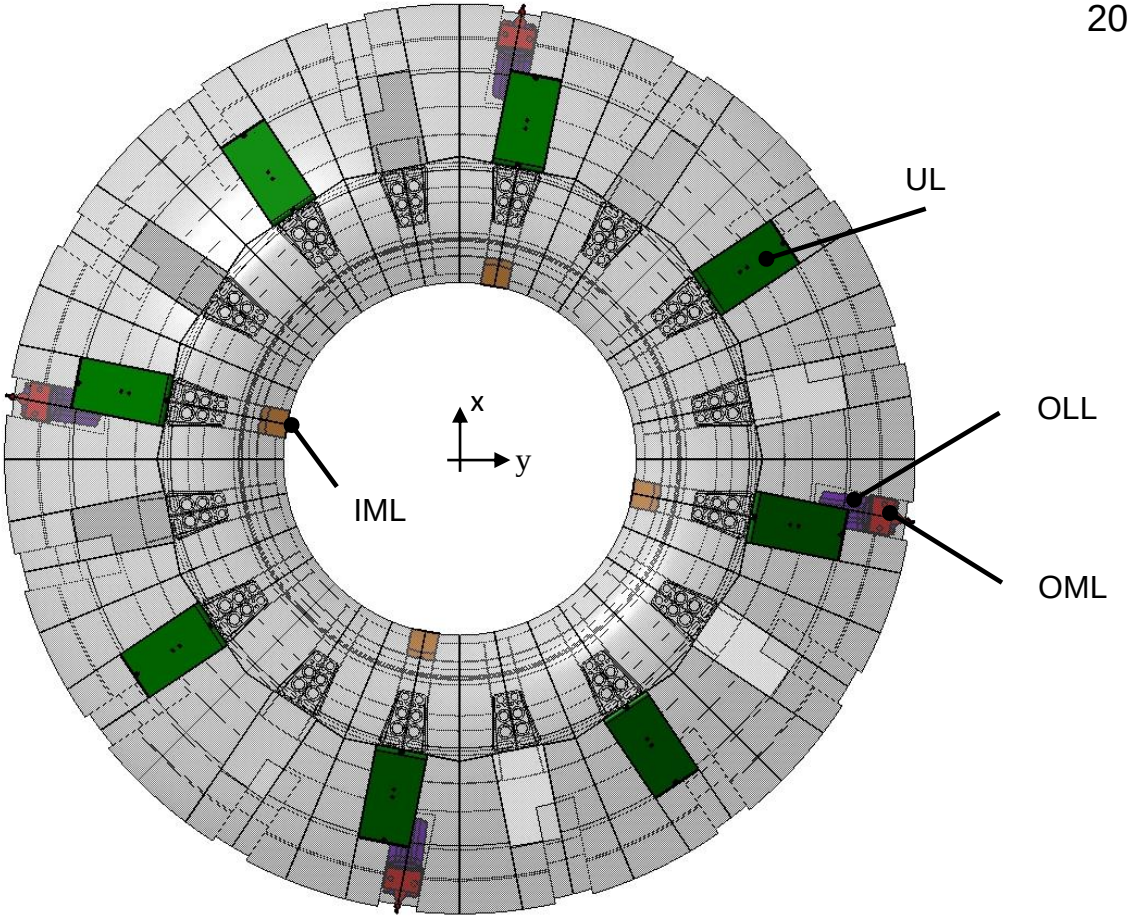
20 Limiters: 8 UL; 4 OML; 4 OLL; 4 IML.

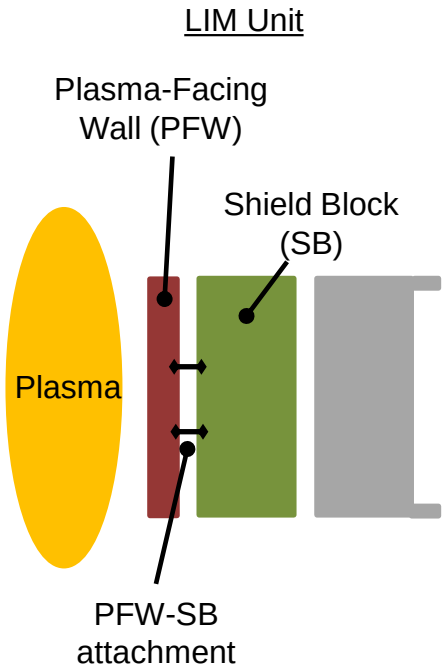




The LIM Unit: General Overview

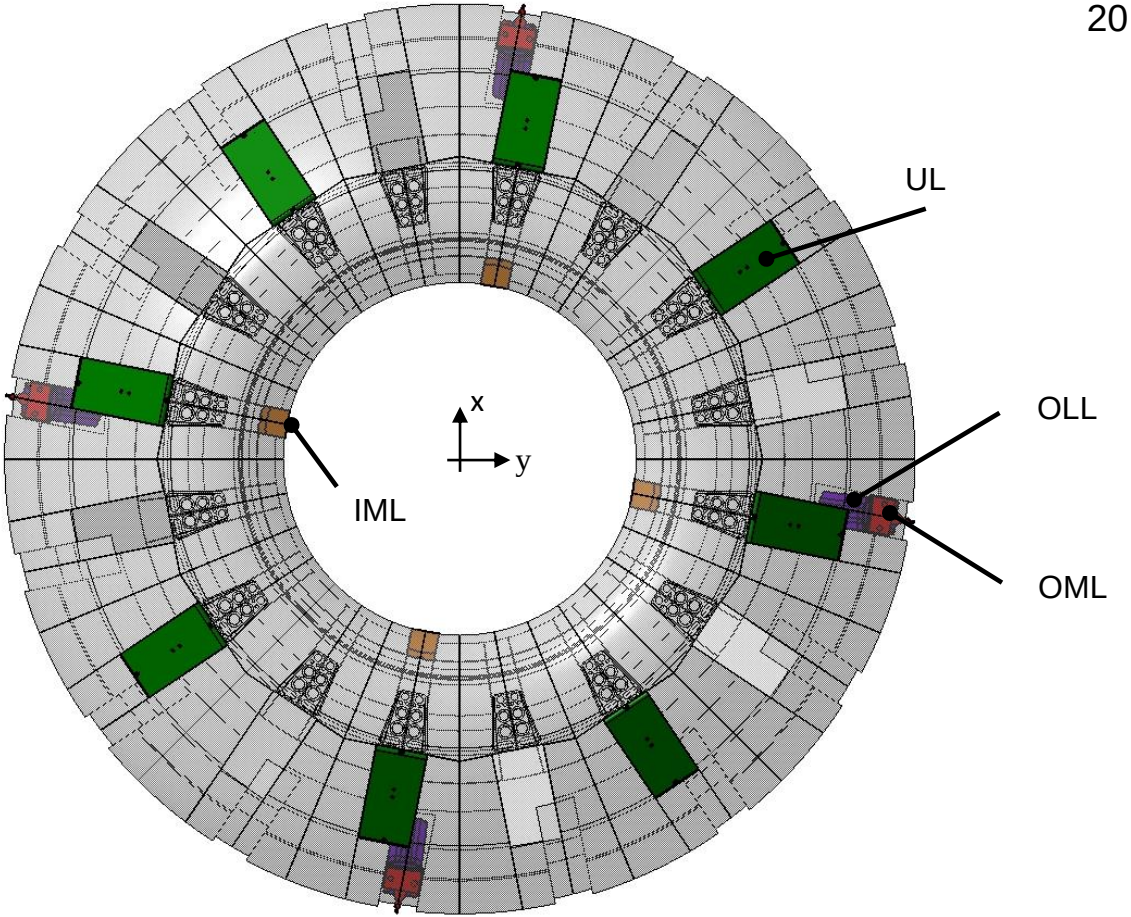
20 Limiters: 8 UL; 4 OML; 4 OLL; 4 IML.

