Description of the COMPASS-U tokamak plasma-facing components (PFC)

R. Dejarnac, V. Balner, P. Vondracek and the COMPASS-U team

This document is intended for the companies that have shown interest in the Preliminary Market Consultation for COMPASS-U plasma-facing components to initiate discussion, to have feedback on fabrication and viability of the components. It provides very basic information about the components which are still in Design Phase.

COMPASS-U BASIC PARAMETERS

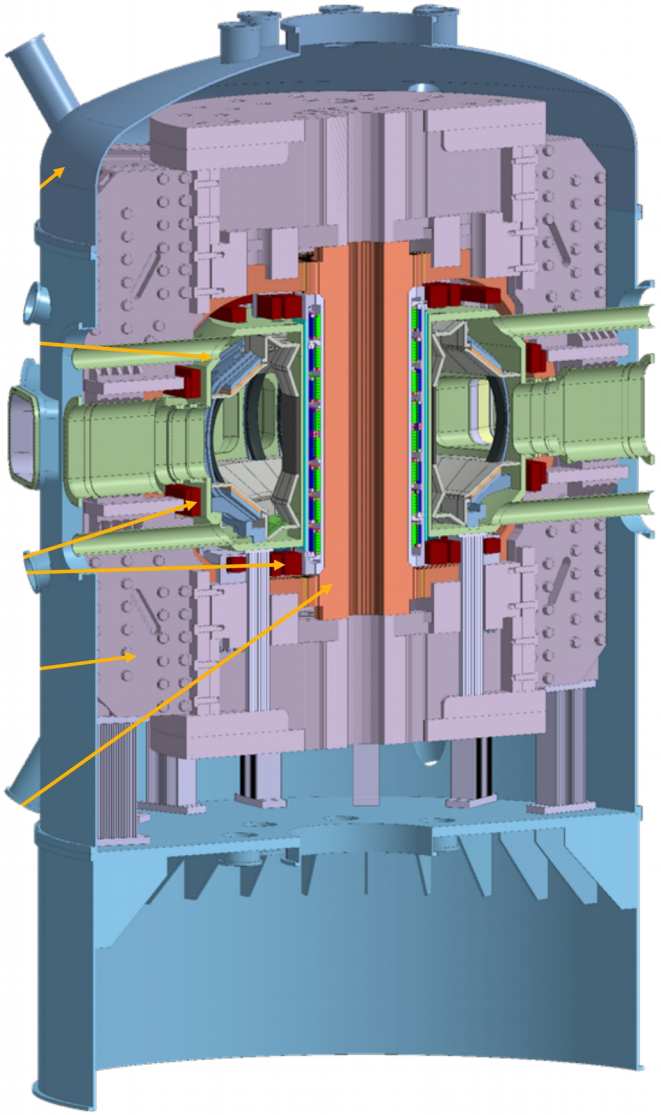
- COMPASS-U will be a high magnetic field (5 T) medium-sized tokamak with high wall temperature (<500°C) operation.
- The scientific program is aimed to address topics of plasma exhaust, liquid metals, enhanced confinement modes and edge plasma physics.

Basic dimensions and parameters:

$R = 0.894$ m	$T_{flat\text{-}top} = 1\text{-}3$ s
$a = 0.27$ m	$\delta = 0.5$
$B_T = 5$ T	$\kappa = 1.8$
$I_p = 2$ MA	$V_{Plasma} \sim 2$ m^3

High capability to address the key Plasma Exhaust Physics challenges

→ robust PFC are of high importance



PFC GENERAL SPECIFICATIONS

PFC functions:

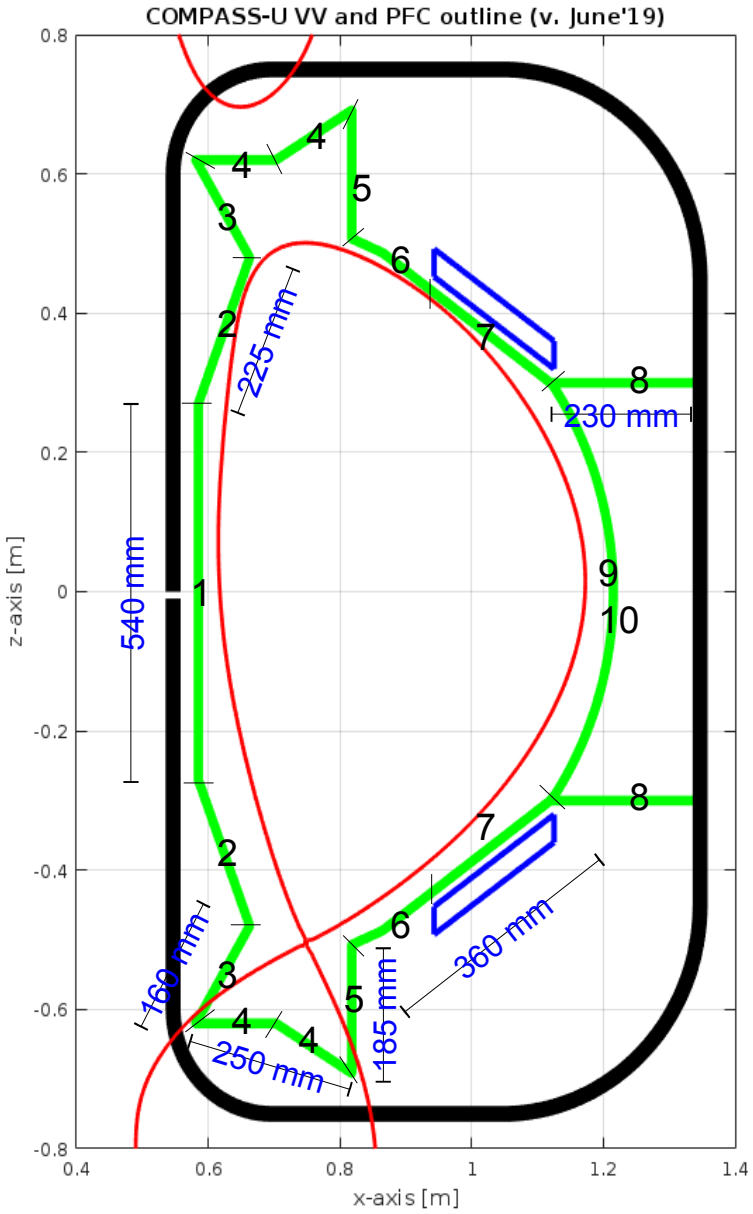
- Absorb the high heat and particle fluxes from the plasma during operation
- Protect the vacuum vessel (VV) and in-vessel components *(diagnostics, RF antennas, mirrors, cables, etc)* from the plasma during standard / off-normal event

PFC design requirement:

- Absorb heat fluxes in the range of several tens of MW/m^2 up to 3 seconds
- Withstand large electro-magnetic forces consequent to disruptions *(sudden loss of plasma control < 1 ms)* with stresses in the range ~500+ MPa locally
- PFC should be metallic *(no carbon/graphite is allowed)* and change of phase *(erosion, melting, plastic deformation, etc)* should be strongly avoided
- Tungsten (W) is the main material foreseen with purity >99.9% & density $>19 g/m^3$
- Surface roughness Ra ≤ 3.2 μm

PFC design constraints:

- PFC should be non-ferromagnetic
- PFC should be compatible with high vacuum ($10^{-6} < P < 1$ Pa)
- PFC should be compatible with high temperature operation (up to 500°C)
- PFC will not be (actively) cooled
- Manufacturability & Price



PFC denomination and dimensions

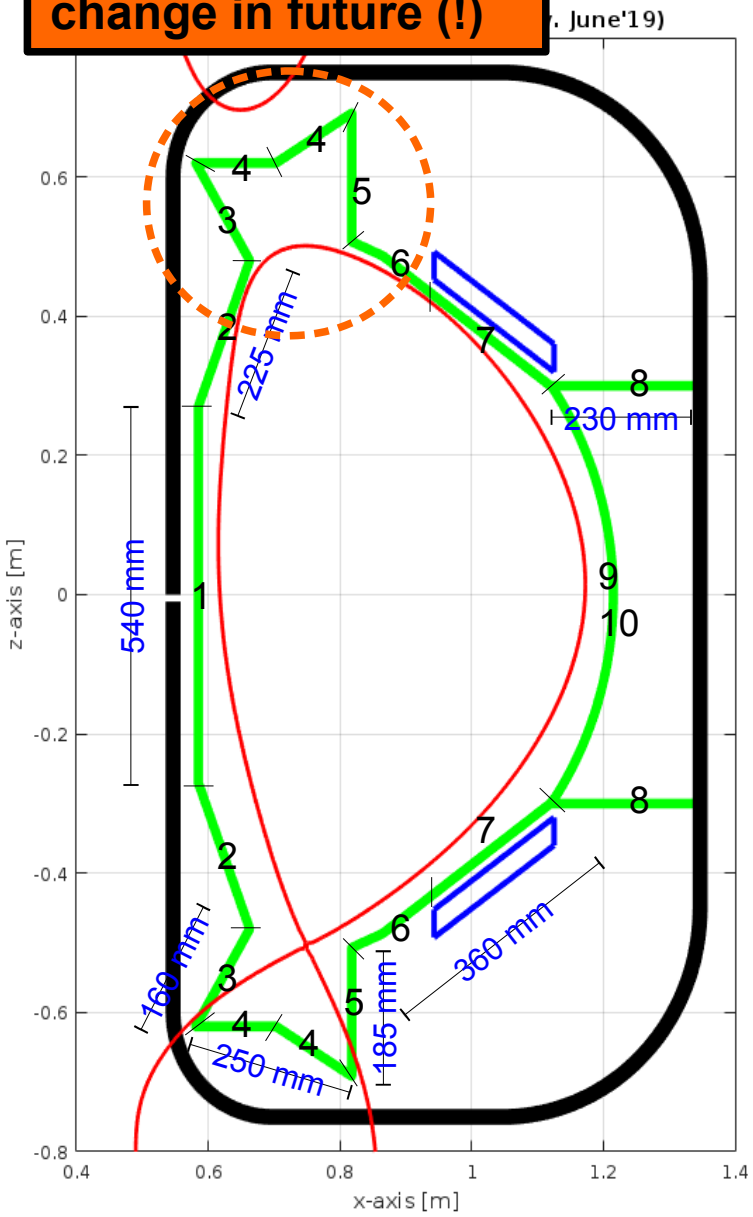
1) **IWL:** inner wall limiter
2) **IDB:** inner divertor baffle
3) **IVT:** inner vertical target
4) **DIF:** divertor floor
5) **OVT:** outer vertical target
6) **ODB:** outer divertor baffle
7) **PSPP:** passive stabilization plate protection
8) **OHP:** outer horizontal plates
9) **OWL:** outer wall limiters
10) **OBP:** outer bridge protection

Choice of material

Tungsten (W)
- high melting point → HHF regions
- low electrical resistivity→ large currents → large forces

Inconel^{718} mainly as PFC with W-coating
Inconel^{625} for support structures
- high yield strength, especially at 500°C
- larger electrical resistivity → low forces
- low melting point

(!) Design here will change in future (!)



