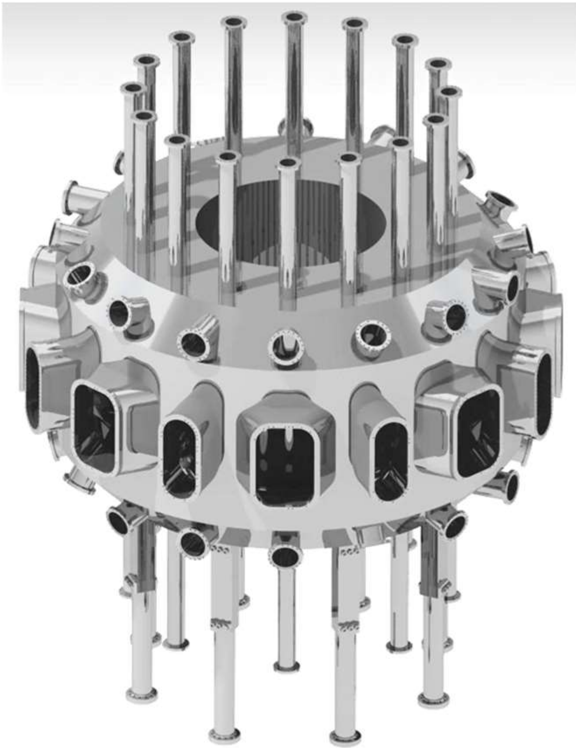
COMPASS-U: Vacuum vessel

PRELIMINARY MARKET CONSULTATIONS

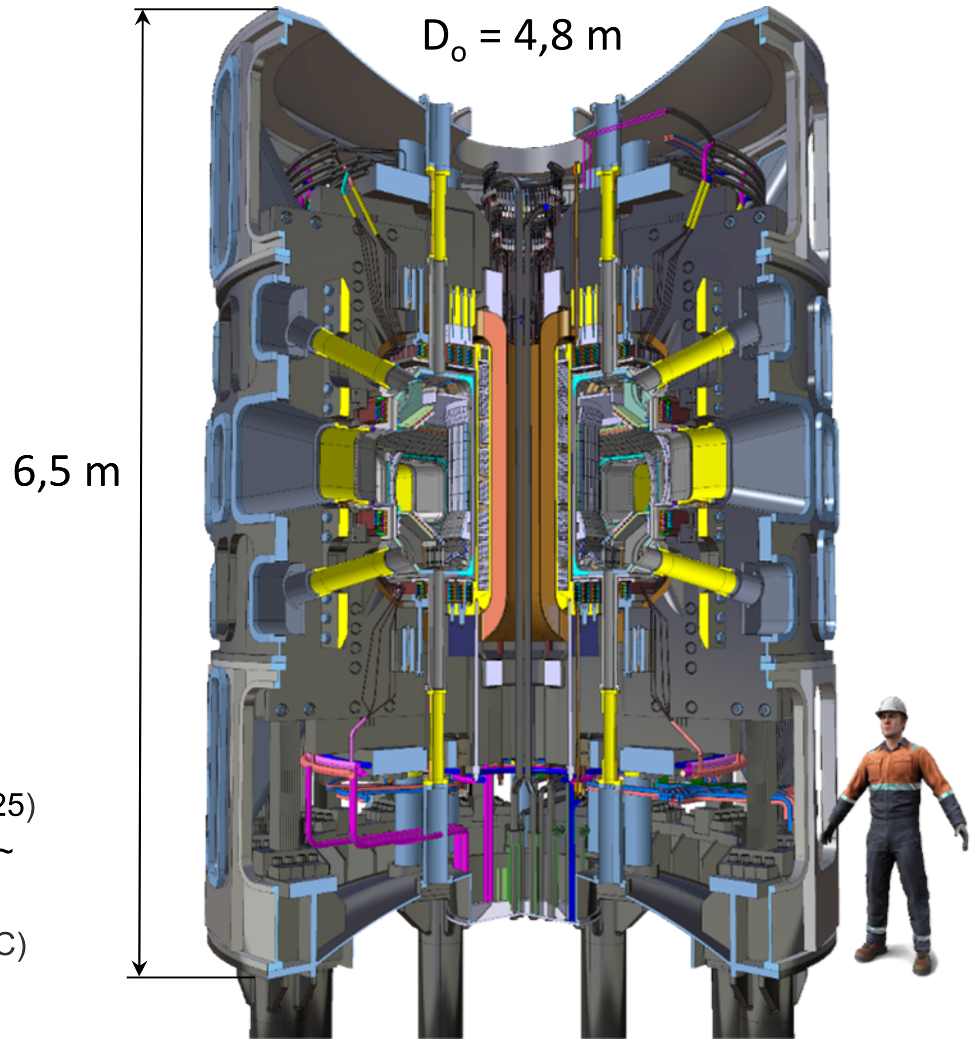


rev. 24.05.2021

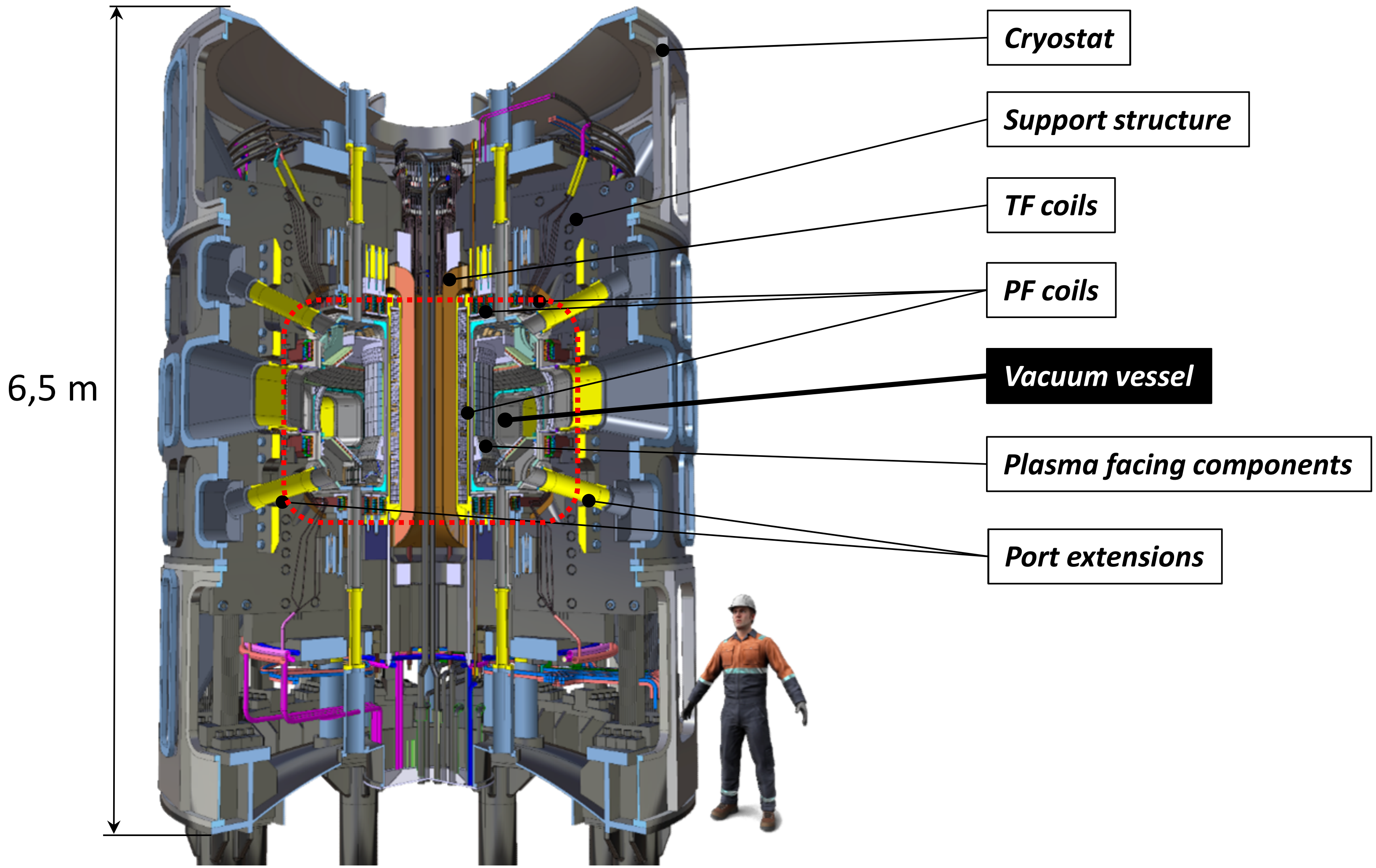
1.1 Brief machine overview – Main tokamak assembly