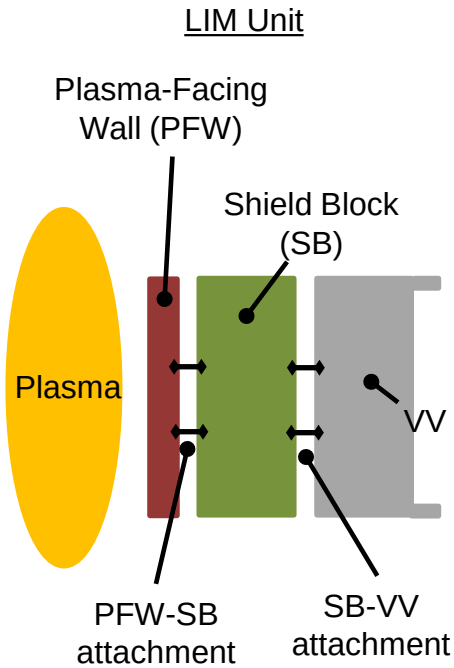




The LIM Unit: General Overview

20 Limiters: 8 UL; 4 OML; 4 OLL; 4 IML.

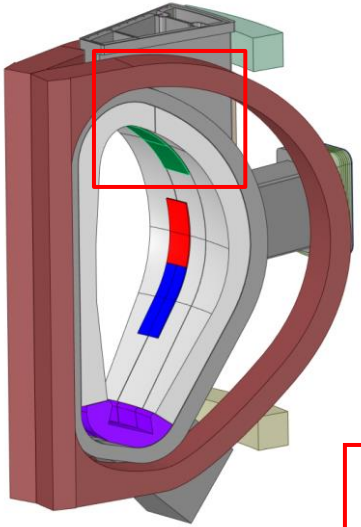


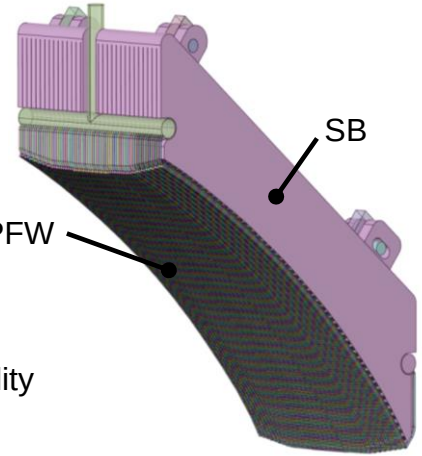


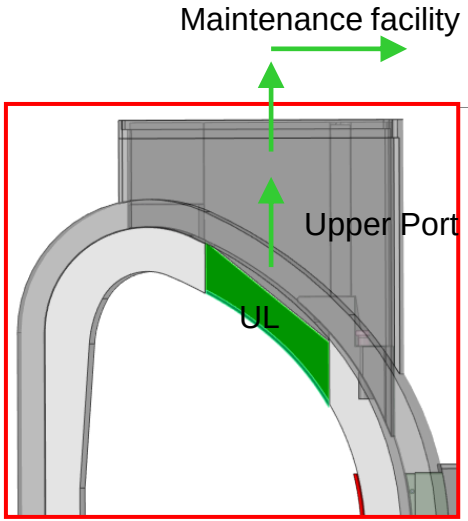
Outline

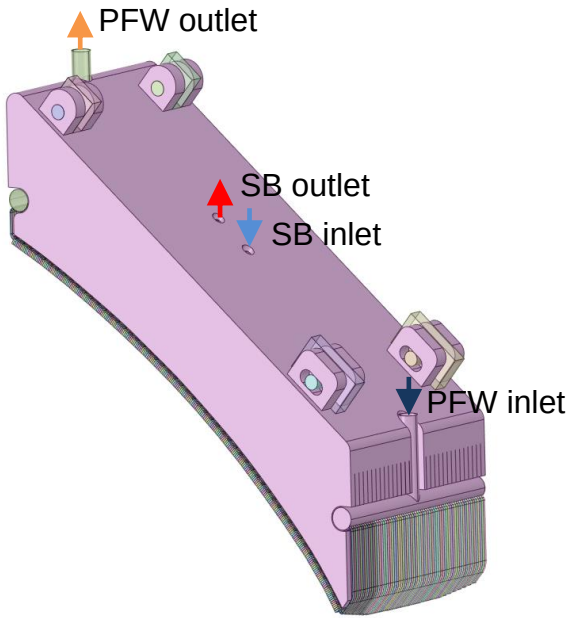
- The EU-DEMO First Wall Protection Strategy
  - Charged Particle Heat Flux Evaluations
- The LIMITER (LIM) System Baseline
  - The LIM Unit: General Overview
- The integrated Upper Limiter (UL) Design Concept
  - W-Armoured PFW Design
  - EUROFER SB Design
  - The UL SB-VV Attachment System
- Assessment workflow
- Conclusions and Outlook