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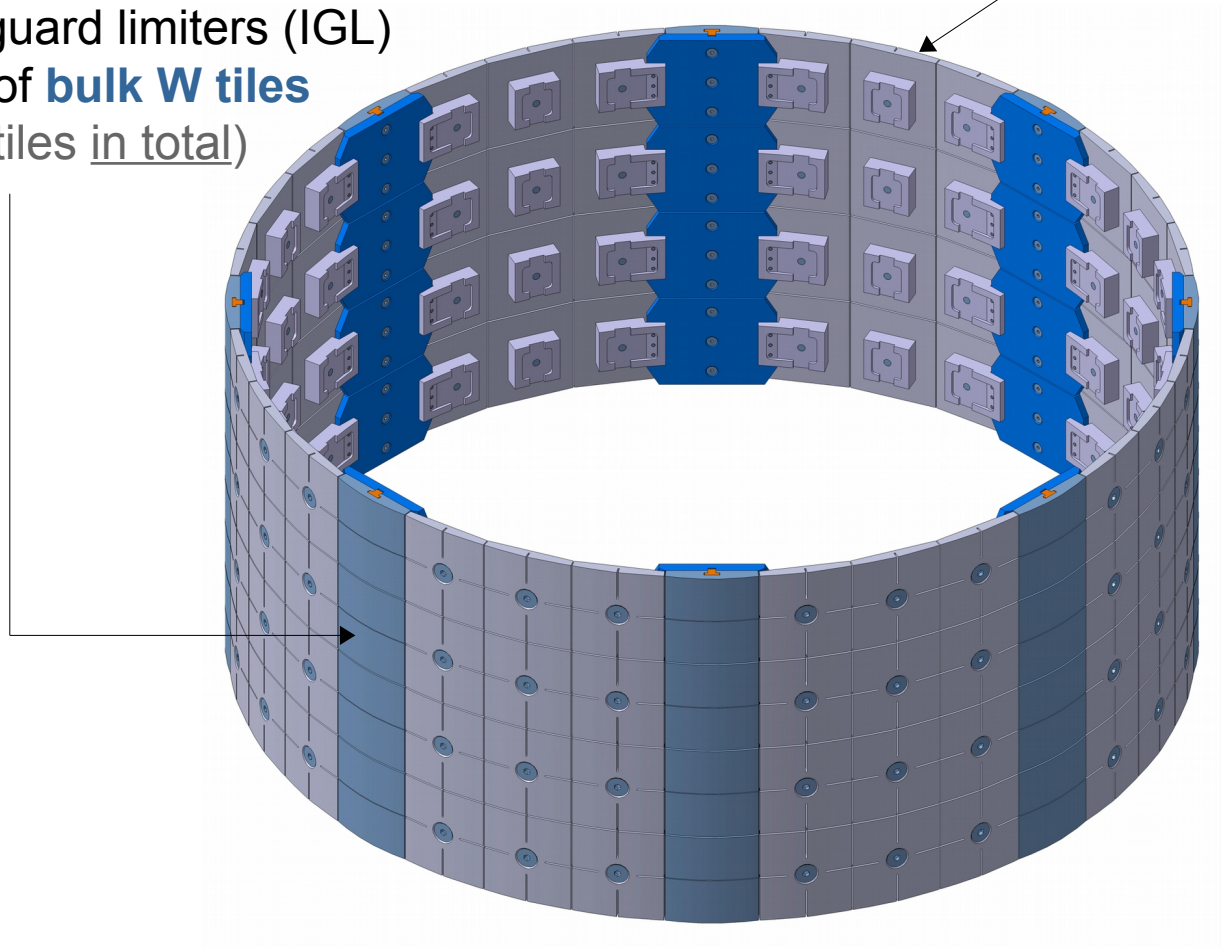
6) ODB: outer divertor baffle
7) PSPP: passive stabilization plate protection
8) OHP: outer horizontal plates
9) OWL: outer wall limiters
10) OBP: outer bridge protection

IWL Design: General Description

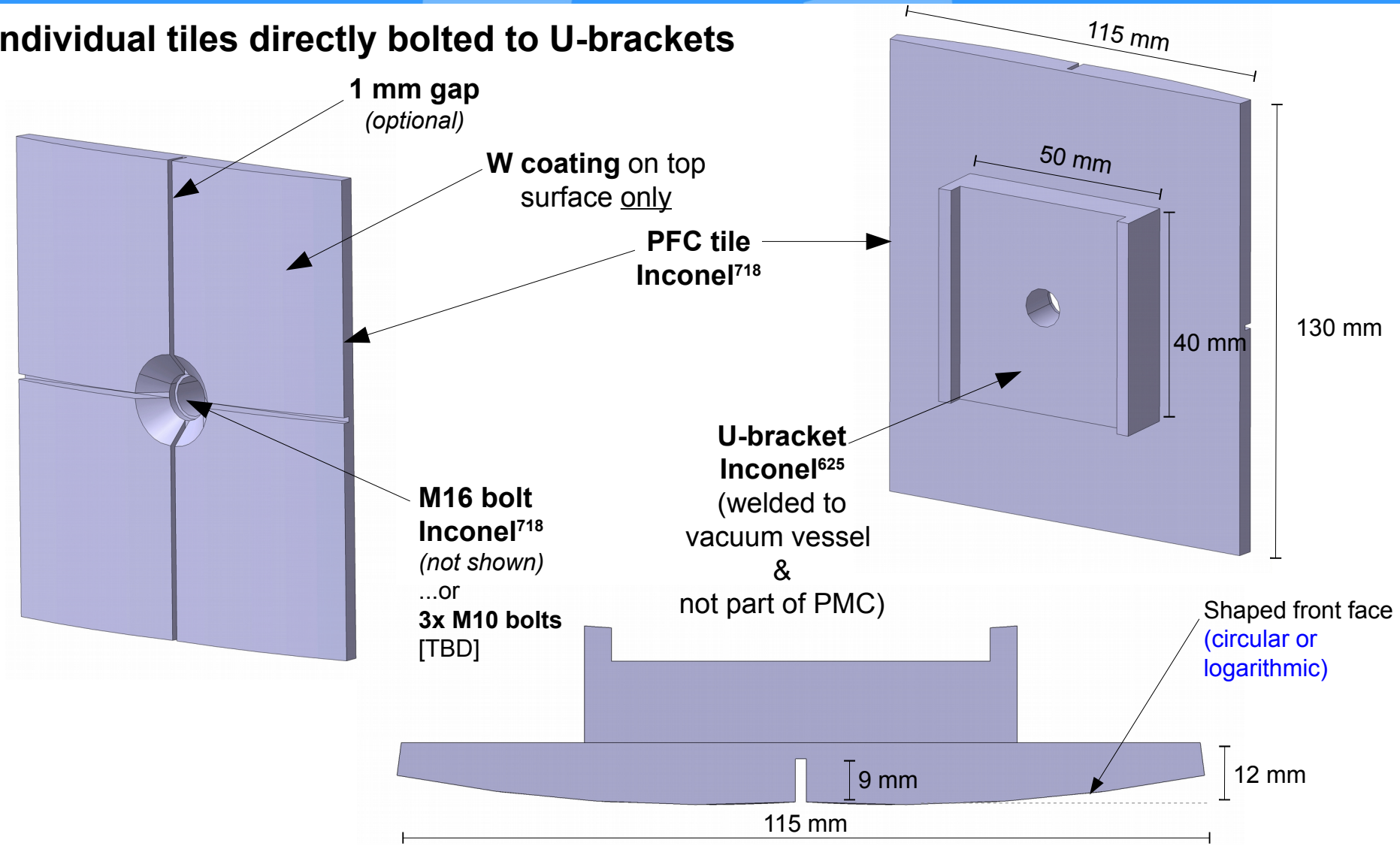
IWL concept is a mixture of:

- **Inconel tiles** with a W-coating (8 x 12 tiles in total)
- Inner guard limiters (IGL) made of **bulk W tiles** (8 x 8 tiles in total)