Main design requirements:

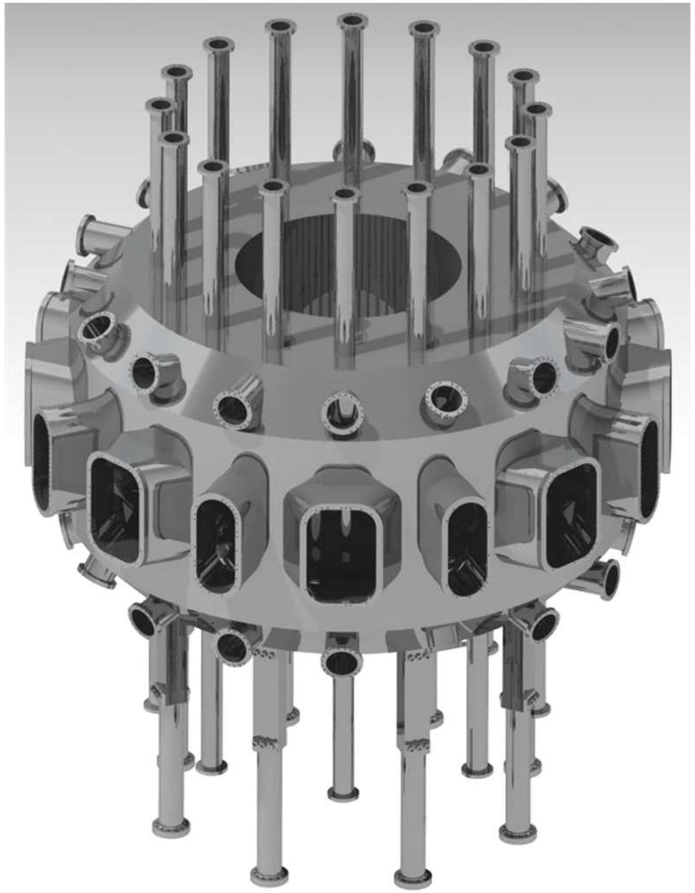
- Toroidal magnetic field $B_t = 5$ T
- Plasma current $I_p = 2$ MA
- Major radius R = 0.894
- Minor radius a = 0.27
- Aspect ratio A = 3.3
- Triangularity δ = 0.3-0.6
- Elongation κ = 1.8
- Enough space for different divertors
- Plasma shapes
    - single lower null, neg. triangularity with limited parameters (Phase 1)
    - double null (Phase 2)
    - snowflake, negative triangularity (Phase 3)
- Heating power
    - Phase 1 P_{NBI} >= 3 MW, P_{ECRH} = 1 MW (P*B/R ~ 25)
    - Phase 2 up to P_{NBI} = 8 MW, P_{ECRH} = 10 MW (P*B/R ~ 100)
- Vacuum vessel operation temperature up to 500°C (min. 300°C)