The integrated Upper Limiter Design Concept

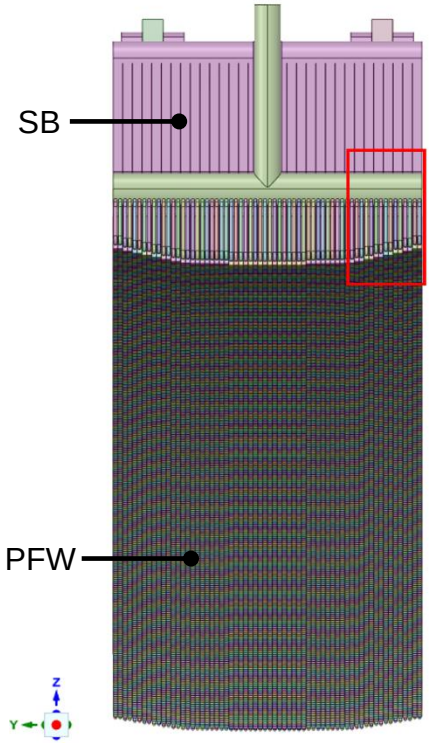


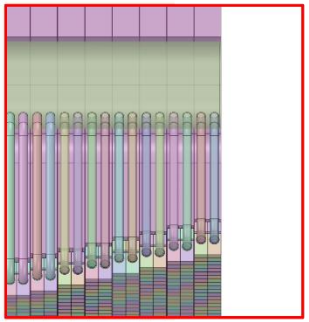


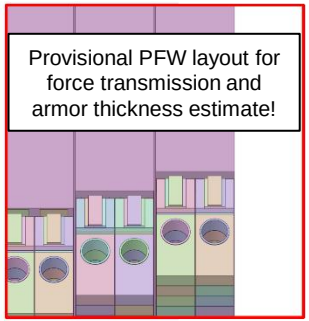




W-Armoured PFW Design



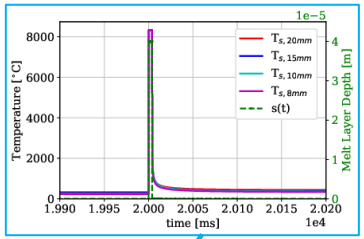




64 poloidally-oriented ITER-like PFUs.

Cooling parameters aligned with the DEMO divertor target: T_i=130°C, P_i=50 bar.

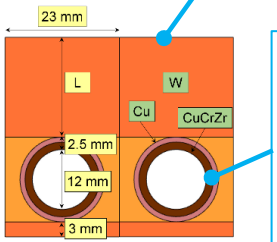
3D-TARTIFL&TTE application for UVDE[1]

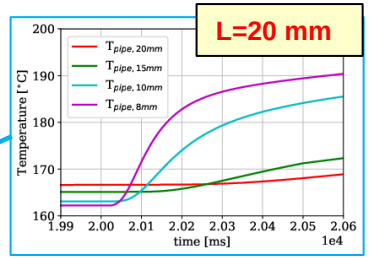


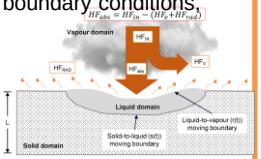
Multi-physics approach for heat transfer on 3D domains under:

a) Melting and vaporization within a deforming domain

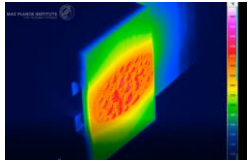
b) Vapour shielding/sputtering not simulated yet, but any mass loss/reduction of heat flux can be easily modelled through boundary conditions, once understood







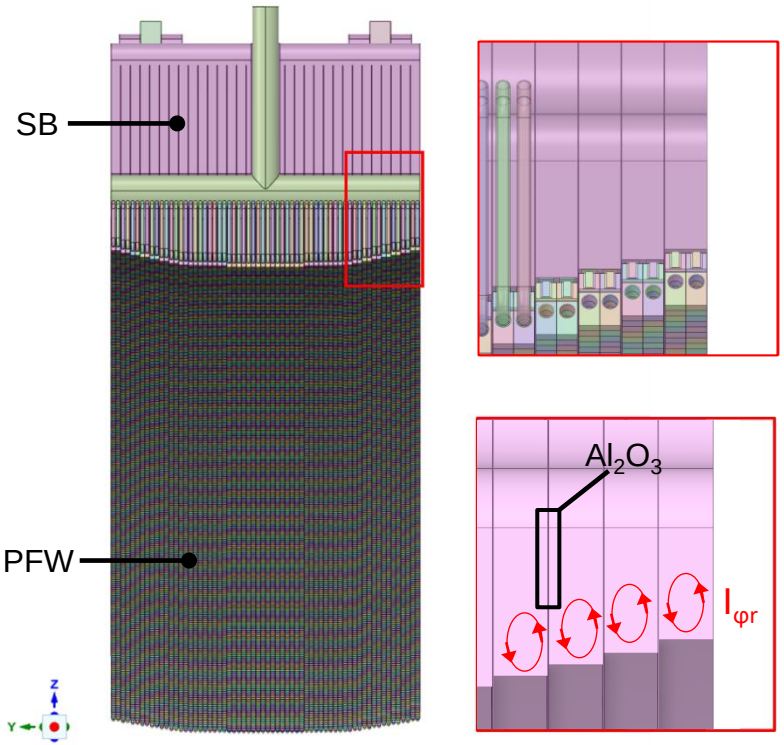
[1]M.L. Richiusa et al., Advances in material phase change modelling approach for EU-DEMO limiter's plasma-facing components. FED, 2023.



VALIDATION against melting experiments in the GLADIS facility:

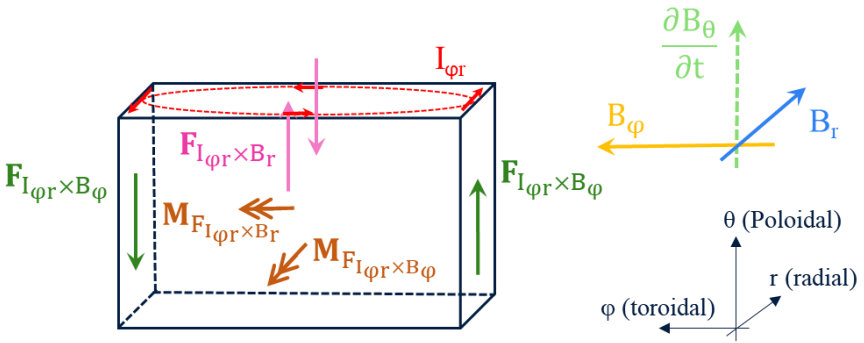
M.L. Richiusa et al., High heat flux tests in support of the 3D computational modelling of melting for the EU-DEMO first wall limiters. Submitted to IEEE TPS.