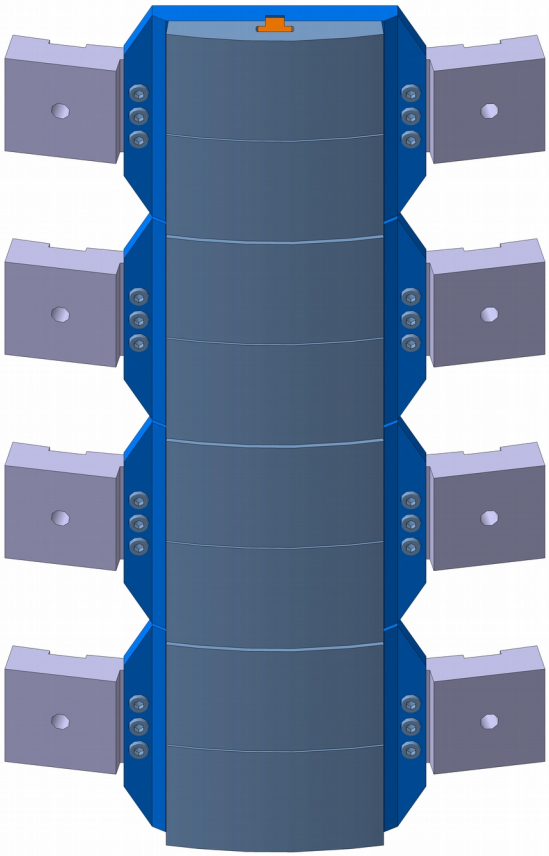
IWL Design: Inconel Tiles

Individual tiles directly bolted to U-brackets



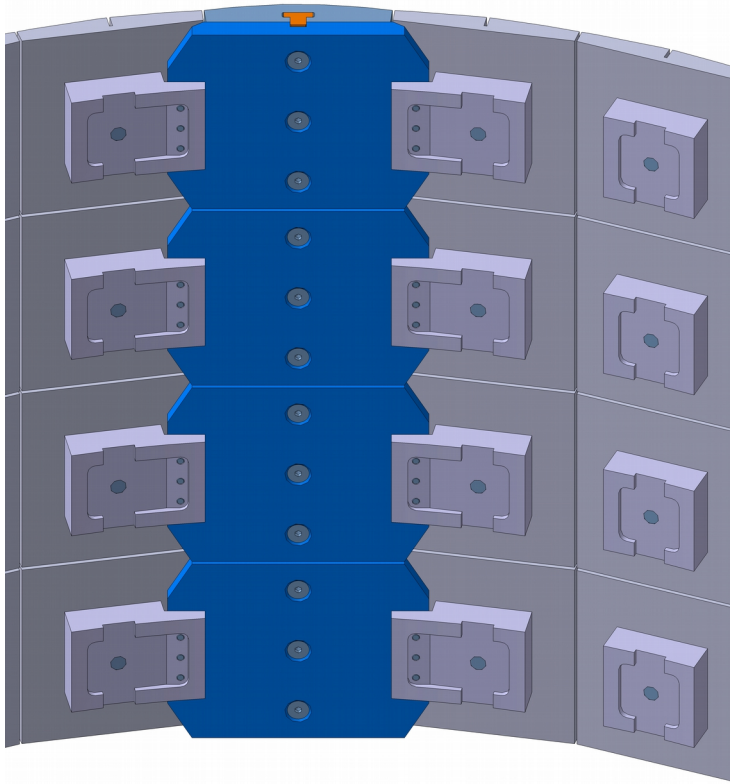
IWL Design: IGL Description

Front side

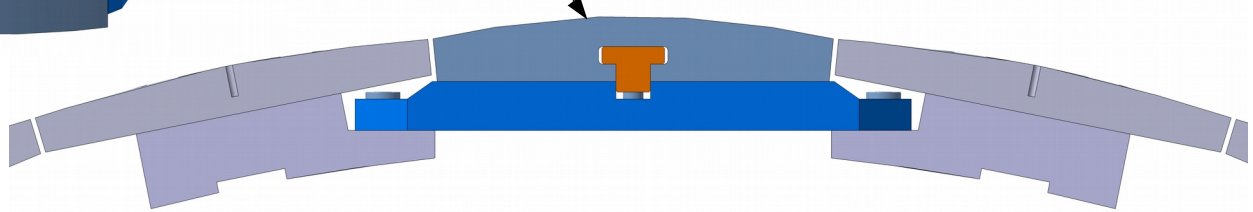


- **W tiles** are fixed to an **inconel[718] baseplate by pairs** using a **central rail** (inconel[718])
- The **rail** is fixed to the **baseplate** by **3 M6 bolts**
- The **baseplate** is fixed to the U-brackets by **3 M6 bolts** on each 'ear'
- In total **96 U-brackets** to be welded to **VV**

Back side

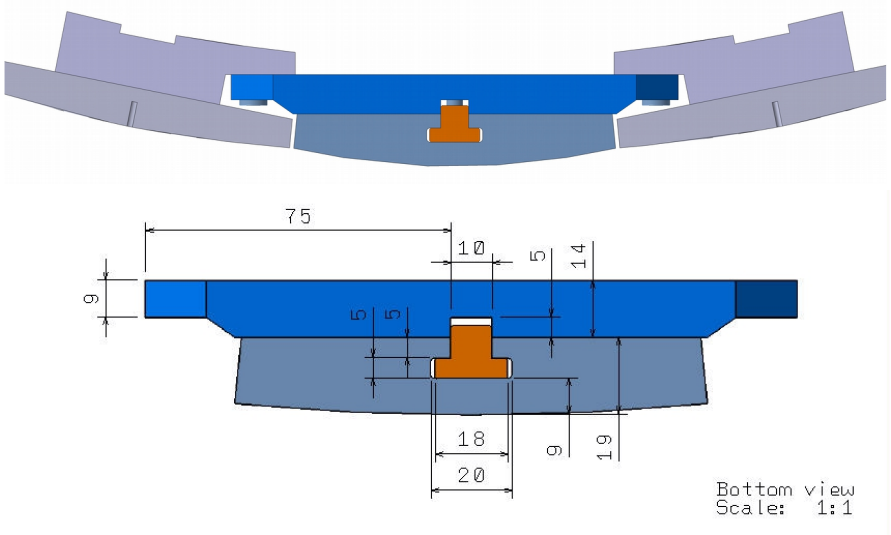


Shaped front face
(circular or
logarithmic)

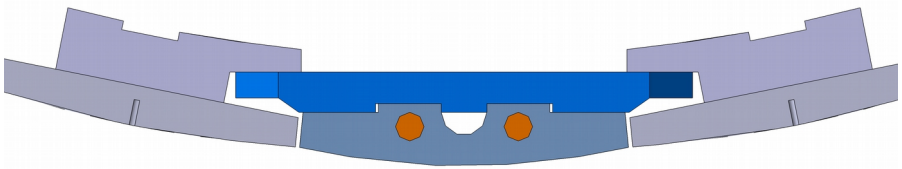


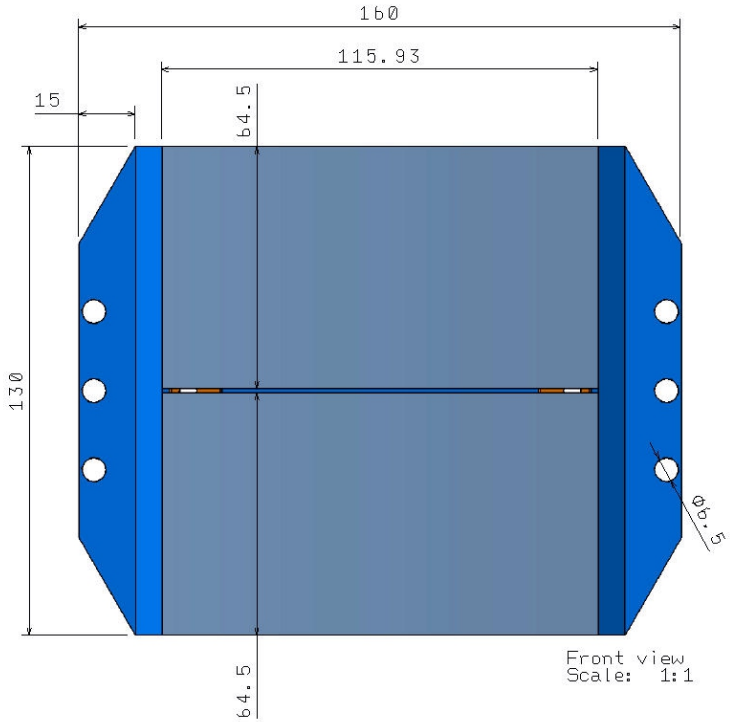
IWL Design: IGL Description

Sub-variant #1 - central rail

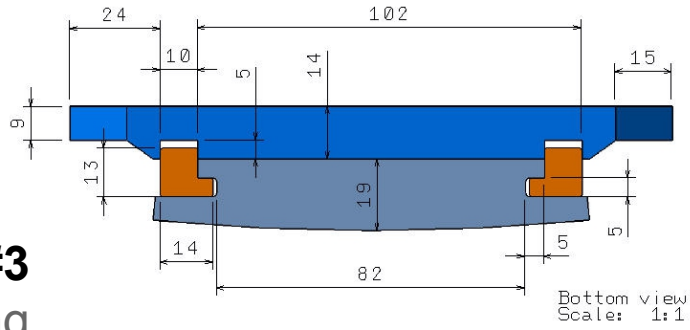


Sub-variant #2 - central pins





Sub-variant #3 clamping



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IWL Summary: elements, materials, dimensions, number

Elements	PFC	Material	Number	~Size [mm]	Notes
IW tiles	IWL	Inconel^{718} with W coating	96	130x115x12	Front face shaping (logarithmic or circular + chamfer)
IGL tiles	IWL	W	64	116x65x19	Central pocket (circular or square section, TBD) or Side grooves for fixation ---------- Front face shaping (logarithmic or circular + chamfer)
U-brackets	*IWL*	*Inconel^{625}*	*96 (32 straight + 64 w/ legs/ears)*	*40x50x20*	*5mm thick legs to be welded to VV and 13 mm thick base (to support the tile) + Precise machining for alignment*
M16 bolts, or M10 bolts	*IWL*	*Inconel^{718}*	*96 288*		*Flat head*
Backplates	*IWL*	*Inconel^{718}*	*32*	*160x130x14*	
** Rails, or * Pins, or * Clamps*	*IWL*	*Inconel^{718}*	*32 64 64*	*18x13x130 10x13x130 14x13x130*	
M6 bolts	*IWL*	*Inconel^{718}*	*288 / 384*		

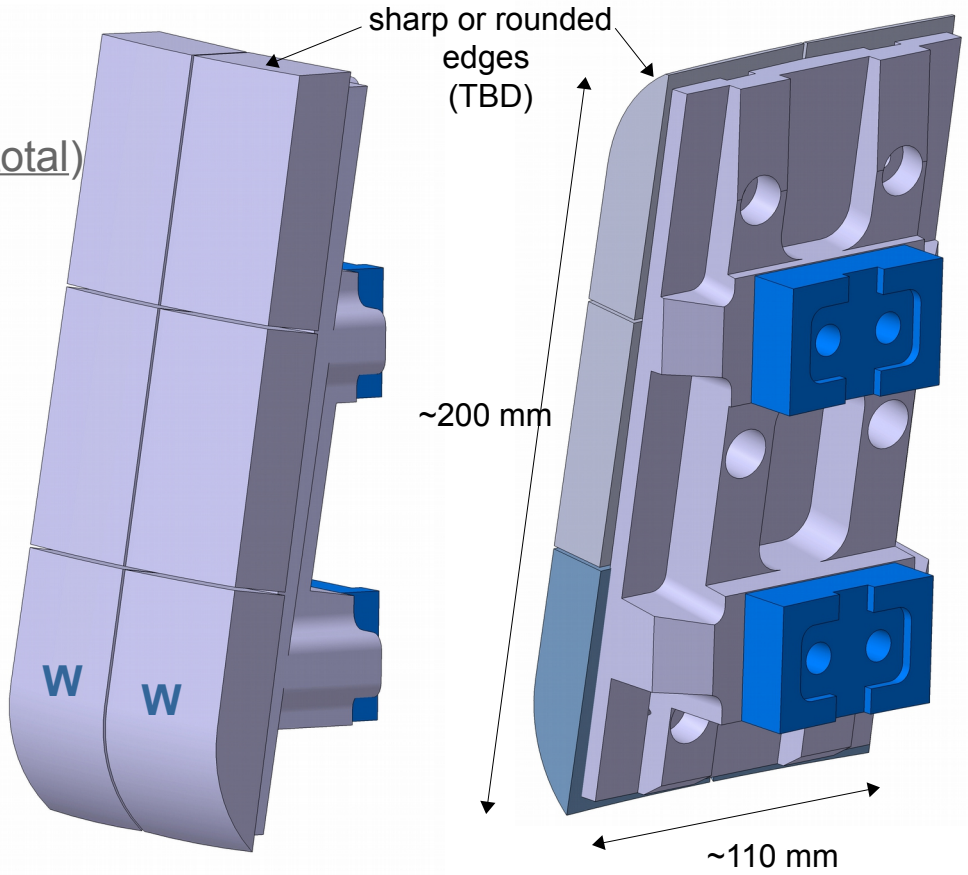
1) IWL: inner wall limiter
2) IDB: inner divertor baffle*
3) IVT: inner vertical target
4) DIF: divertor floor
5) OVT: outer vertical target
6) ODB: outer divertor baffle
7) PSPP: passive stabilization plate protection
8) OHP: outer horizontal plates
9) OWL: outer wall limiters
10) OBP: outer bridge protection