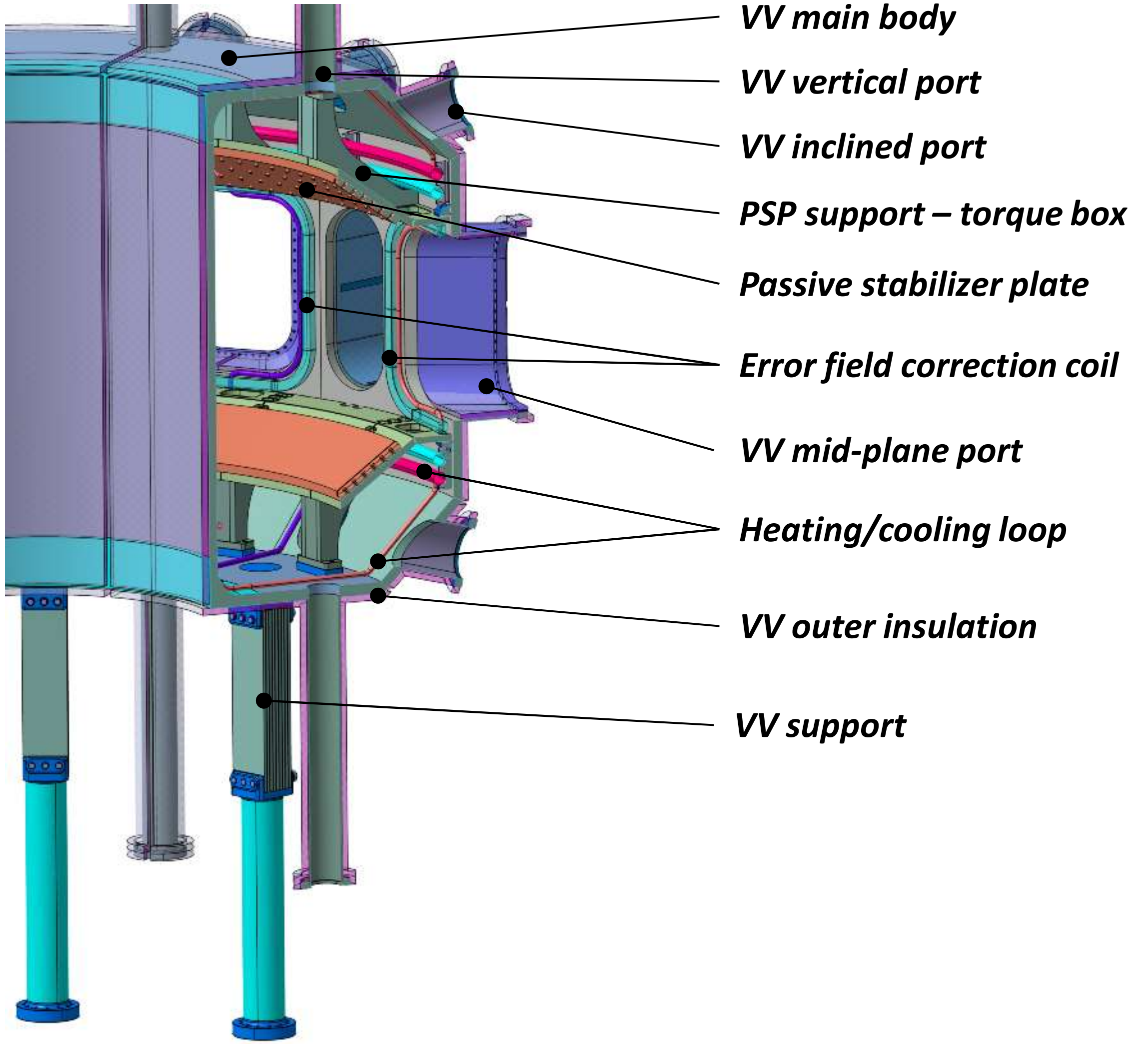


1.1 Brief machine overview – Main tokamak assembly



1.2 Brief machine overview – Vacuum vessel

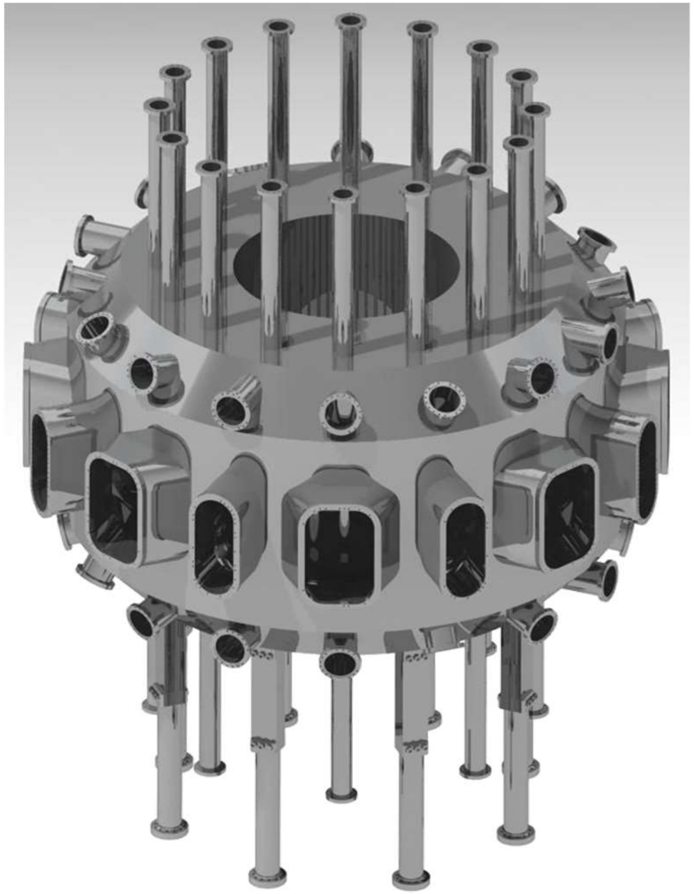




1.3 Vacuum vessel – Design requirements and constraints

DESIGN REQUIREMENTS

- Provide a reliable structural boundary for life time of the tokamak
- **Withstand all possible critical load combinations** from external pressure, component weight to electromagnetic loads
- Provide a high vacuum for the experiments
- **Provide structural support for the in-vessel components**
- **Provide access** ports for external diagnostic systems, heating and current drive systems and in-vessel components maintenance
- Material of VV should have high electrical resistance



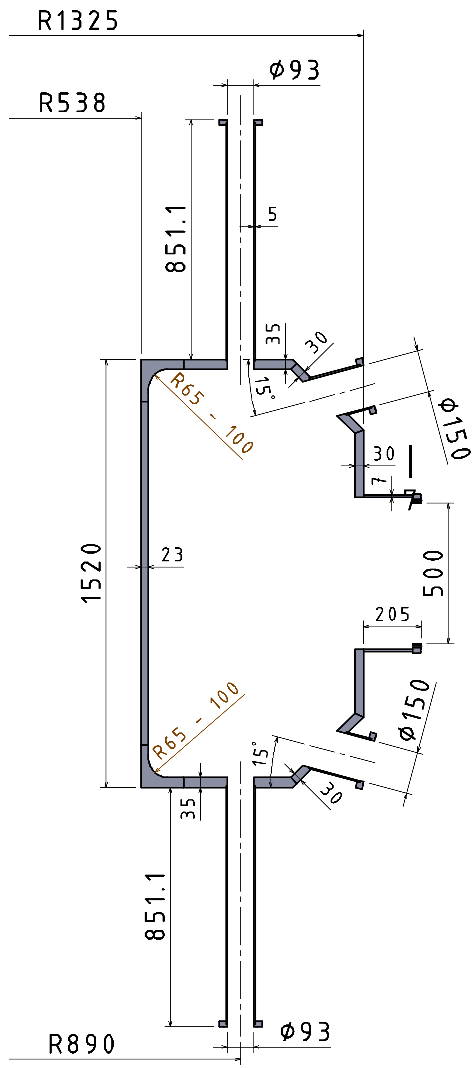
DESIGN CONSTRAINTS

- **Very high electromagnetic forces during disruptions**
- Design based on believed the worst case load scenarios
- **High temperature operation up to 500 °C**
- **Tight spatial constraints** due to the compact design of the machine
- **Manufacturing and material costs**