EUROFER SB Design

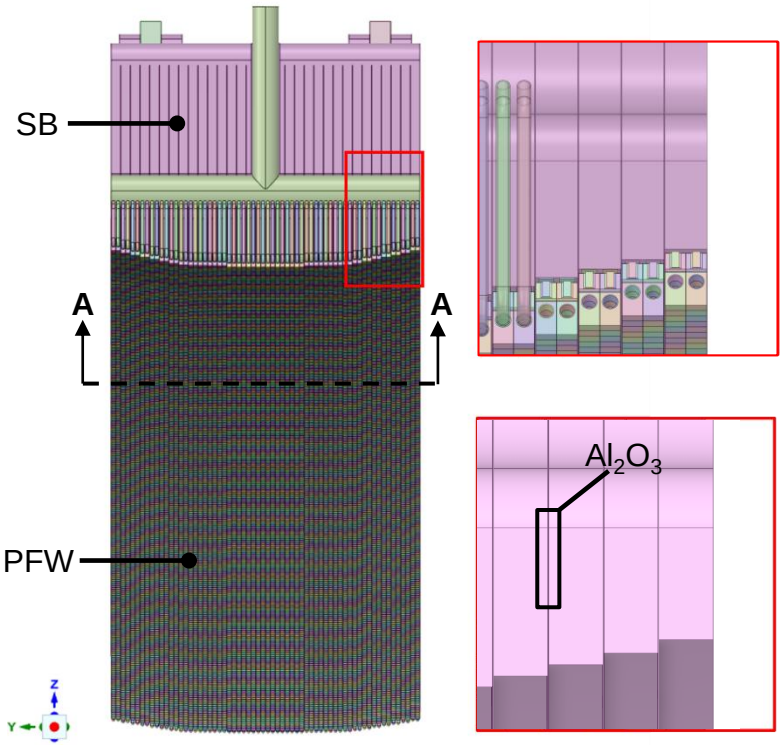


Sliced into 32 actively-cooled poloidal plates, electrically insulated by Alumina layers.

DN~0.020 m, serpentine inside each plate (~7%Water, 88% EUROFER, 5% Alumina). Same cooling parameters as the DEMO divertor cassette: T_i=295°C, P=155 bar.

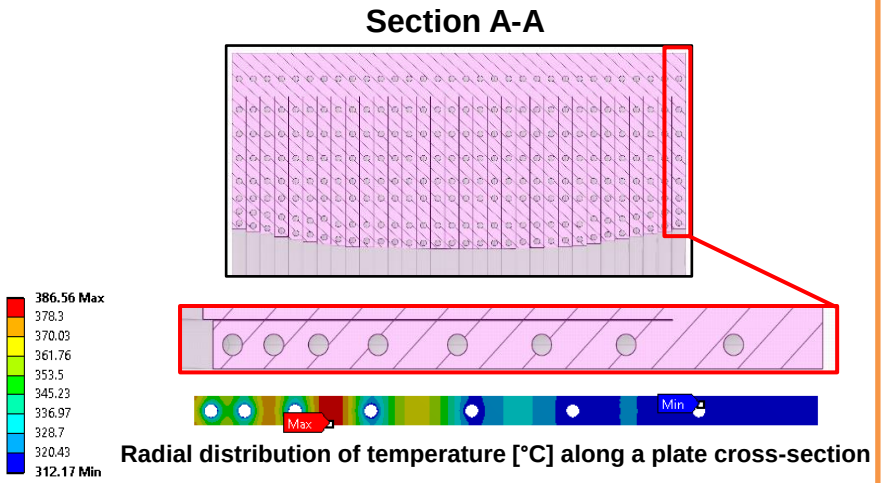


EUROFER SB Design



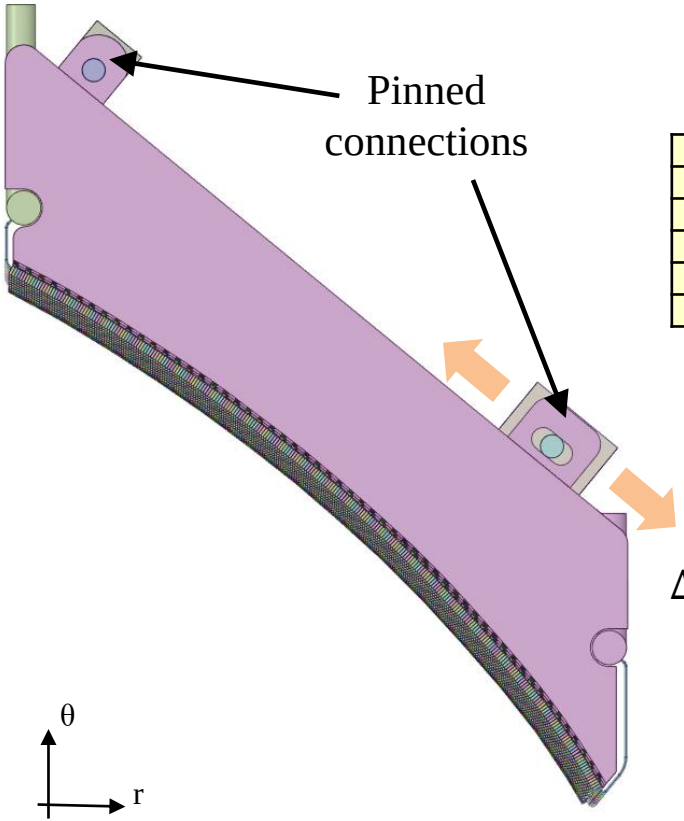
Sliced into 32 actively-cooled poloidal plates, electrically insulated by Alumina layers.

DN~0.020 m, serpentine inside each plate (~7%Water, 88% EUROFER, 5% Alumina). Same cooling parameters as the DEMO divertor cassette: T_i=295°C, P=155 bar.