*description for one IDB

IDB Design: General Description

Inner Divertor Baffle:

- **6 tiles per baffle** (x32)
  - **4 inconel tiles** [top] with W coating (128 in total)
  - **2 W tiles** [bottom] (64 tiles in total)
- **Approximate tiles size:**
  - Thickness: ~20mm
  - Height (poloidal): ~66 mm
  - Width (toroidal): ~55 mm
- **Cylindrical pocket*** in each W tile for an inconel central pin with ∅ **~ 10 mm**
- **1x M8 bolt per tile** (192 in total) - **TBC**
  → one hole in each W tile
- **4x M6 bolts per baffle** to fix the back-plate to U-brackets (128 in total)
- **Flat front surface**



- Full view of the six tiles at one IDB -
[front side (left) & back side (right)]
(design in progress)

*The tiles attachment *(not shown here)* is generic for most of the PFC and consists of the central, cylindrical pin inserted in the tile with transverse bolt(s) for fixation to a support plate (see e.g., IVT tiles)

IDB Summary*: elements, materials, dimensions, number

Elements	PFC	Material	Number	~Size [mm]	Notes
Upper tiles	IDB	Inconel^{718} with W coating	128	66x55x20	Central pocket (circular cross-section) ---------- Flat front face (TBC)
Lower tiles	IDB	W	64	66x55x20	Central pocket (circular cross-section) ---------- Flat front face (TBC)
U-brackets	*IDB*	*Inconel^{625}*	*64*	*TBD*	
M8 bolts	*IDB*	*Inconel^{718}*	*192*		
Backplates	*IDB*	*Inconel^{718}*	*32*	*200x110x14*	
M6 bolts	*IDB*	*Inconel^{718}*	*128*		

*description for one IDB

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7) PSPP: passive stabilization plate protection
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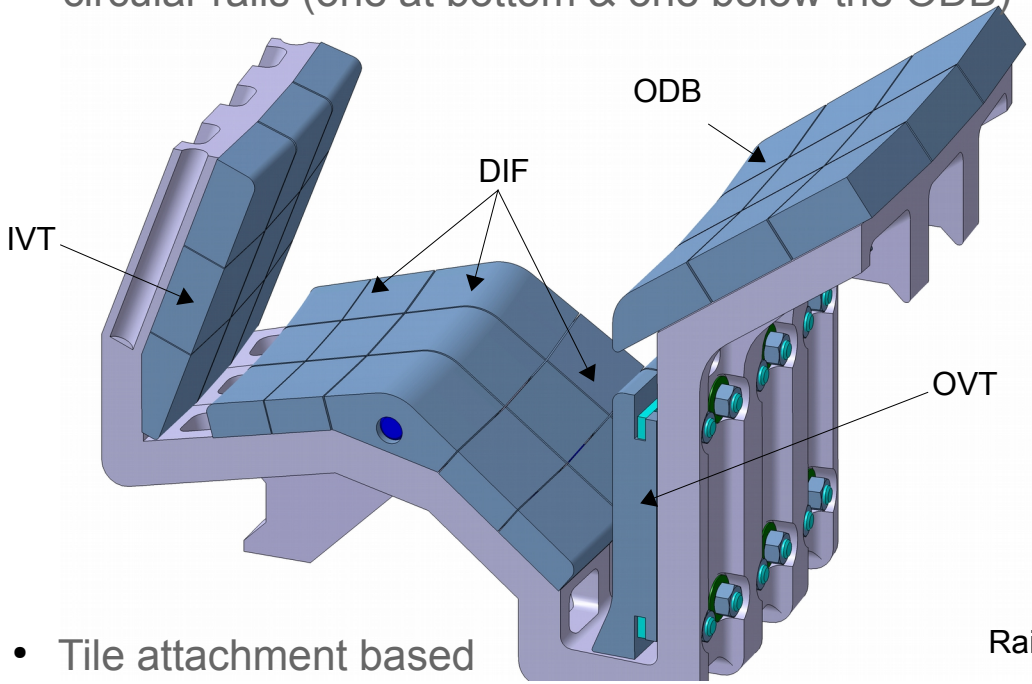
So-called DIVERTOR*

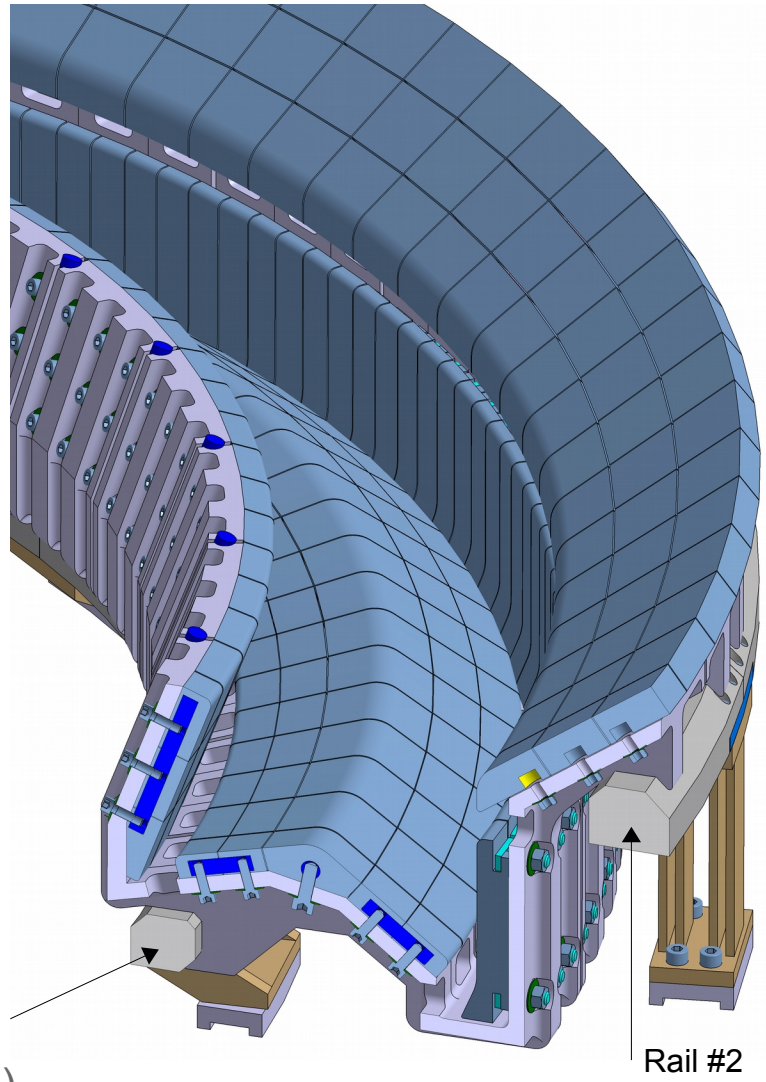
*description for one divertor (bottom one) as the upper one will be different

DIVERTOR Design: General Description

The divertor is composed of elements no.3 (IVT) to no.6 (ODB):

- **PFC tiles** (**W**) are fixed to an **inconel structure**, so-called **'cassette'**. Cassettes (32) are fixed together using inconel **pins** to make a unique, rigid element
- Cassettes are anchored to the VV using 2 massive circular rails (one at bottom & one below the ODB)





- Tile attachment based on a central pin (inconel) with transverse bolts (inconel)

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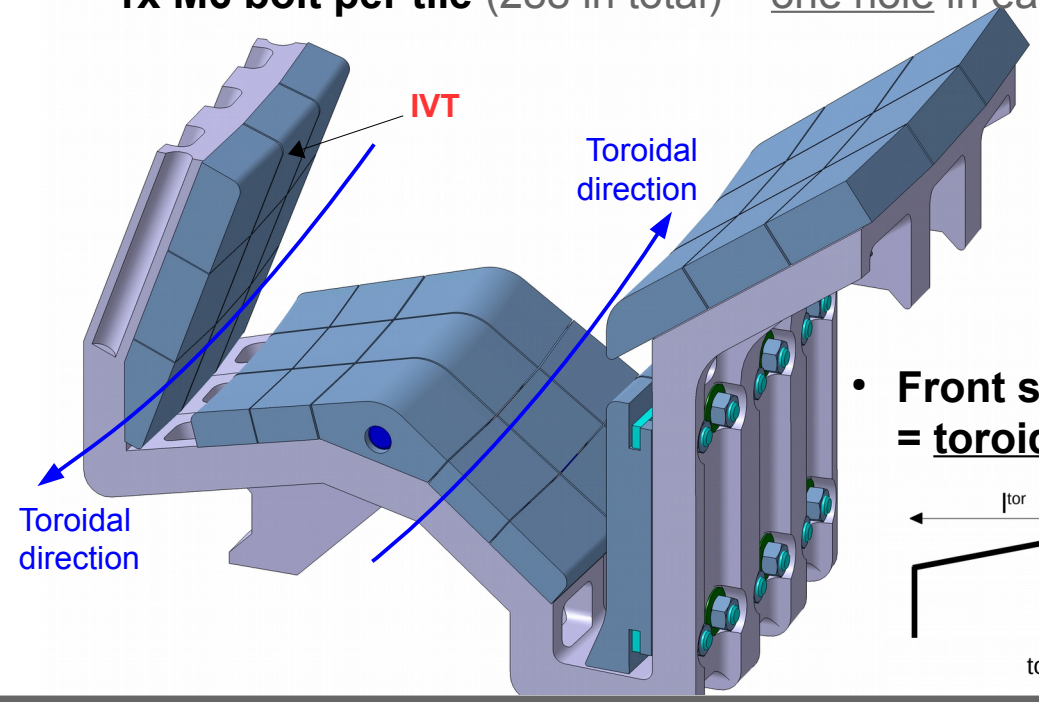
7) PSPP: passive stabilization plate protection
8) OHP: outer horizontal plates
9) OWL: outer wall limiters
10) OBP: outer bridge protection