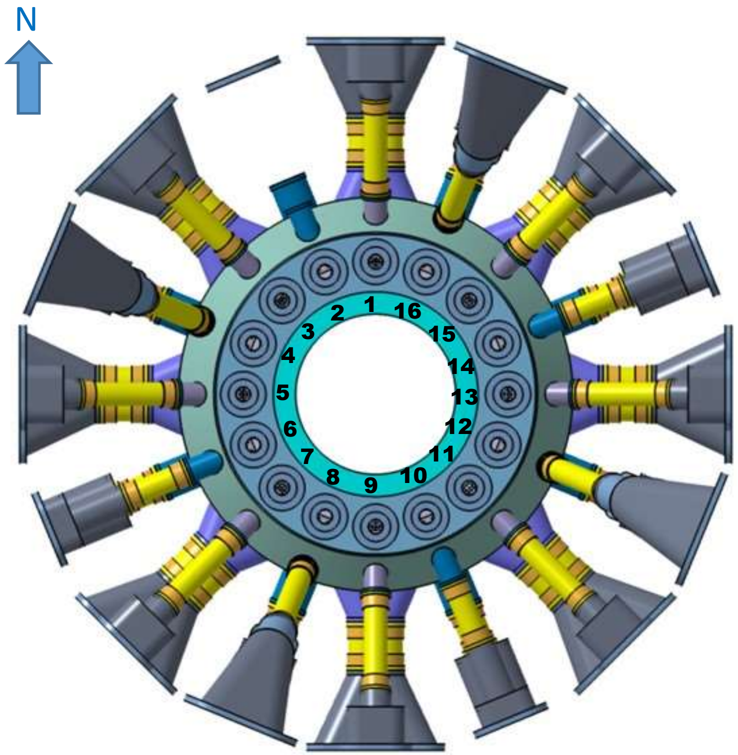
1.4 Vacuum vessel – General dimensions and parameters

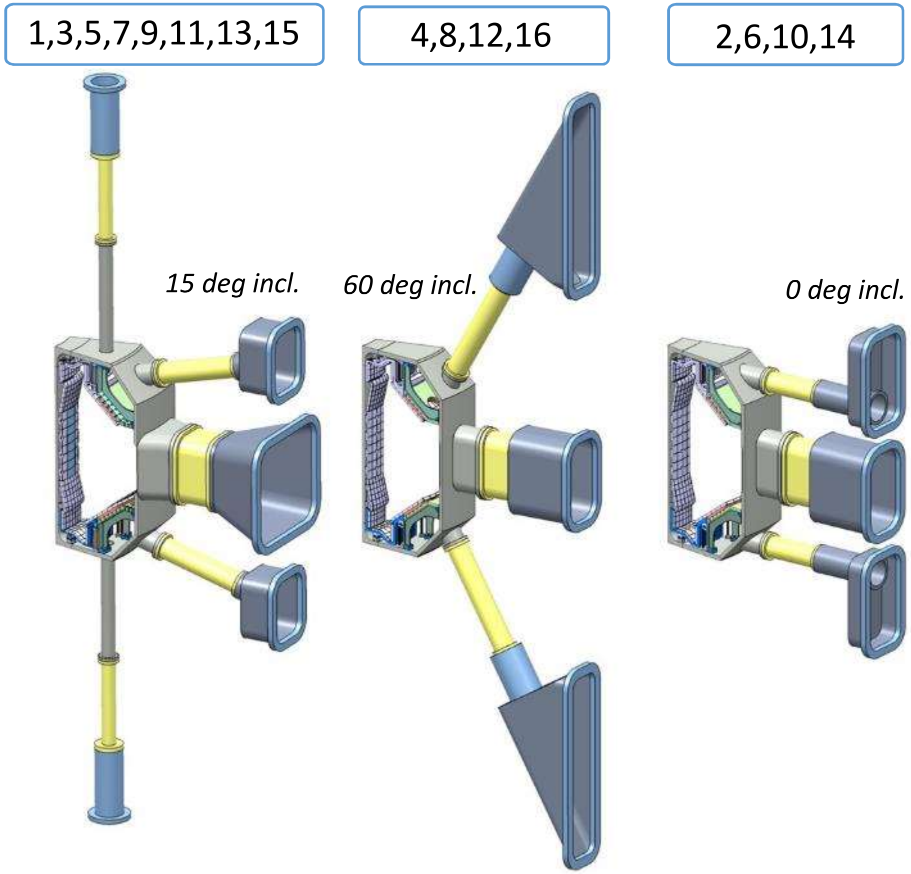
PARAMETER	VALUE
Outer radius (excl. ports)	1325 mm
Inner radius (excl. ports)	538 mm
Total height (excl. ports)	1520 mm
Wall thickness	23 – 35 mm
Ports wall thickness	7 mm
Vessel inner surface	~ 10,5 m^2
Total weight – vessel	5970 kg
Total weight – supports	914 kg
Total weight – stabilizer system	1620 kg
Total weight VV assembly	**8504 kg**
Base vessel pressure	10^{-6} Pa
Base material	Inconel 625
Operating temperature	300 / 500°C

Main material of the VV, Inconel 625, kept due to high mechanical stresses and elevated temperature. An alternative material AISI 316LN is still in consideration in case of insufficient budget.