Radial distribution of temperature [°C] along a plate cross-section

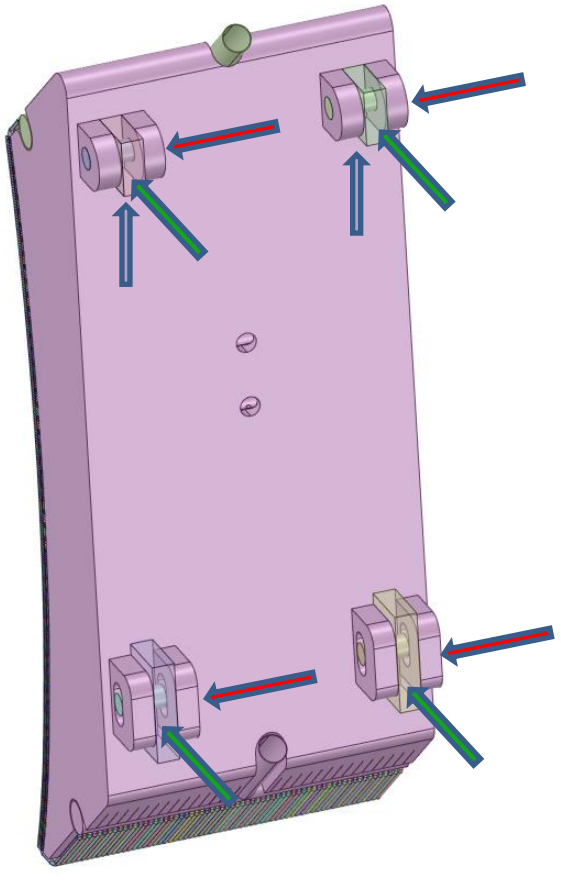
The UL SB-VV Attachment System



	Expected Reaction Forces			
	Pin_{up}	Pin_{down}	$Lugs_{up}$	$Lugs_{down}$
Fr	x	x		
Fφ			x	x
Fθ	x			
Mr	x		x	x
Mφ	x	x		
Mθ	x	x		

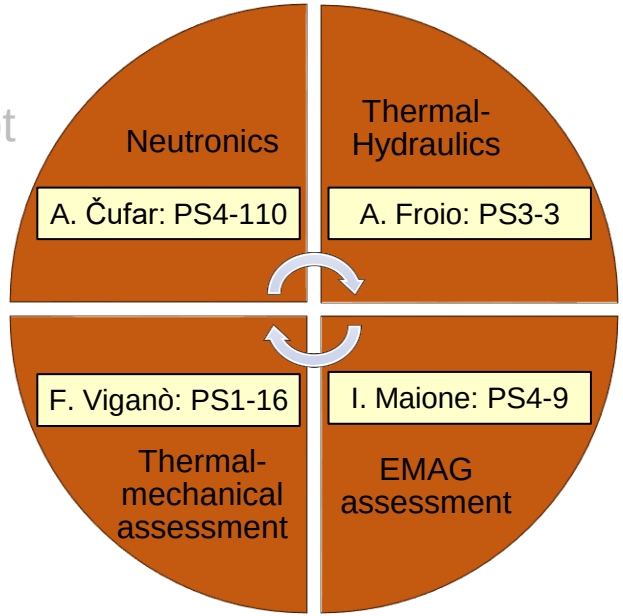
Slotted hole for poloidal thermal expansion

$$\Delta L_{\phi} \approx 0.6cm < \Delta L_{\theta} \approx 1cm$$



Outline

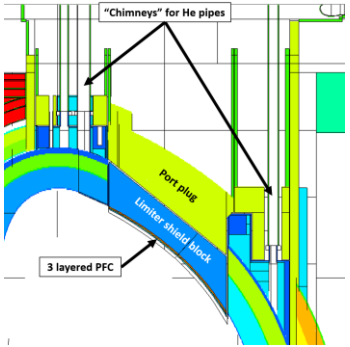
- The EU-DEMO First Wall Protection Strategy
  - Charged Particle Heat Flux Evaluations
- The LIMITER (LIM) System Baseline
  - The LIM Unit: General Overview
- The integrated Upper Limiter (UL) Design Concept
  - W-Armoured PFW Design
  - EUROFER SB Design
  - The UL SB-VV Attachment System
- Assessment Workflow
- Conclusions and Outlook



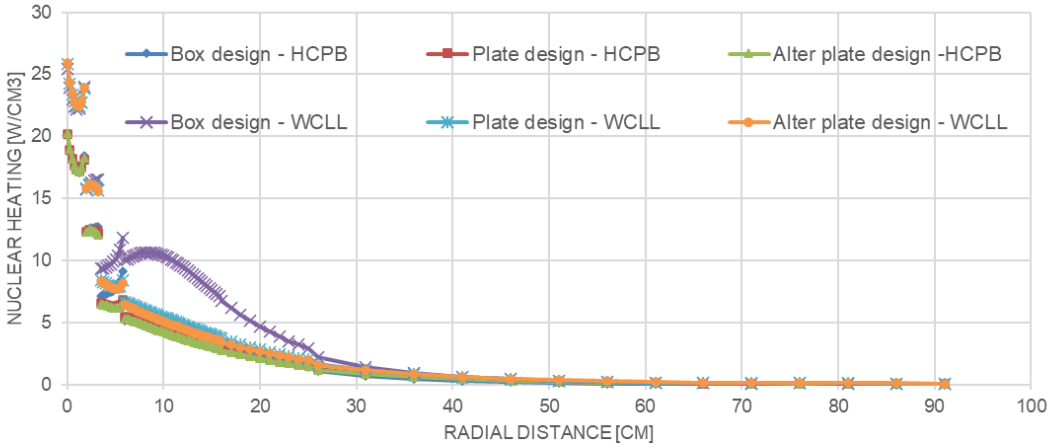
Neutronics Evaluations

A. Čufar: PS4-110

FIRST ITERATION

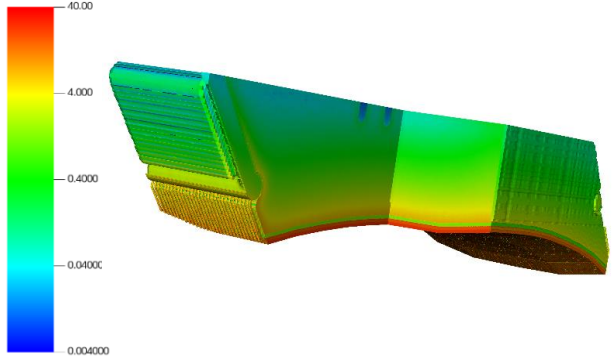


	Material composition (vol%)		
	Box design	**Plate design**	**Alternative plate design**
PFC-1 - armour	W		
PFC-2 – tube layer	W (39.5), CuCrZr (17.0), Cu (13.5), water (30)		
PFC-3 – W bottom layer	Eurofer (39.5), W (21.0), void (39.5)		
Shielding block	Eurofer (53), water (47, at 0.92 g/cm^3)	Eurofer (87.5), water (7.4 at 0.92 g/cm^3), void (5.1)	Eurofer (87.5), water (7.4 at 0.7 g/cm^3), void (5.1)



SECOND ITERATION

NH [W/cm^3]