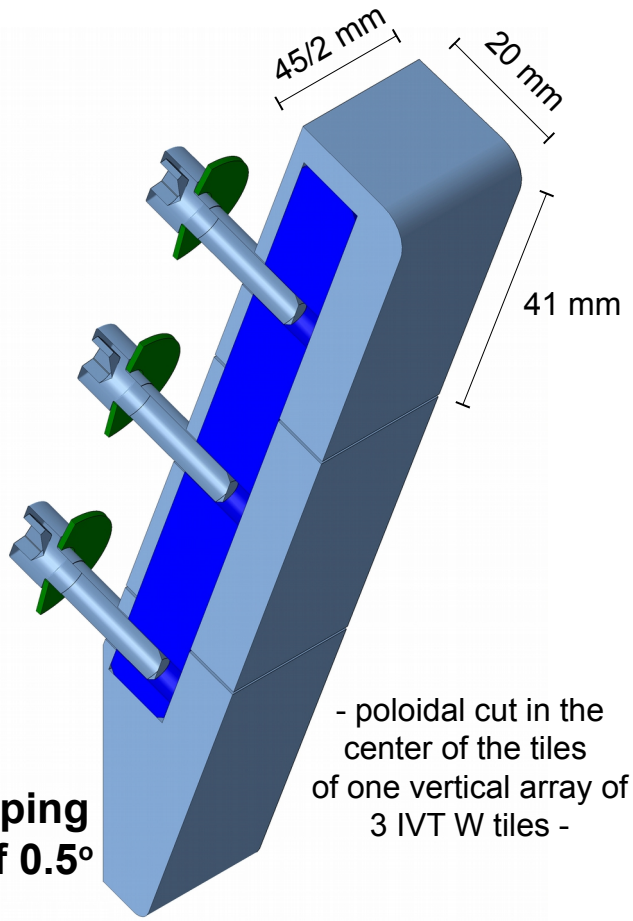
*description for one IVT (bottom one) as the upper one will be different

IVT Design: General Description

IVT tiles:

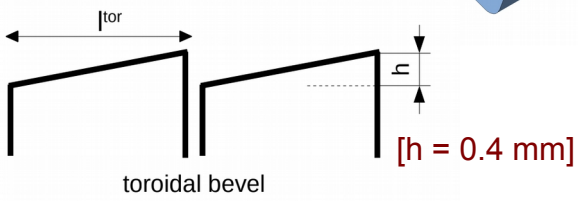
- **9 tungsten tiles per cassette** (288 in total)
  - Thickness: 20mm
  - Height (poloidal): 41 mm
  - Width (toroidal): 45 mm [= l^{tor}]
- **Cylindrical pocket** in each W tile for inconel central pin with ∅ **= 10 mm**
- **1x M6 bolt per tile** (288 in total) = one hole in each W tile





- poloidal cut in the center of the tiles of one vertical array of 3 IVT W tiles -

- **Front surface shaping = toroidal bevel of 0.5°**



[h = 0.4 mm]

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8) OHP: outer horizontal plates
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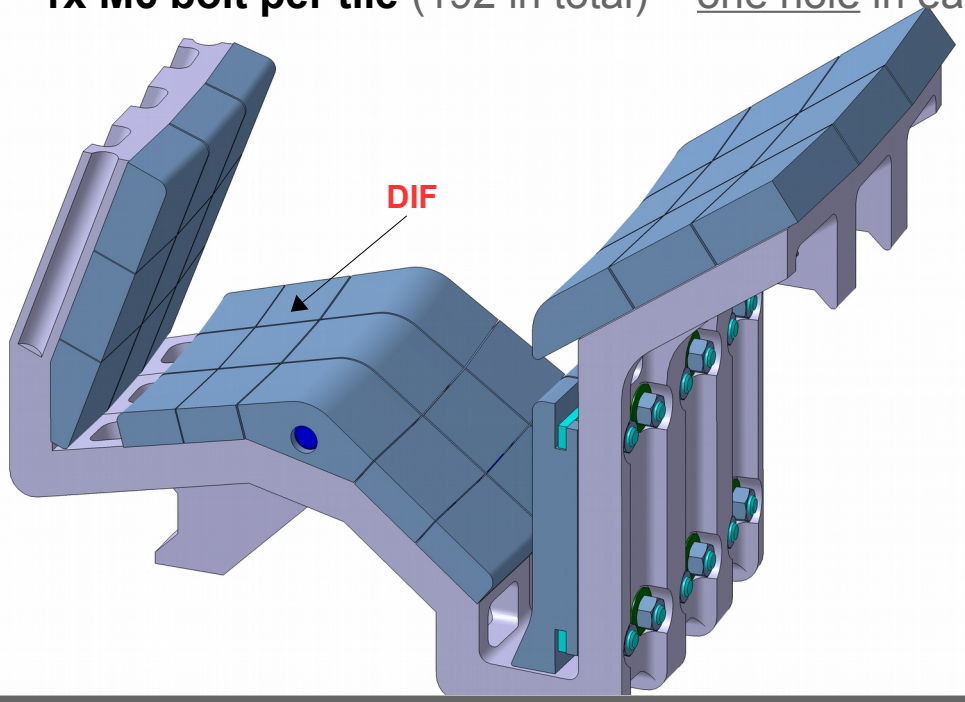
10) OBP: outer bridge protection

*description for one floor (bottom one) as the upper one will be different

DIF Design: General Description

DIF tiles:

- **6 tungsten tiles per cassette** at inner side (192 in total)
  - Thickness: 15 mm
  - Length (poloidal): 28 mm
  - Width (toroidal): 44 mm
- **Cylindrical pocket** in each W tile for inconel central pin with ∅ **= 10 mm**
- **1x M6 bolt per tile** (192 in total) = one hole in each W tile



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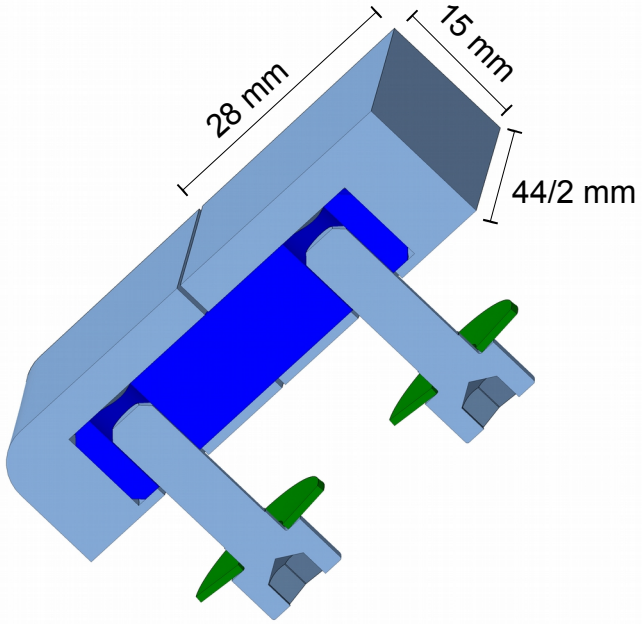
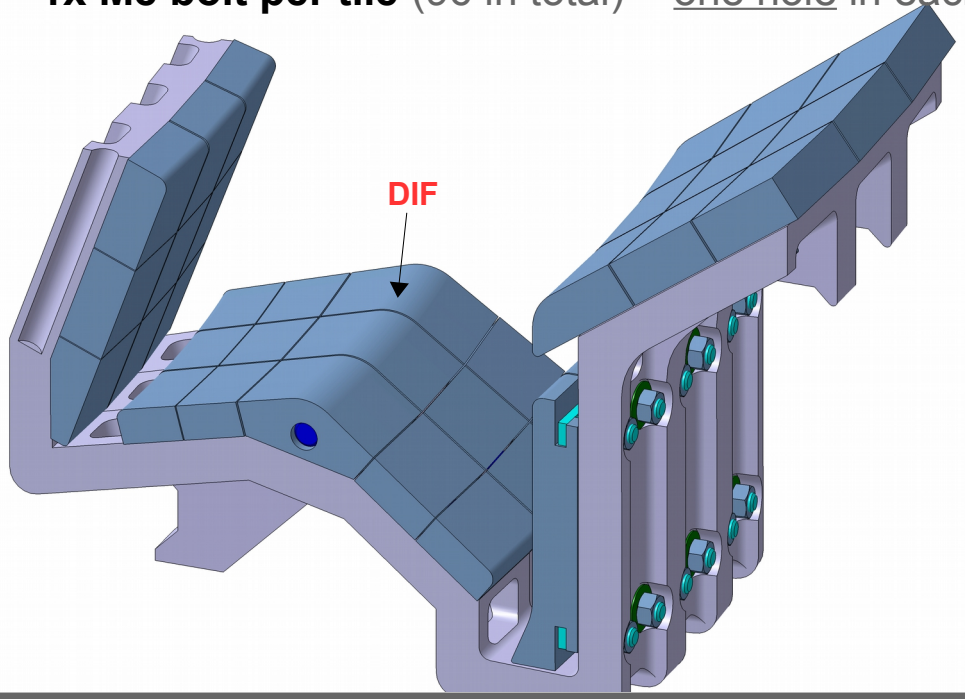


- Poloidal cut in the center of two horizontal tiles at the inner DIF -

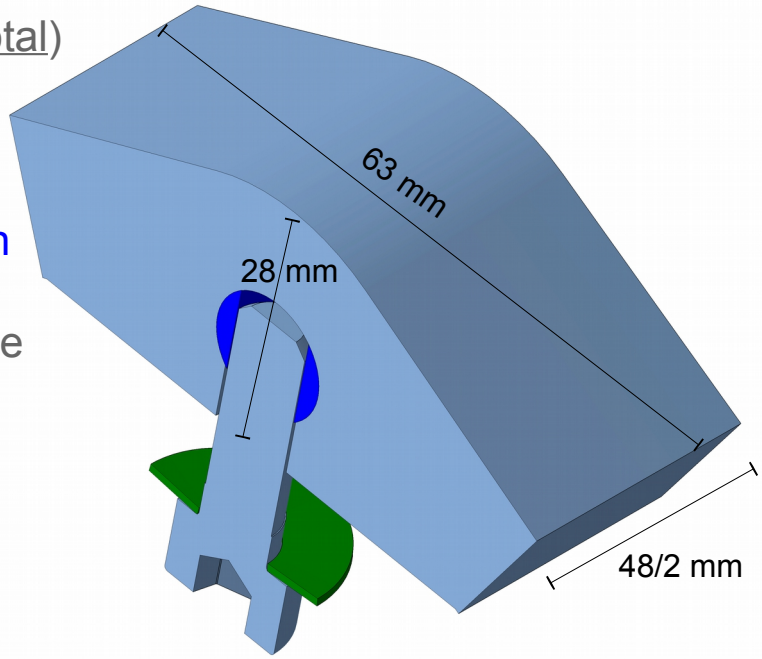
DIF Design: General Description

DIF tiles:

- **3 tungsten tiles per cassette** at central dome (96 in total)
  - Thickness (max): 28 mm
  - Length (poloidal): 63 mm
  - Width (toroidal): 48 mm
- **Cylindrical pocket** in each W tile for inconel central pin with ∅ **= 12 mm**
- **1x M8 bolt per tile** (96 in total) = one hole in each W tile