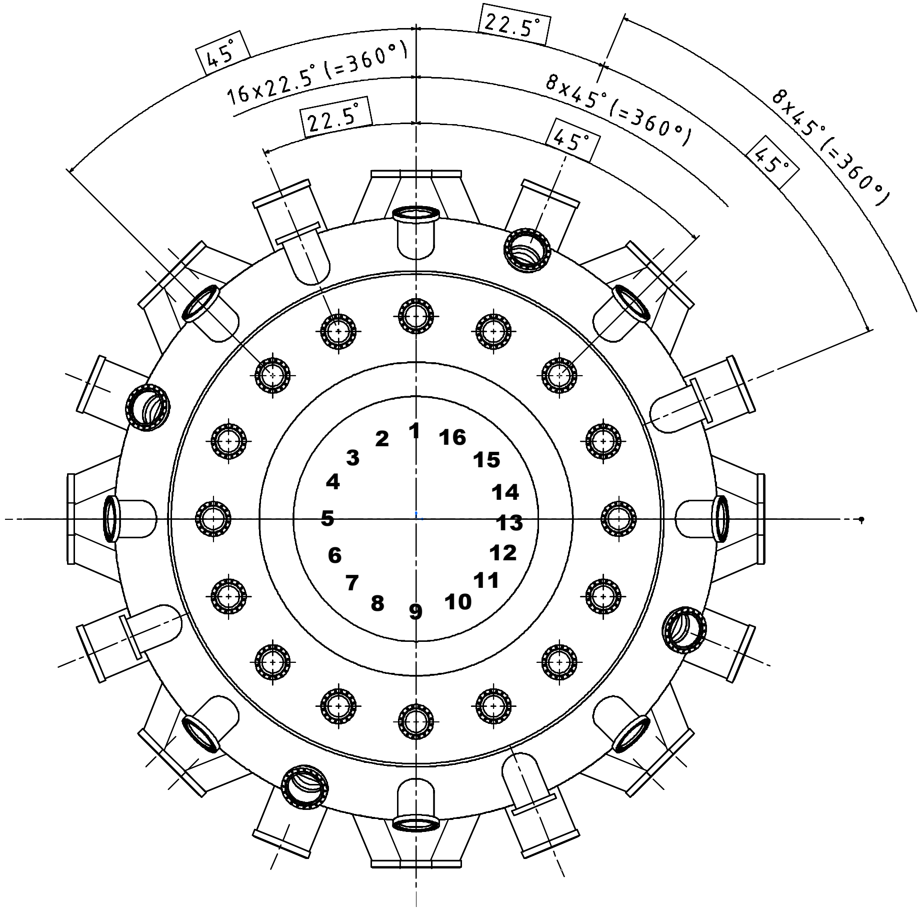
1.5 Vacuum vessel – Ports layout



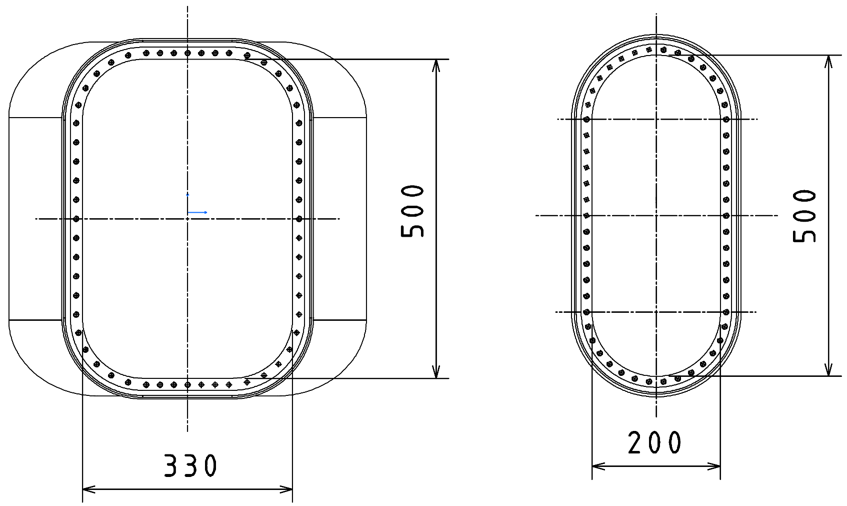


- Ports: 16 Equatorial, 16 Upper-Outboard, 16 Lower-Outboard, 16 Vertical-Upper, 8 Vertical-Lower (in total 72 ports)
- Ports in sector 2 will not be used (blinded) due to the TF and PF coils outlet (in total 3 ports)
- Port extensions will integrate bellows to allow the thermal expansion and movement of the vacuum vessel

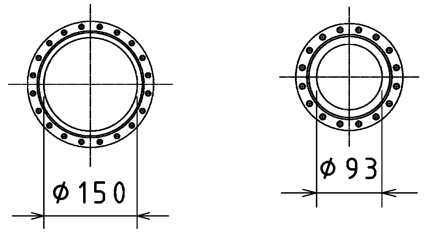
1.5 Vacuum vessel – Ports layout



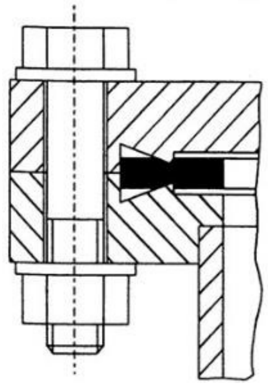
Mid-plane ports dimensions



Inclined ports and vertical ports dimensions



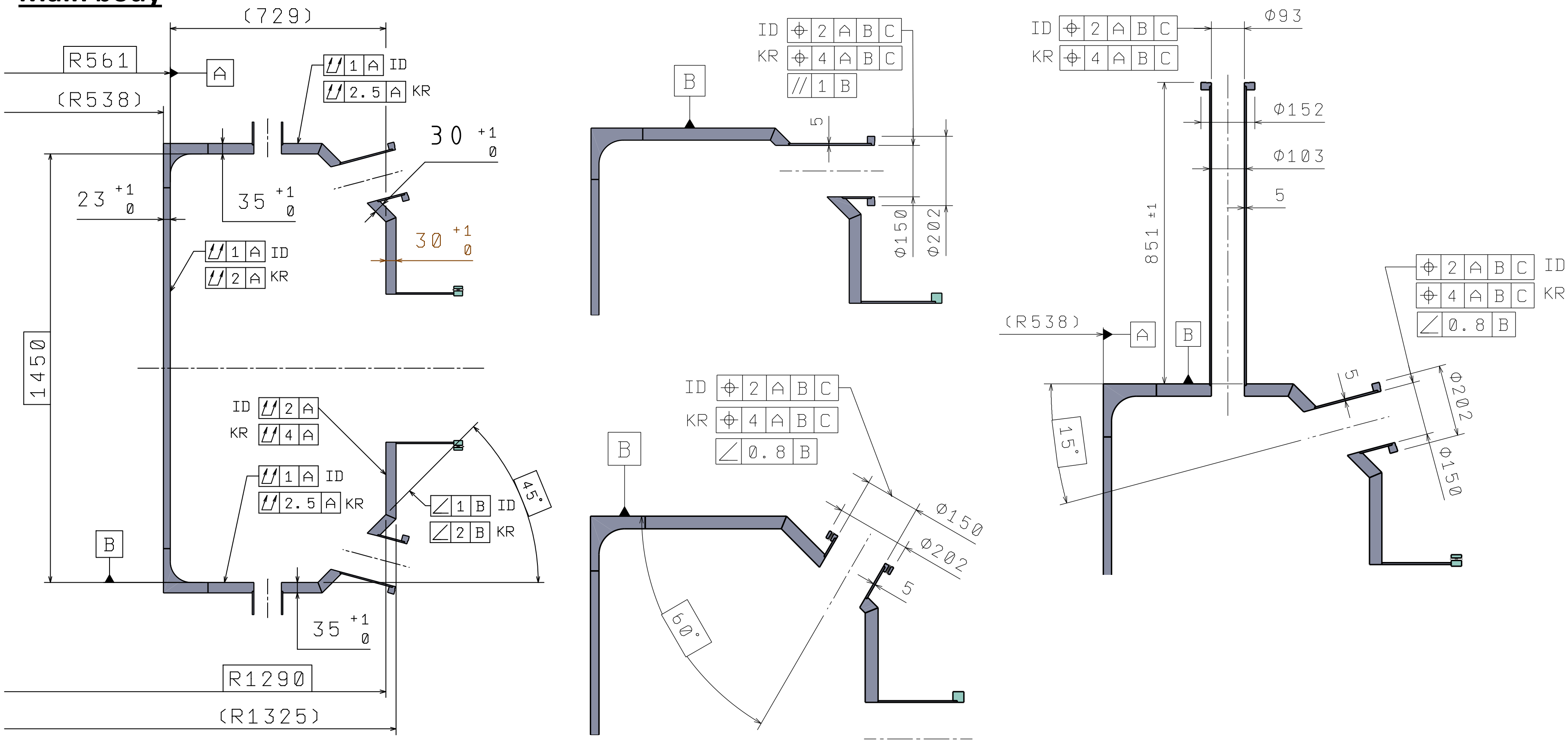
standard CF Flange and seal



- All port interfaces of the VV will use the **standard CF (ConFlat) sealing concept and will be bolted**.
- The gasket material will be chosen OFHC copper/silver plated or annealed nickel gaskets – depends on **Helium leak tightness** at temperature around 450 °C.