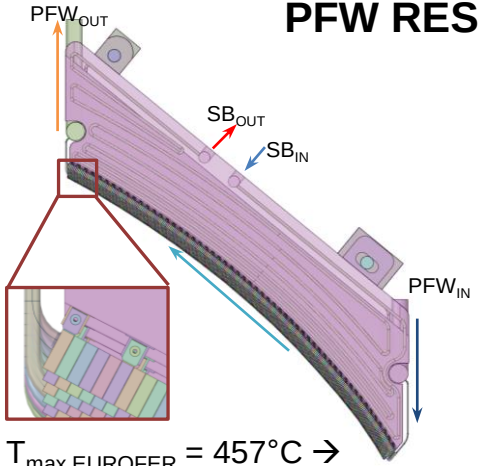
Layer	NH [MW]	Max DPA/FPY	Max He [appm/fpy]
PFW	4.35	5.6	4.4
SB	5.18	8.4	120

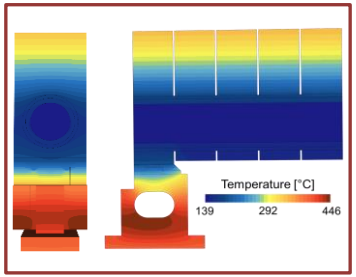
Constraints	NH	DPA
TFC	6 W/m^3 (<50W/m^3)	--
VV	--	0.2 DPA/6FPY (<2.75 DPA/lifetime)

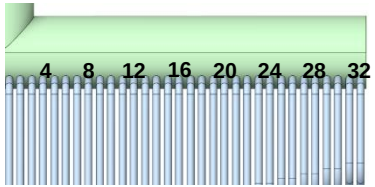
Thermal-Hydraulic Assessment

A. Froio: PS3-3

PFW RESULTS

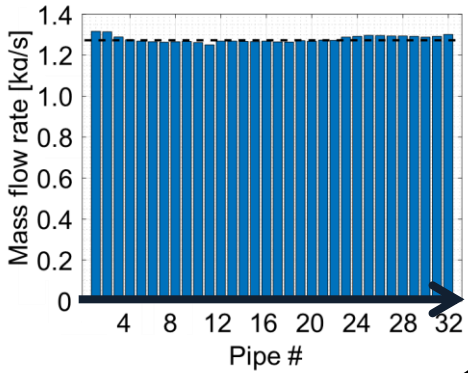






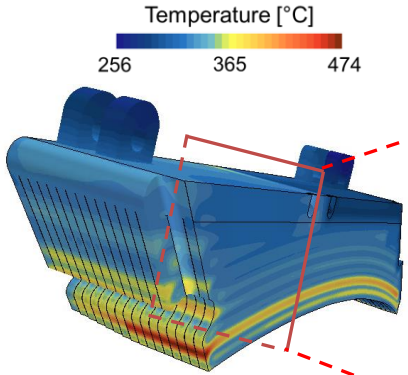
$T_{max,EUROFER}$ = 457°C → Within the operational EUROfer Temperature range (350-550°C)

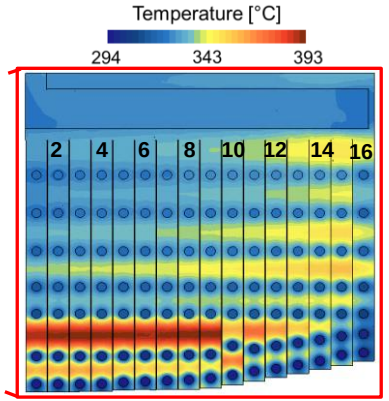
Mass flow rate uniformly distributed over the pipes.



ΔP_{PFW} = 4.3 bar

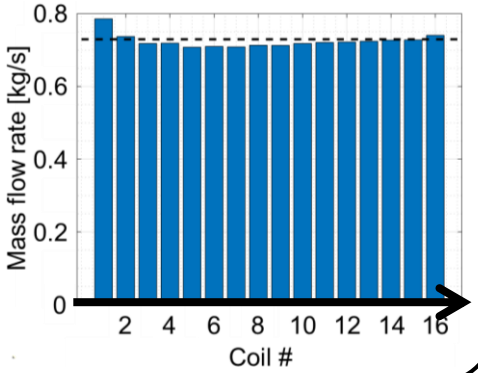
SB RESULTS





$T_{max,EUROFER}$ = 477°C → Within the operational EUROfer Temperature range (350-550°C)

Mass flow rate uniformly distributed over the plates.