- **Flat front surface**

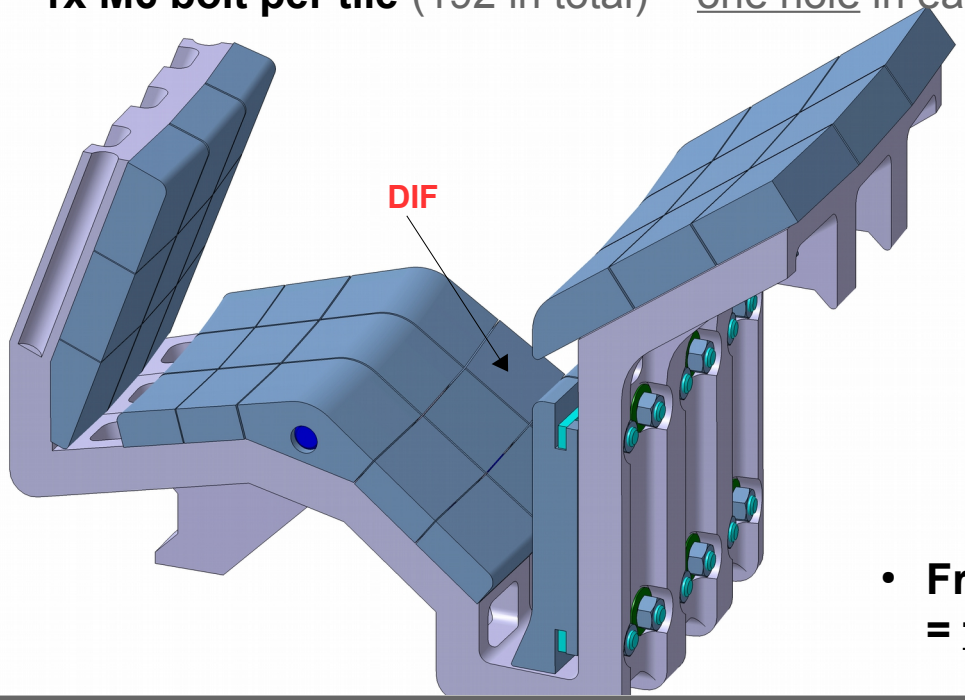


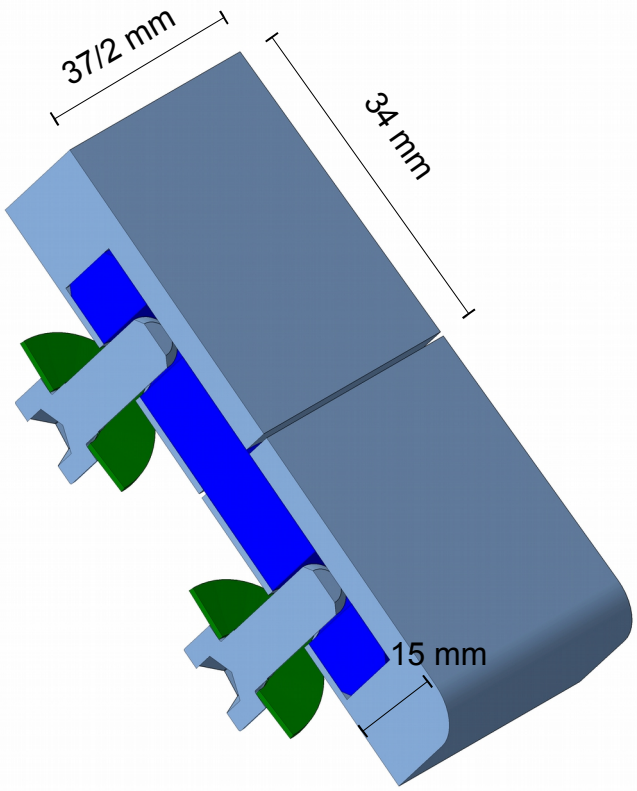
- Poloidal cut in the center of one tile at the central dome -

DIF Design: General Description

DIF tiles:

- **6 tungsten tiles per cassette** at outer side (192 in total)
  - Thickness: 15 mm
  - Length (poloidal): 34 mm
  - Width (toroidal): 37 mm
- **Cylindrical pocket** in each W tile for inconel central pin with ∅ **= 10 mm**
- **1x M6 bolt per tile** (192 in total) = one hole in each W tile





- Poloidal cut in the center of two two horizontal tiles at the outer DIF -

- **Front surface shaping = toroidal bevel of 0.5°**

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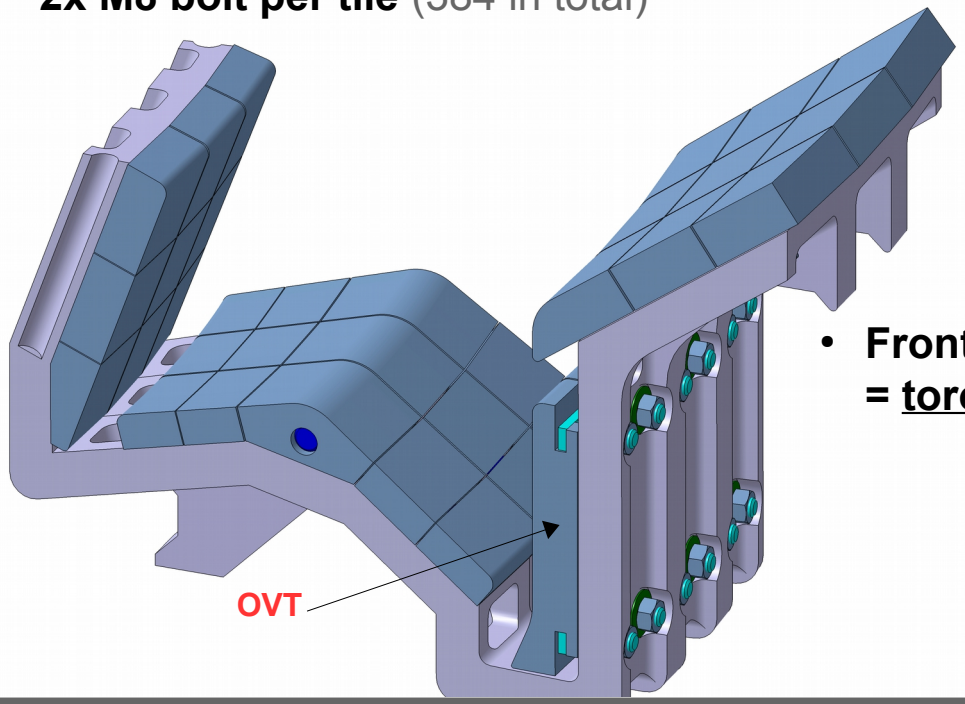
3) IVT: inner vertical target
4) DIF: divertor floor
5) **OVT: outer vertical target***
6) ODB: outer divertor baffle
7) PSPP: passive stabilization plate protection
8) OHP: outer horizontal plates
9) OWL: outer wall limiters
10) OBP: outer bridge protection

*description for one OVT (bottom one) as the upper one will be different

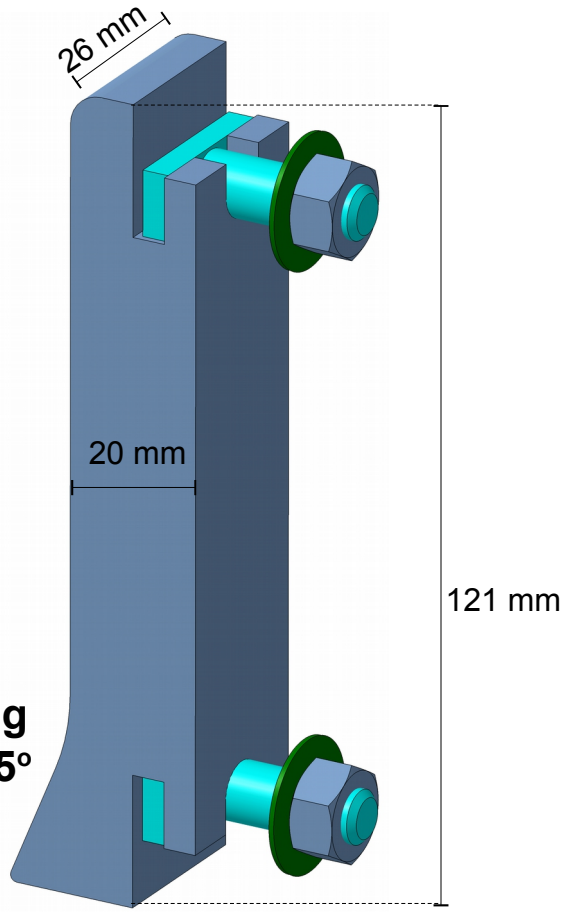
OVT Design: General Description

OVT tiles:

- **6 tungsten tiles per cassette** (192 in total)
  - Thickness (central): 20mm
  - Height (poloidal): 121 mm
  - Width (toroidal): 26 mm
- **One groove at each side** of one W tile for inconel clamping attachment system
- **2x M8 bolt per tile** (384 in total)



- **Front surface shaping = toroidal bevel of 0.5°**



- View of one full vertical tile at the OVT -

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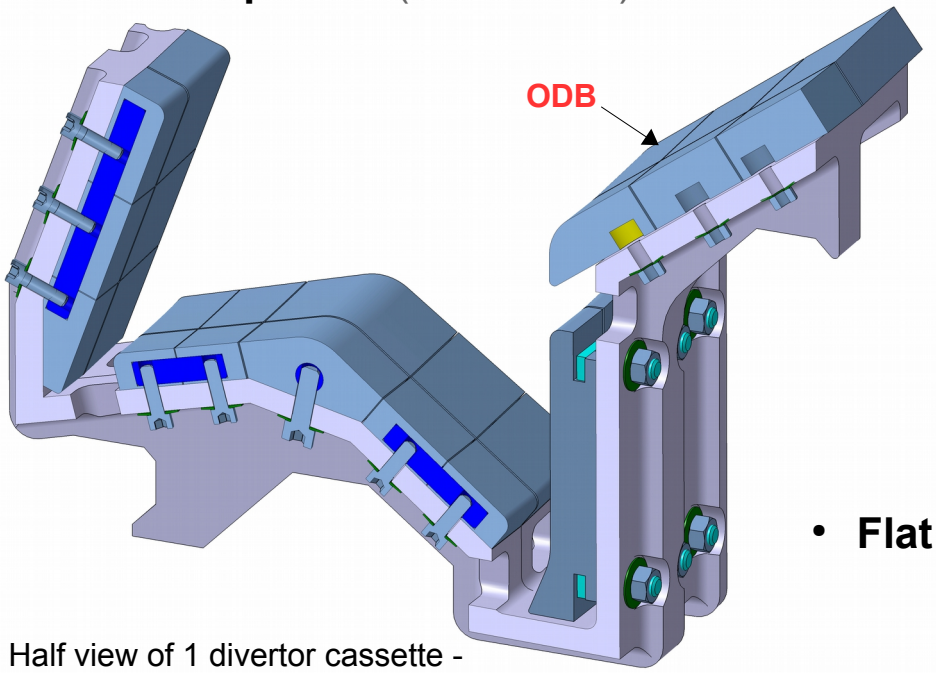
5) OVT: outer vertical target
6) **ODB: outer divertor baffle***
7) PSPP: passive stabilization plate protection
8) OHP: outer horizontal plates
9) OWL: outer wall limiters
10) OBP: outer bridge protection