1.6 Vacuum vessel – main body manufacturing tolerances

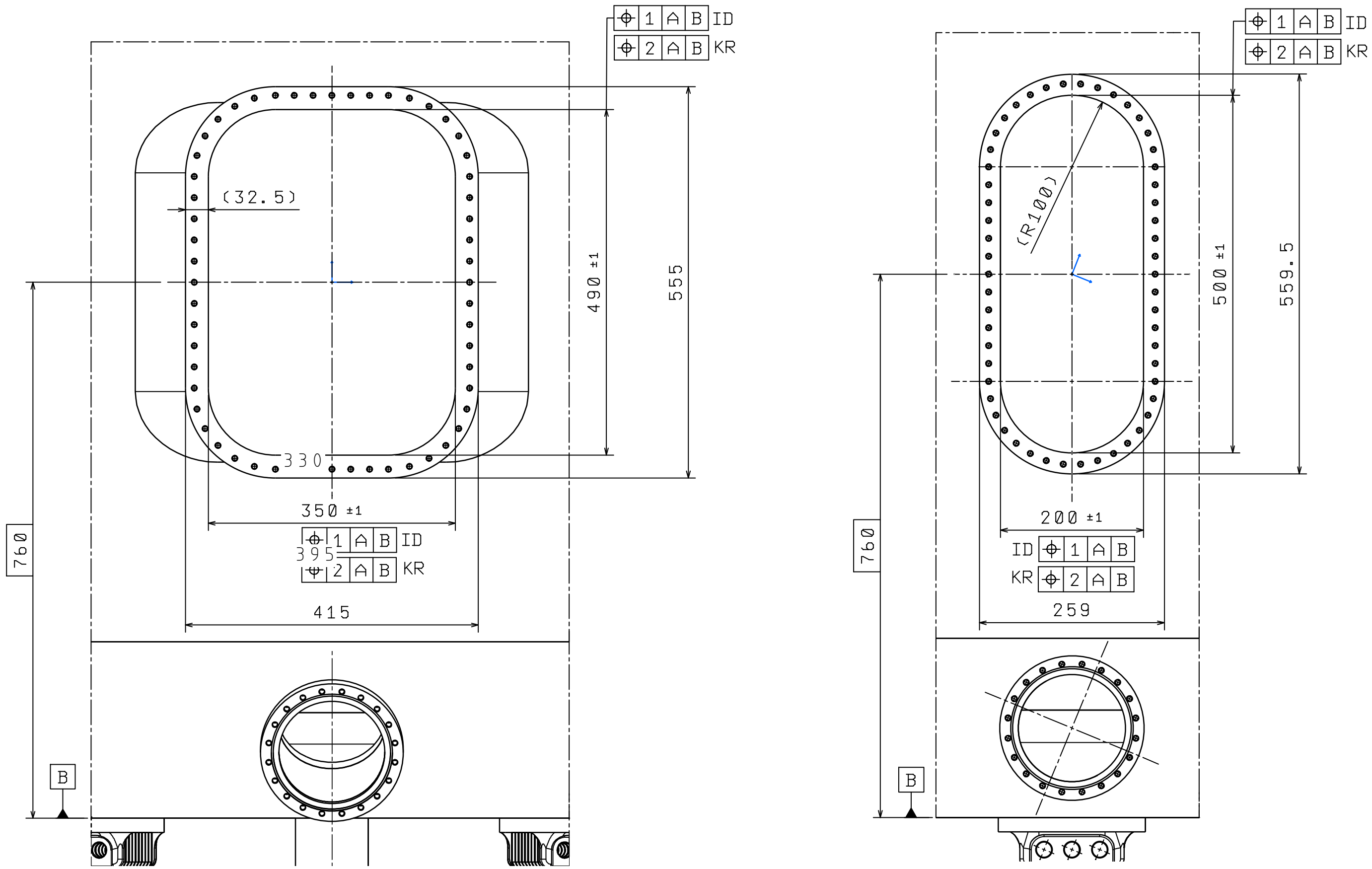
Main body



ID…ideal value of the achieved manufacturing tolerance
KR…critical value of the achieved manufacturing tolerance

1.6 Vacuum vessel – main body manufacturing tolerances

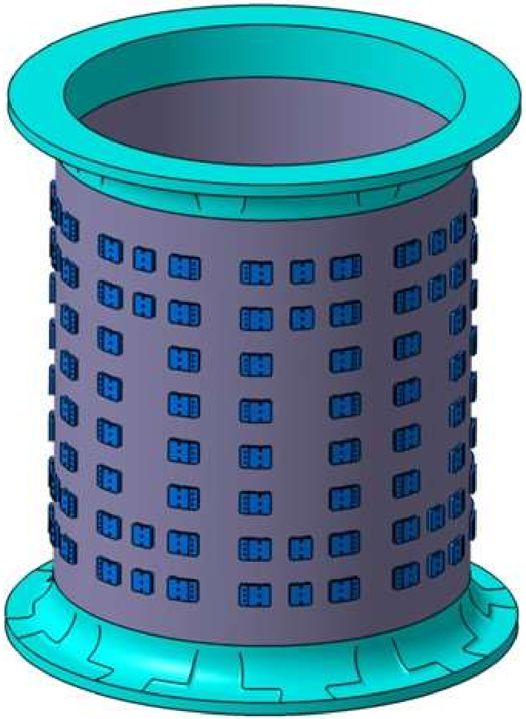
Main body

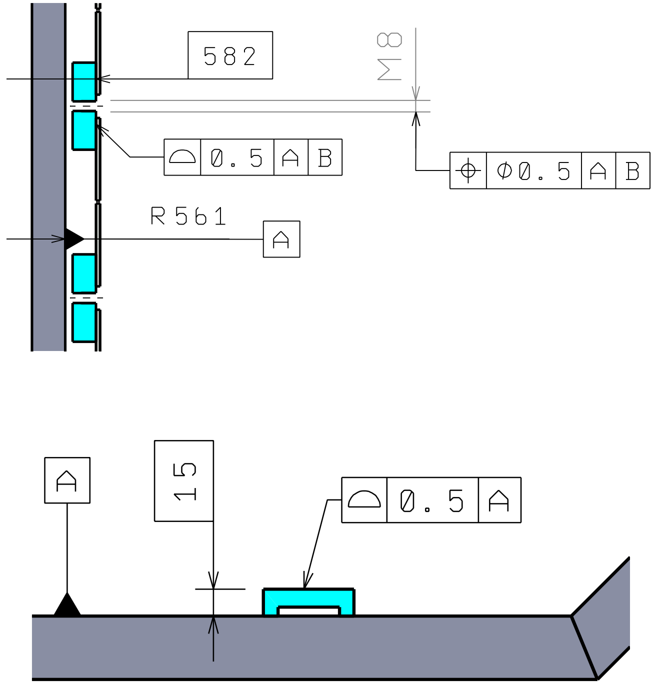


- Preliminary manufacturing tolerances are set for inquiry purposes and will be further discussed with suppliers to achieve maximum reasonable precision with low manufacturing costs.