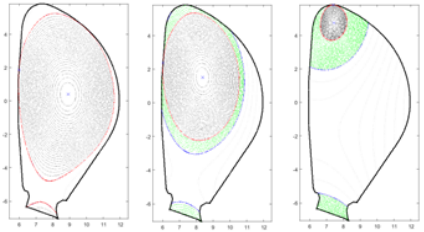


ΔP_{SB} = 1.06 bar

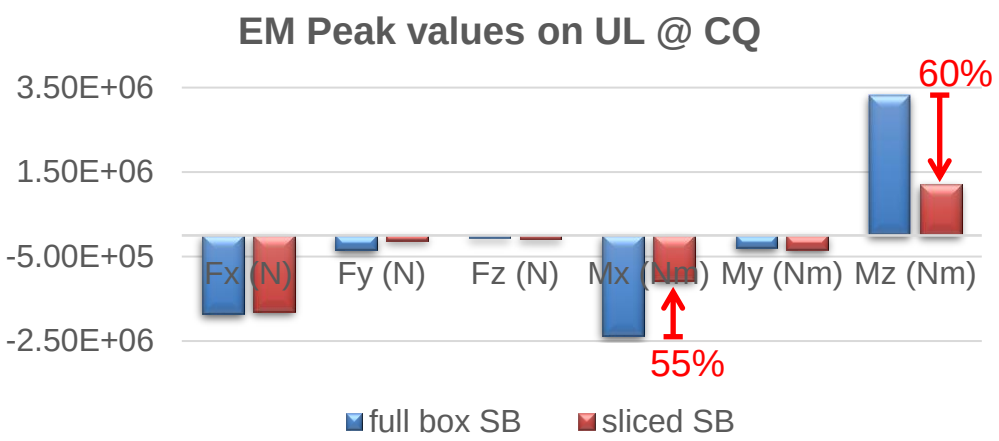
Electro-Magnetic Assessment

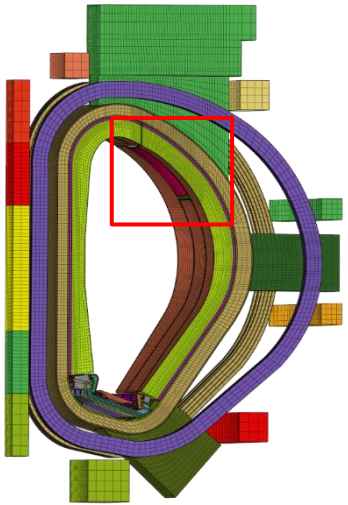
I. Maione: PS4-9

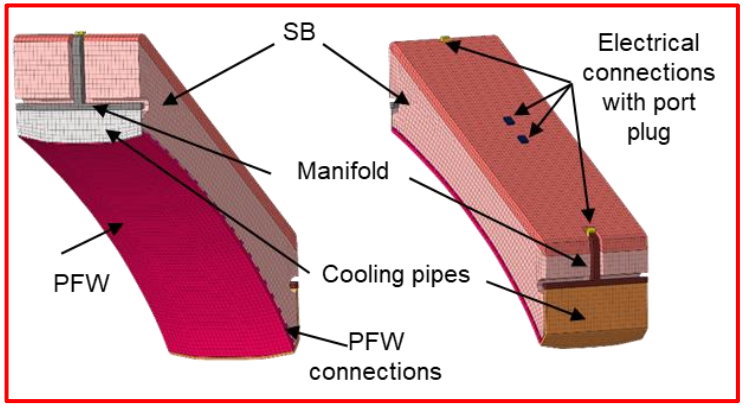
CarMa0NL simulation of plasma evolution during UVDE



Courtesy of F. Villone & CREATE Team





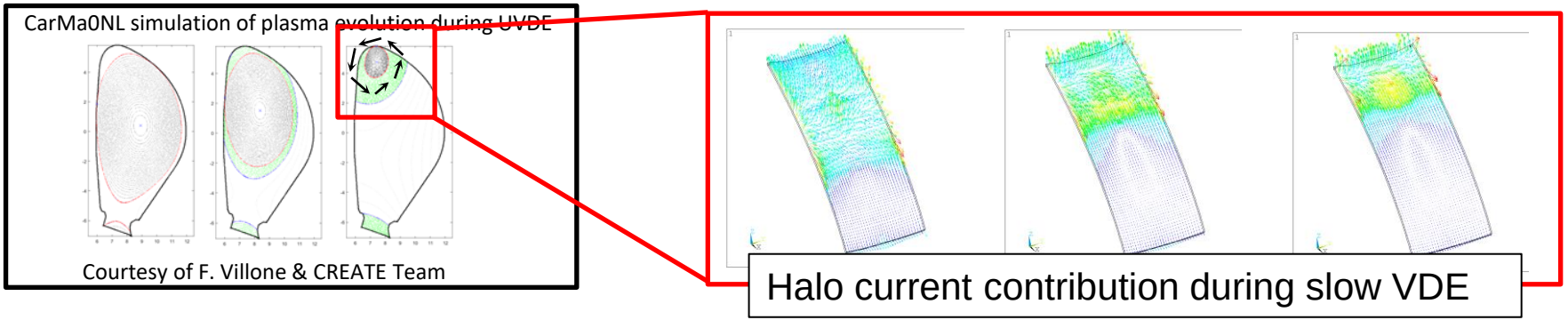


Full SB: Isotropic material properties

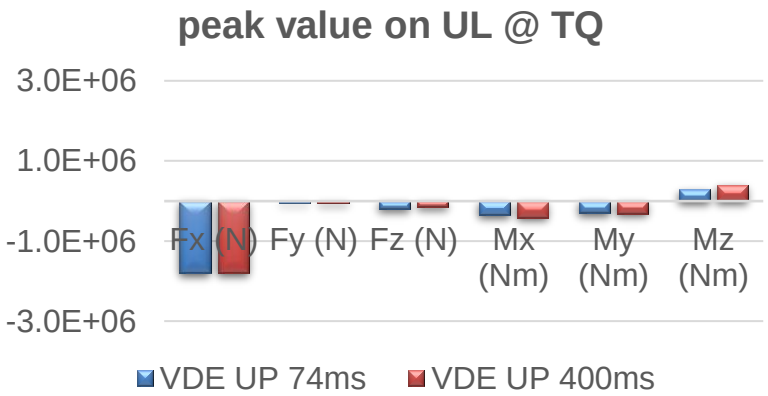
Sliced SB: orthotropic material properties