*description for one ODB

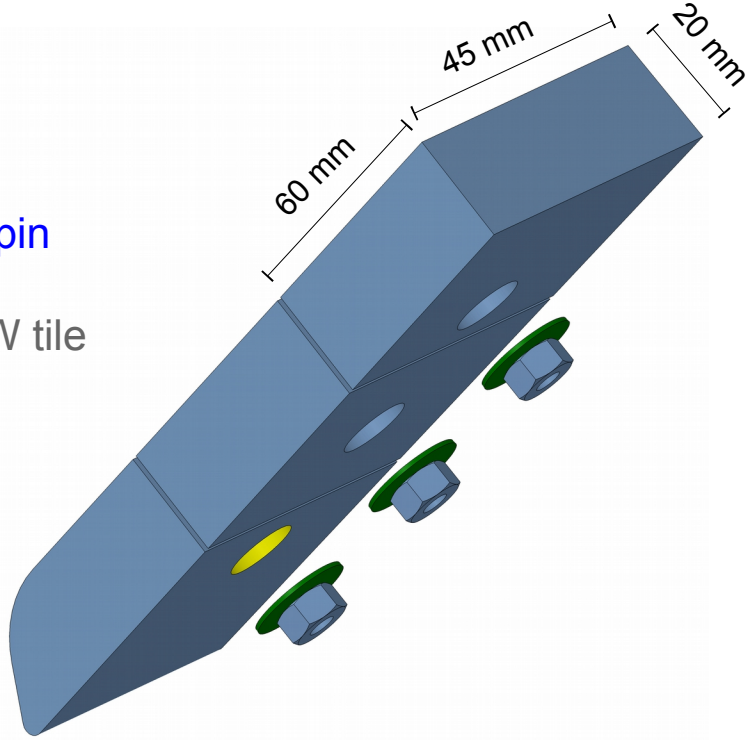
ODB Design: General Description

ODB tiles:

- **9 tungsten tiles per cassette** (288 in total)
  - Thickness: 20mm
  - Length (poloidal): 60 mm
  - Width (toroidal): 45 mm
- **Cylindrical pocket** in each W tile for inconel central pin with ∅ **= 10 mm**
- **1x M6 bolt per tile** (288 in total) = one hole in each W tile



- Half view of 1 divertor cassette -



- Full view of three tiles at the ODB -
(design in progress)

- **Flat front surface**

DIVERTOR Summary*: elements, materials, dimensions, number

Elements	PFC	Material	Number	~Size [mm]	Notes
Front tiles	IVT	W	288	41x45x20	Cylindrical pocket + 1 hole per tile (top surface w/ 0.5° toroidal bevel)
Front tiles	DIF inner DIF dome DIF outer	W W W	192 96 192	28x44x15 63x48x28 34x37x15	Cylindrical pocket + 1 hole per tile (top surface w/ 0.5° toroidal bevel ...except for the dome tiles = flat surface)
Front tiles	OVT	W	192	121x26x20	Grooves at both ends for clamping (top surface w/ 0.5° toroidal bevel)
Front tiles	ODB	W	288	60x45x20	Cylindrical pocket + 1 hole per tile (flat front surface [TBC])
M6 bolts	*IVT+IDF +ODF+ODB*	*Inconel^{718}*	*960*		
M8 bolts	*Dome+OVT*	*Inconel^{718}*	*480*		
Backplates	*TBD*	*Inconel^{718}*	*TBD*		

*description for one DIV (bottom one) as the 2nd one will have a different design

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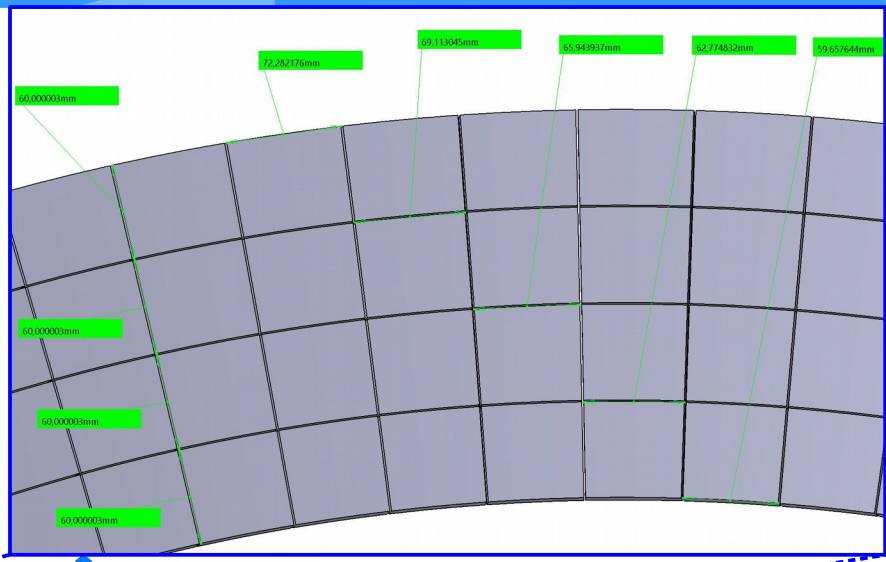
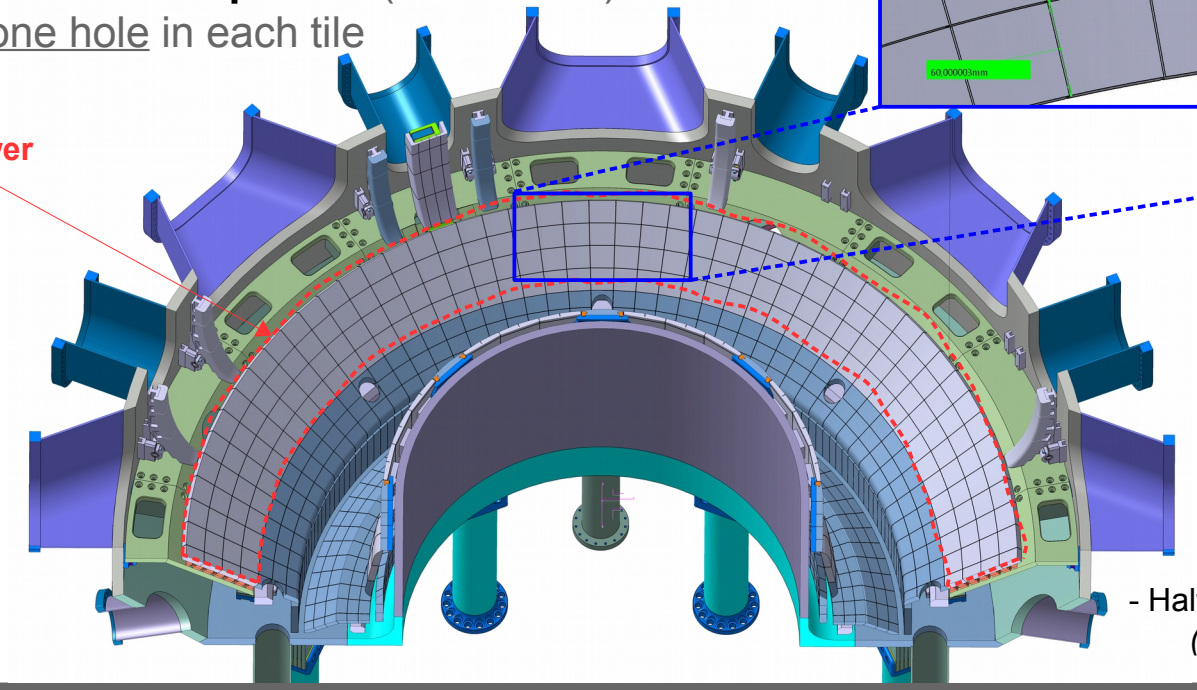
6) ODB: outer divertor baffle
7) **PSPP: passive stabilization plate protection**
8) OHP: outer horizontal plates
9) OWL: outer wall limiters
10) OBP: outer bridge protection

PSPP Design: General Description

PSPP tiles:

- **768 inconel tiles** with **W coating** **in total**
  - Thickness: 15 mm
  - Length (poloidal): 60 mm
  - Width (toroidal): ~65 mm
- **Flat front surface**
- **Tiles bolted to support** (as for IWL tiles, see p.8)
- **One M16 bolt per tile** (768 in total)
  = one hole in each tile





- Half view of bottom PSPP -
(design in progress)

PSPP Summary*: elements, materials, dimensions, number

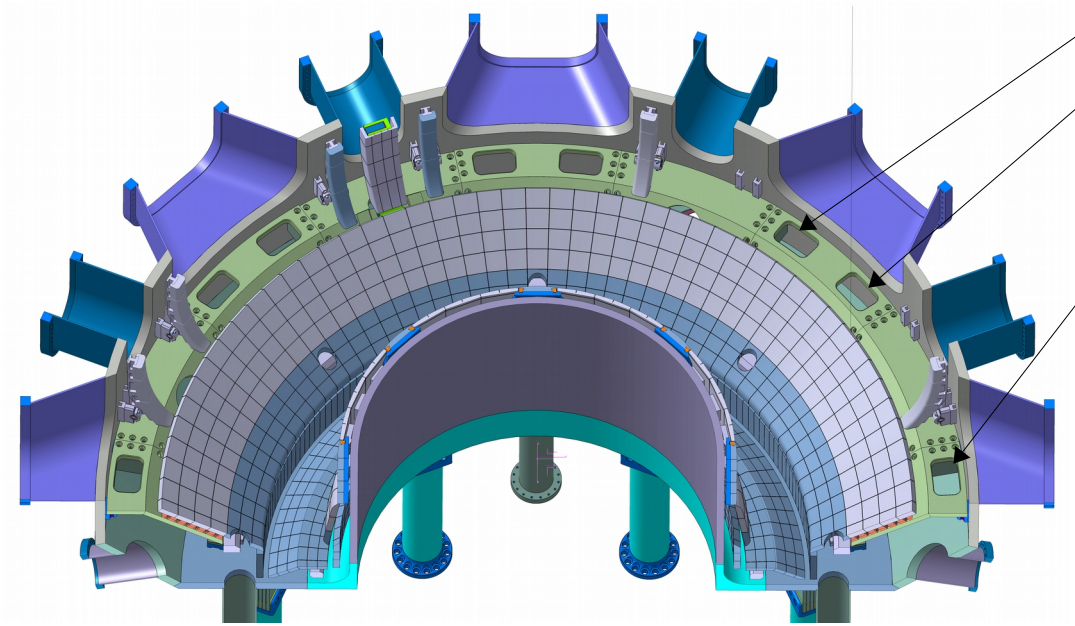
Elements	PFC	Material	Number	~Size [mm]	Notes
Tiles	PSPP	Inconel^{718} with W coating	768	60x65x15	Directly bolted to support
M16 bolts	*PSPP*	*Inconel^{718}*	*768*		