1.6 Vacuum vessel – main body manufacturing tolerances

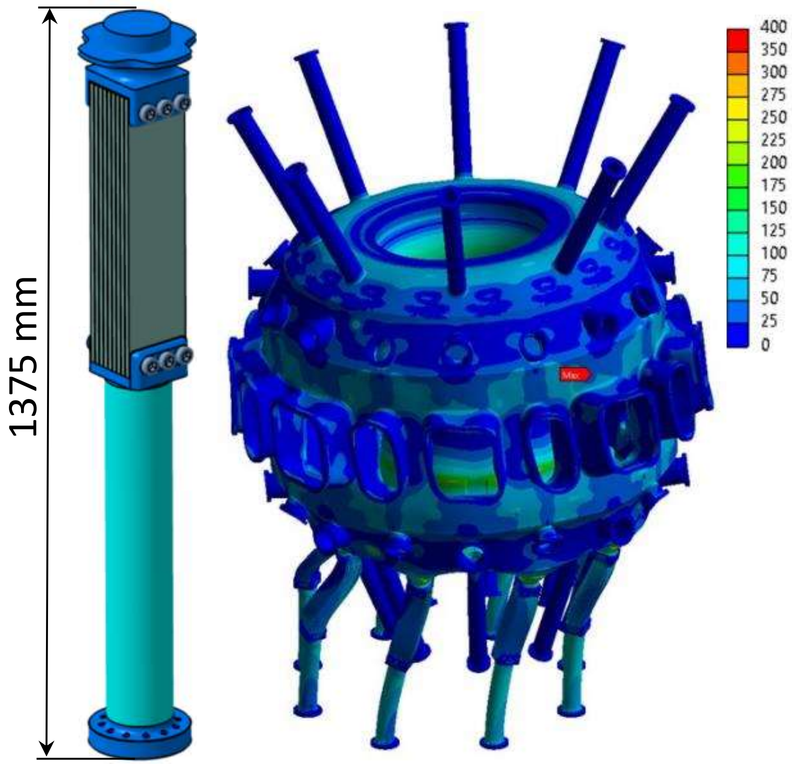
Inner mounting elements & brackets



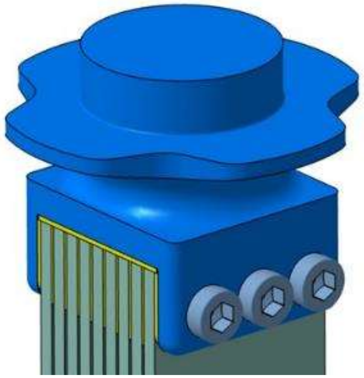


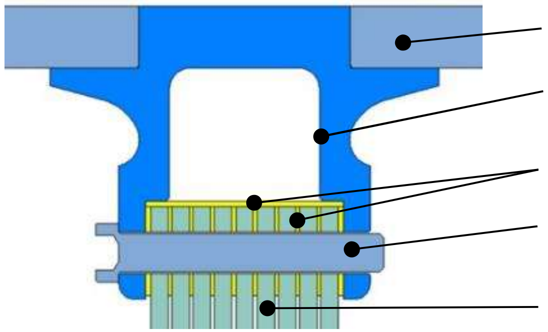
- To secure the tight tolerances on the mounting elements and to be able to compensate the rough tolerances for the VV main body walls, the **post process milling will be needed**.
- The front surfaces of the mounting elements will be therefore milled before the main body will be welded and closed.
- We would require the tolerance at least **± 0.25 mm**.