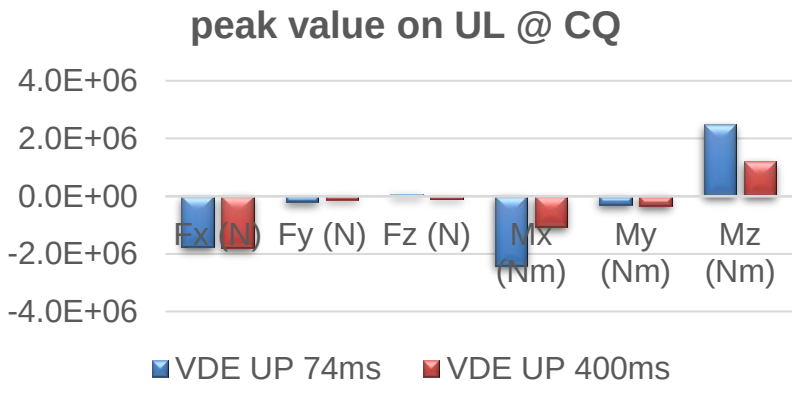
Electro-Magnetic Assessment

I. Maione: PS4-9



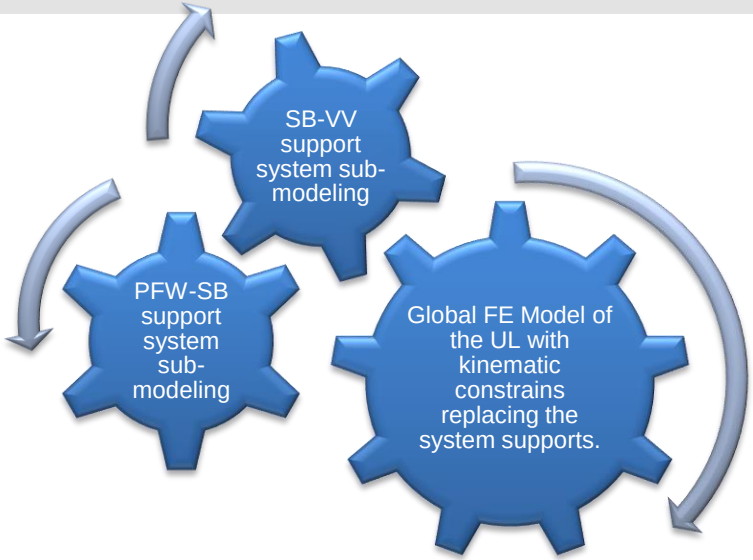
Fast vs Slow UVDE on UL with sliced SB



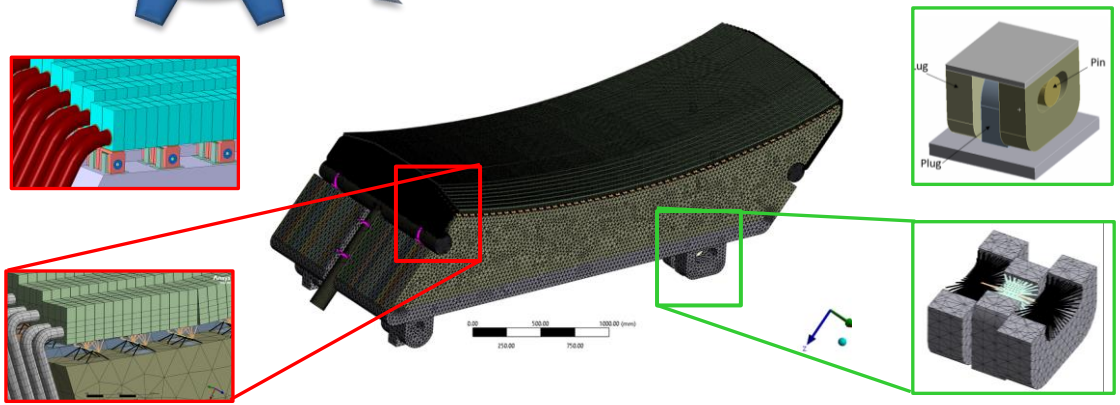


Structural Assessment

F. Viganò: PS1-16

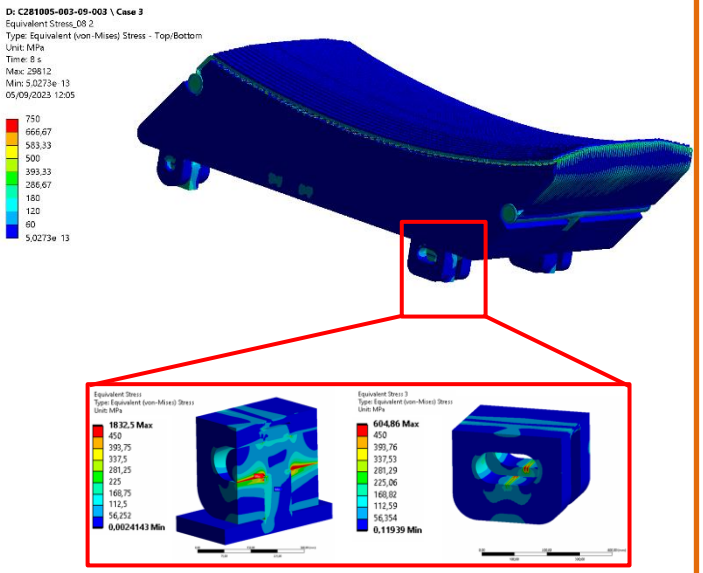


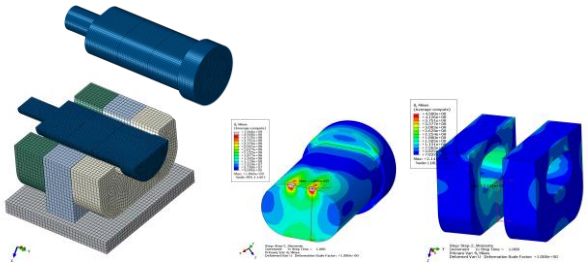
- Thermal–Mechanical assessment under:
  - Dead Weight
  - Cooling Pressure
    - PFW manifolds and pipes: 5 MPa
    - SB manifolds and channels: 15.5 MPa
  - Thermal loads (NO)
  - EM loads (fast UVDE, slow UVDE + HALO)

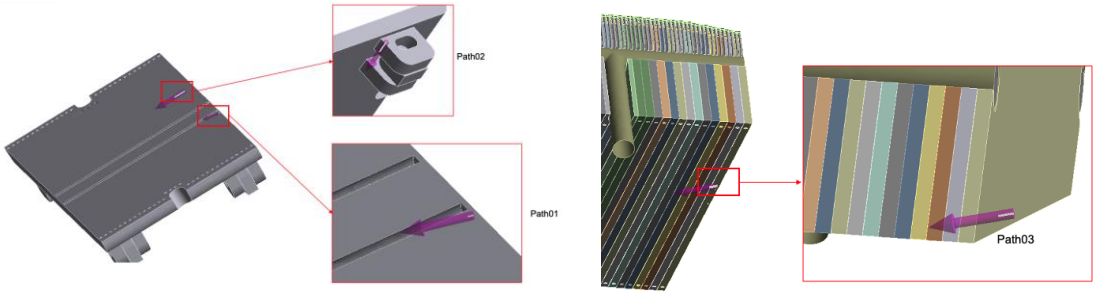


Structural Assessment

F. Viganò: PS1-16

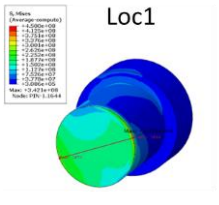


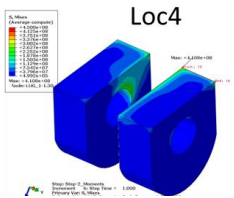




Location	P-type Margins
Path 01	2.39
Path 02	3.86
Path 03	6.88

Location	P-type Margins
Path 01	1.12
Path 04	1.13





Conclusions and Outlook

- UL conceptual engineering design is promising.
- UL design workflow and lessons learned to be inherited by other sacrificial limiters.
- The PFW design is following the up-to-date plasma physics assumptions.
- Ongoing R&D within EUROfusion for limiter PFW solutions. New PFW-SB fixation concept to be developed.
- Integration issues have started to be addressed. Remote maintenance feedback to drive a realistic design handling.
- An *Integration Node* is addressing the design and integration challenges of inboard protection systems and OLL, which do not have a dedicated port.

Conclusions and Outlook

- UL conceptual engineering design is promising.
- UL design workflow and lessons learned to be inherited by other sacrificial limiters.
- The PFW design is following the up-to-date plasma physics assumptions.
- Ongoing R&D within EUROfusion for limiter PFW solutions. New PFW-SB fixation concept to be developed.
- Integration issues have started to be addressed. Remote maintenance feedback to drive a realistic design handling.
- An *Integration Node* is addressing the design and integration challenges of inboard protection systems and OLL, which do not have a dedicated port.

Thank You!

This conference - Contributions

Neutronics: A. Čufar [PS4-110]

Thermal-hydraulics: A. Froio [PS3-3]

Electro-magnetism: I. Maione [PS4-9]

Structural assessment: F. Viganò [PS1-16]