*for both upper and lower regions
+ design in progress

1) IWL: inner wall limiter
2) IDB: inner divertor baffle
3) IVT: inner vertical target
4) DIF: divertor floor
5) OVT: outer vertical target
6) ODB: outer divertor baffle
7) PSPP: passive stabilization plate protection
8) **OHP: outer horizontal plates**
9) OWL: outer wall limiters
10) OBP: outer bridge protection

OHP Summary*: elements, materials, dimensions, number

Elements	PFC	Material	Number	~Size [mm]	Notes
Tiles	OHP	SS or inconel^{625}	32	140x70x10	Plates to cover openings
Attachment	*TBD*	*TBD*	*TBD*		



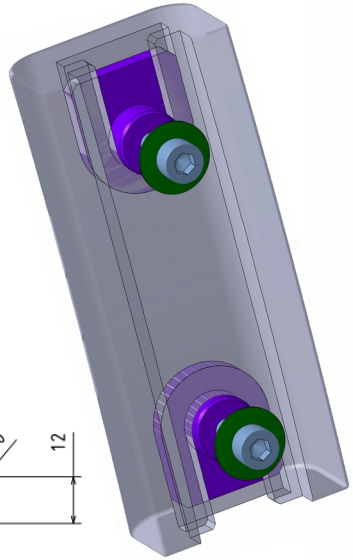
*for both upper and lower regions

1) IWL: inner wall limiter
2) IDB: inner divertor baffle
3) IVT: inner vertical target
4) DIF: divertor floor
5) OVT: outer vertical target
6) ODB: outer divertor baffle
7) PSPP: passive stabilization plate protection
8) OHP: outer horizontal plates
9) **OWL: outer wall limiters**
10) OBP: outer bridge protection

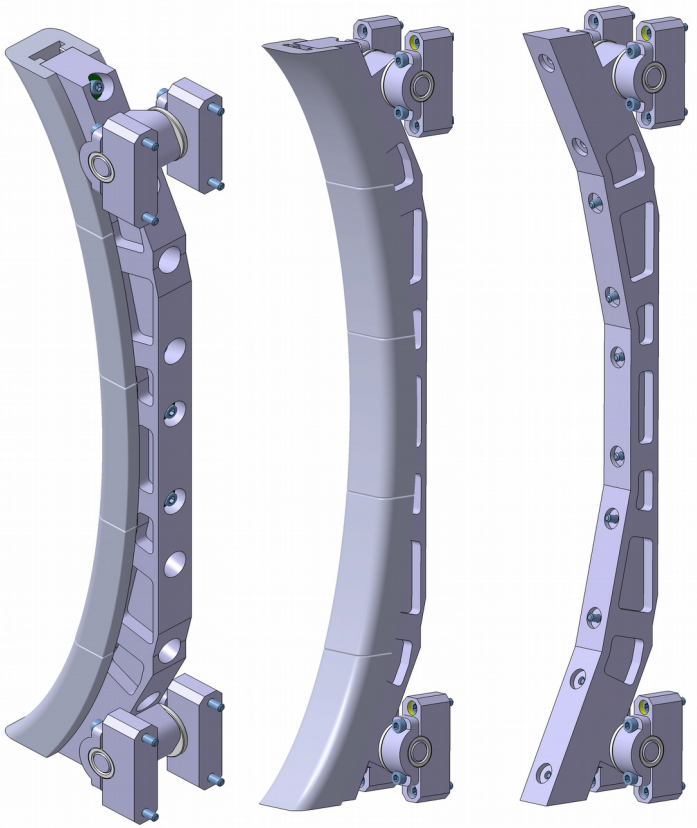
OWL Design: General Description

Outer Wall Limiters:

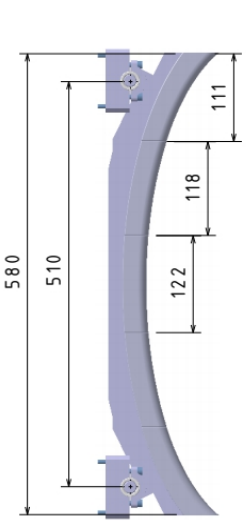
- **8 OWL** (narrow ribs) with **inconel tiles** with **W coating**
- **5 inconel tiles per OWL** (40 in total)
  - Thickness: 30 mm
  - Length (poloidal): 111-122 mm
  - Width (toroidal): 50 mm
- **Pocket** (design in progress) in each tile for inconel insert
- **Front surface TBD**
- **2x M6 bolts per tile** (80 in total)

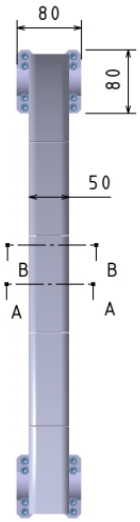


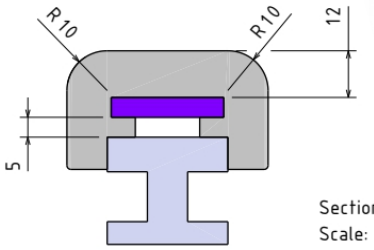
- One OWL tile -

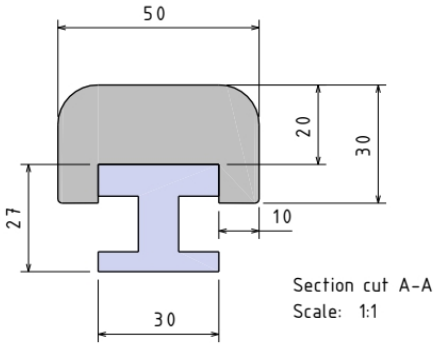


- Full view of one OWL with *(left+middle)* and without *(right view)* tiles -









OWL Summary: elements, materials, dimensions, number

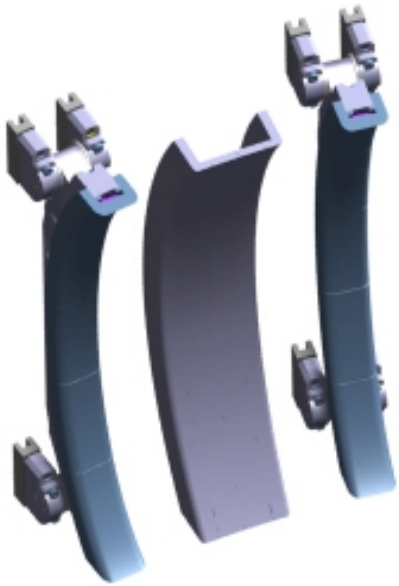
Elements	PFC	Material	Number	~Size [mm]	Notes
Tiles	OWL	Inconel^{718} with W coating	40	(111-122)x50x30	Complex pocket for fixation (but design in progress) + Front surface shaping TBD
M16 bolts	*OWL*	*Inconel^{718}*	*80*		
Support structures	*OWL*	*Inconelt^{718}*	*8*	*TBD*	

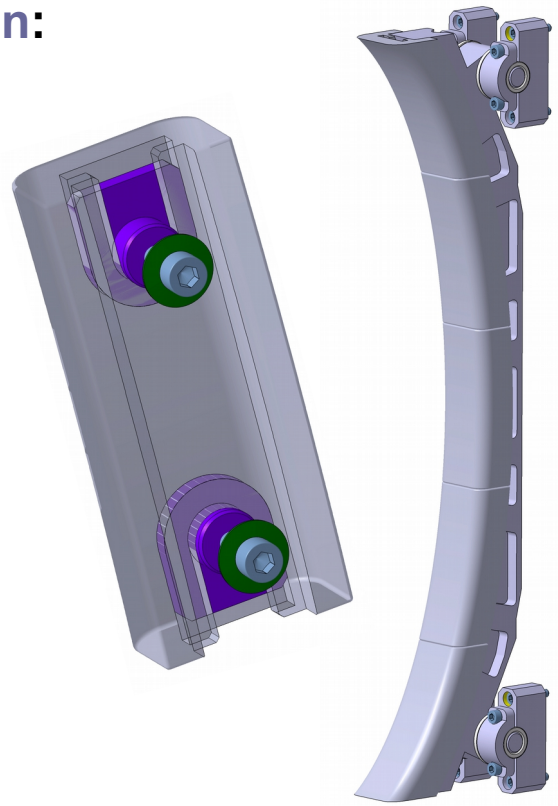
1) IWL: inner wall limiter
2) IDB: inner divertor baffle
3) IVT: inner vertical target
4) DIF: divertor floor
5) OVT: outer vertical target
6) ODB: outer divertor baffle
7) PSPP: passive stabilization plate protection
8) OHP: outer horizontal plates
9) OWL: outer wall limiters
10) OBP: outer bridge protection

OBP Design: General Description

OBP consists of 2 OWL and 1 PSP bridge (coil) protection:

- **2 OBP** (narrow ribs) with **bulk W tiles (!)**
  - **5 W tiles per OBP** (10 in total) with front surface TBD
    - Thickness: 30 mm
    - Length (poloidal): 111-122 mm
    - Width (toroidal): 50 mm
  - **Pocket** (design in progress) in each tile for inconel insert
  - **2x M6 bolts per tile** (20 in total)
- **1 PSP bridge protection** in **inconel^{718}** with **W coating**
  - Design in progress





- View of one OBP tile *(left)* and one limiter *(right)* -

OBP Summary: elements, materials, dimensions, number

Elements	PFC	Material	Number	~Size [mm]	Notes
OWL tiles	OBP	Bulk W	10	(111-122)x50x30	Complex pocket for fixation (but design in progress) + Front surface shaping TBD
Bridge protection tiles	OBP	Inconel^{718} with W coating	TBD	TBD	
M16 bolts	*OBP*	*Inconel^{718}*	*20 + ??*		
Support structures	*OBP*	*Inconel^{718}*	*2*	*TBD*	

Final Summary: Total number of elements

Elements	PFC name	Number	Size [mm]	Notes
W tiles	**all** IWL 2x IDB IVT DIF-in DIF-dome DIF-out OVT ODB OBP	**1450** 64 128 288 192 96 192 192 288 10	--- 116x65x19 66x55x20 41x45x20 28x44x15 63x48x28 34x37x15 121x26x20 60x45x20 (111-122)x50x30	Complex machining + ----- Only the lower closed DIV is counted -----
Inconel^{718} tiles	**all** IWL 2x IDB PSPP OHP OWL OBP	**1192** 96 256 768 32 40 --	--- 130x115x12 66x55x20 60x65x15 140x70x10 (111-122)x50x30 --	Machining + PSP bridge protection of OBP not counted
W coating	**all**	**1160**	**5.9 m^2**	PSP bridge protection of OBP not counted
M16 bolts	*all*	***868***		*in inconel^{718}*
M10 bolts	*all*	***288 (?)***		*in inconel^{718}*
M8 bolts	*all*	***864***		*in inconel^{718}*
M6 bolts	*all*	***1504/1600***		*in inconel^{718}*
U-brackets	*all*	***224***		*Pads for DIV & OWL not counted*