1.7 Vacuum vessel – Supports

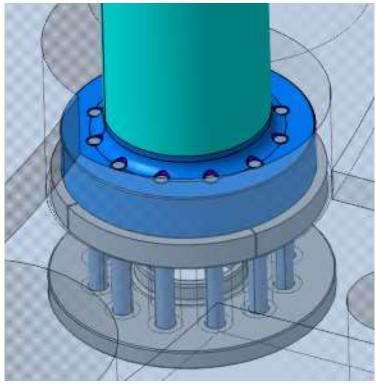


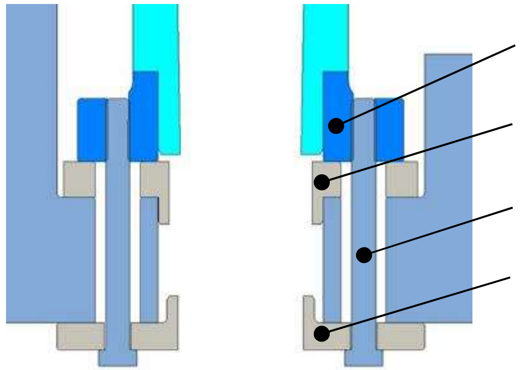
Connection to VV





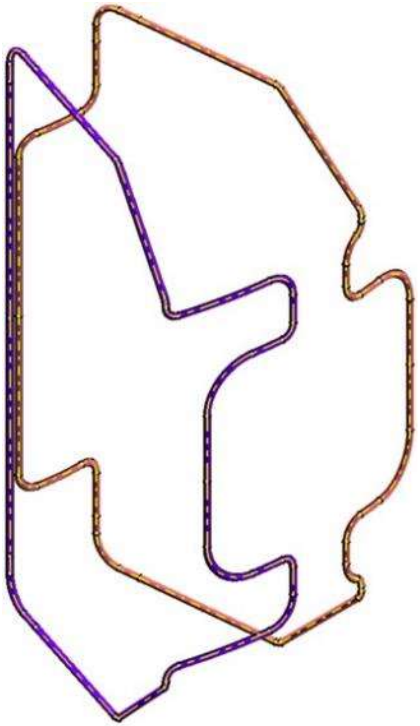
Connection to SS

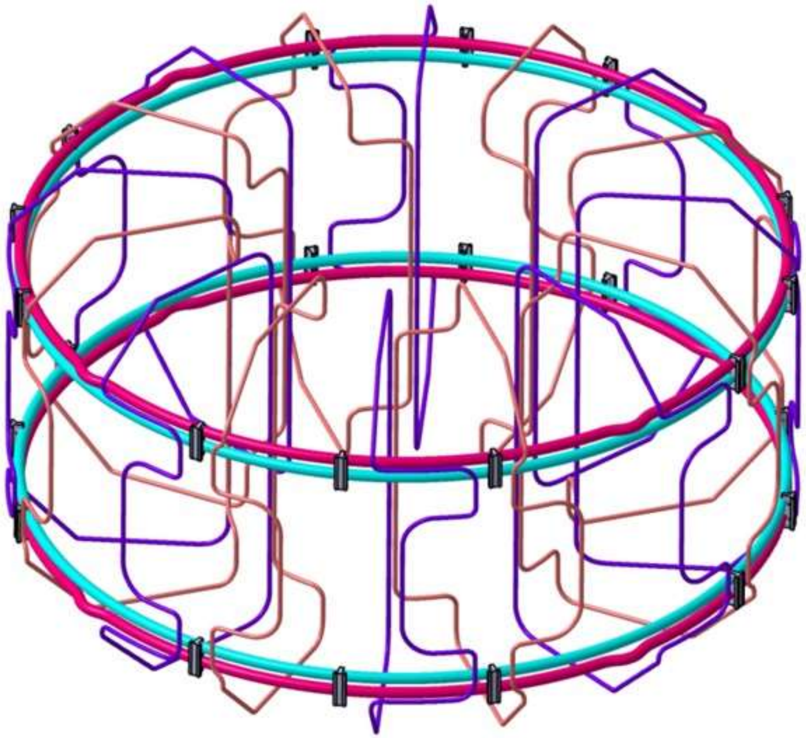


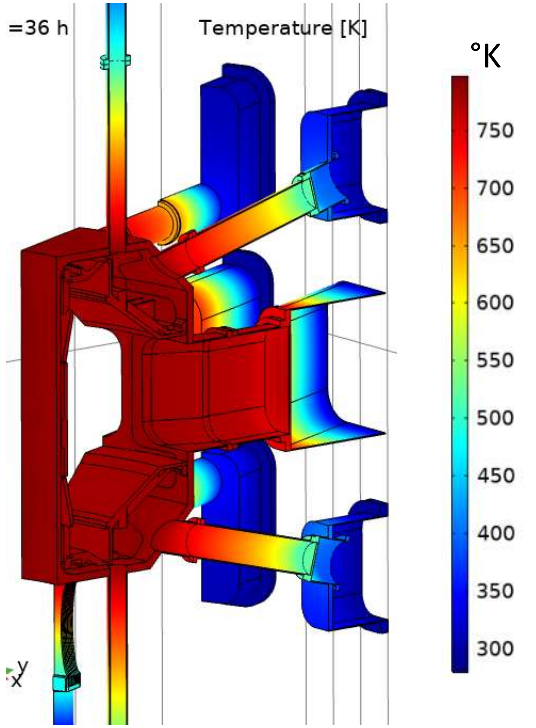


- The VV supports compensate the vessel own weight, thermal expansion and movements during the disruptions
- There will be in total **8 supports placed toroidally**, insert welded to the VV body, adjustable connection to the SS
- Stack of **9 flexible plates** made of Inconel 625 with spacers and bolted together **to allow radial expansion** of the VV
- To survive **high lateral and toroidal forces** the **toroidal stabilizer** mechanism will take over the rest load from the supports

2.1 Auxiliary systems – Heating & cooling system

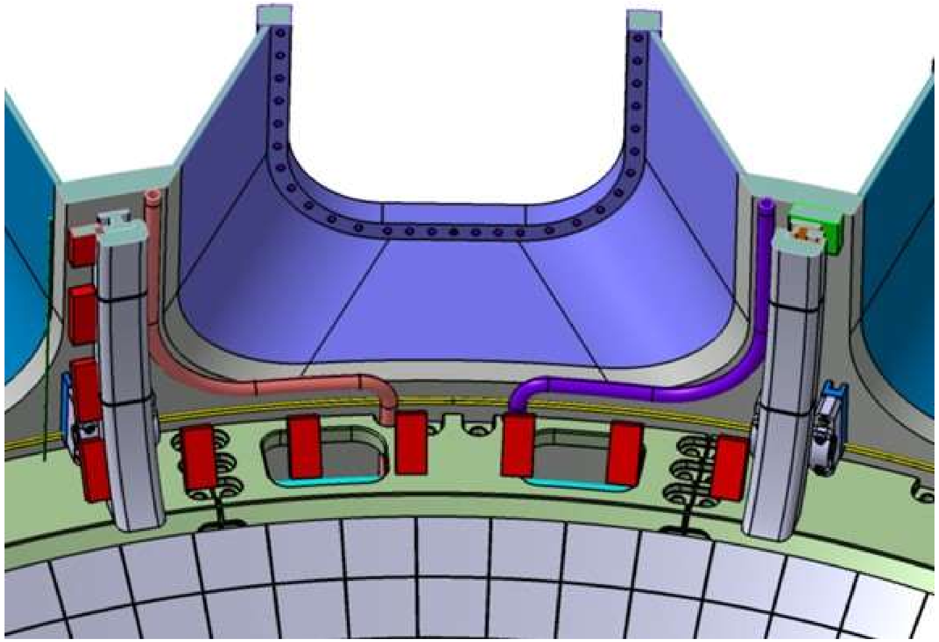


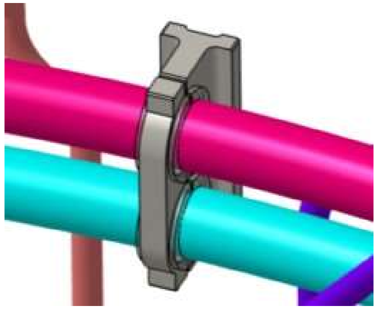


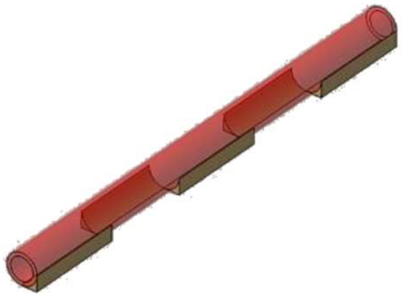


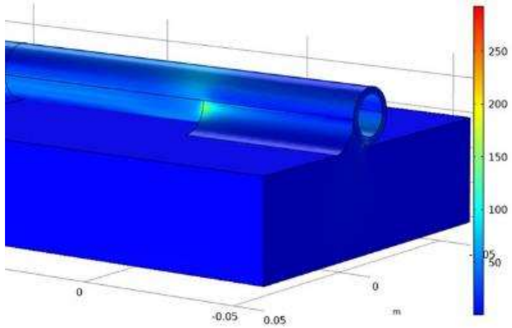
- **Active heating & cooling system** of the VV main body using inner welded heating pipes.
- **16 poloidal loops including HFS** with two common buses in upper and lower area **with planned redundancy.**
- Tubes made of Inconel 625 with outer tube diameter of 16 mm and wall thickness 2 mm.
- **Maximum heating temperature up to 800 °K**, medium Helium or CO_2, **system base pressure** set to **60 bar.**
- Total loop length: ~ 6,3 m (~ 12,6 m needed to cover 1/8 of VV, ~ 50,4 m needed to cover the whole VV body).
- Heat transfer simulations have been performed and **proved heating route to be feasible.**

2.1 Auxiliary systems – Heating & cooling system









- Heating loops were designed to fit together with complex neighboring assemblies and with routes as straight as possible.