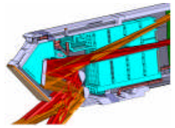

ECHULA (ECH Upper LAuncher) partners:
CNR Milano, CRPP Lausanne,
FOM Rijnhuizen, FZK Karlsruhe,
IPP Garching / IPF Stuttgart

FUSION FOR ENERGY
THE EUROPEAN JOINT UNDERTAKING FOR ITER AND THE DEVELOPMENT OF FUSION ENERGY

Design and testing of
the ITER ECRH Upper Launcher

PROTOTYPING AND TESTING OF ITER ECH UPPER LAUNCHER COMPONENTS

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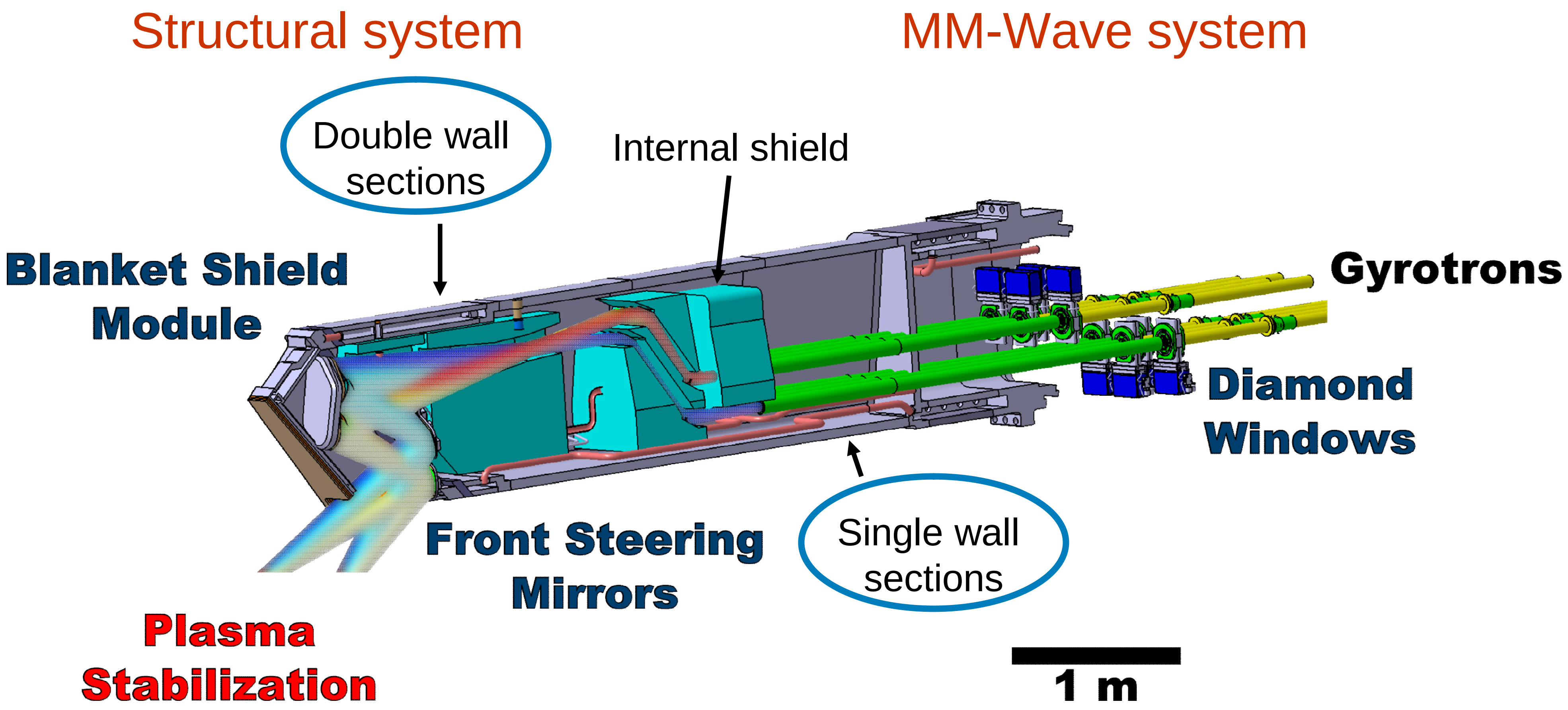
P. Späh, A. Meier, A. Vaccaro
FZK, Karlsruhe

KIT - Die Kooperation von
Forschungszentrum Karlsruhe GmbH
und Universität Karlsruhe (TH)
Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft
Universität Karlsruhe (TH)
Forschungsuniversität · gegründet 1825

Port plug with integrated mm-wave beam lines (QO)

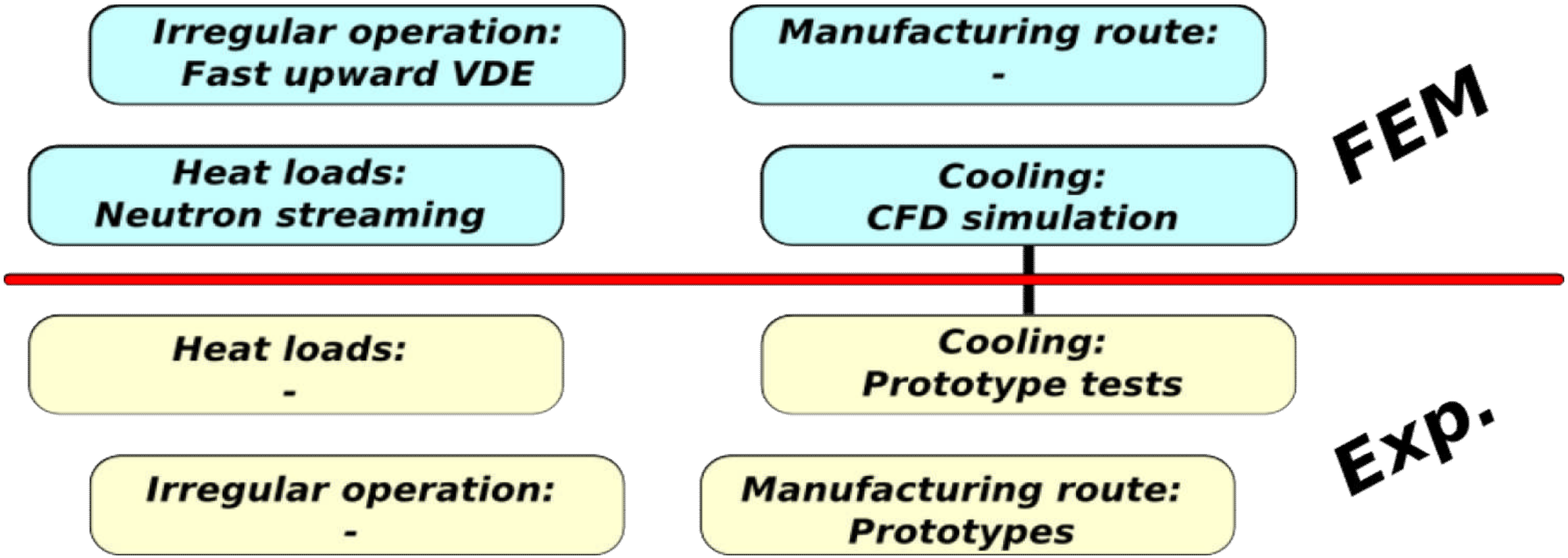


Role of prototypes for design validation

Only very limited load scenarios can be tested experimentally.

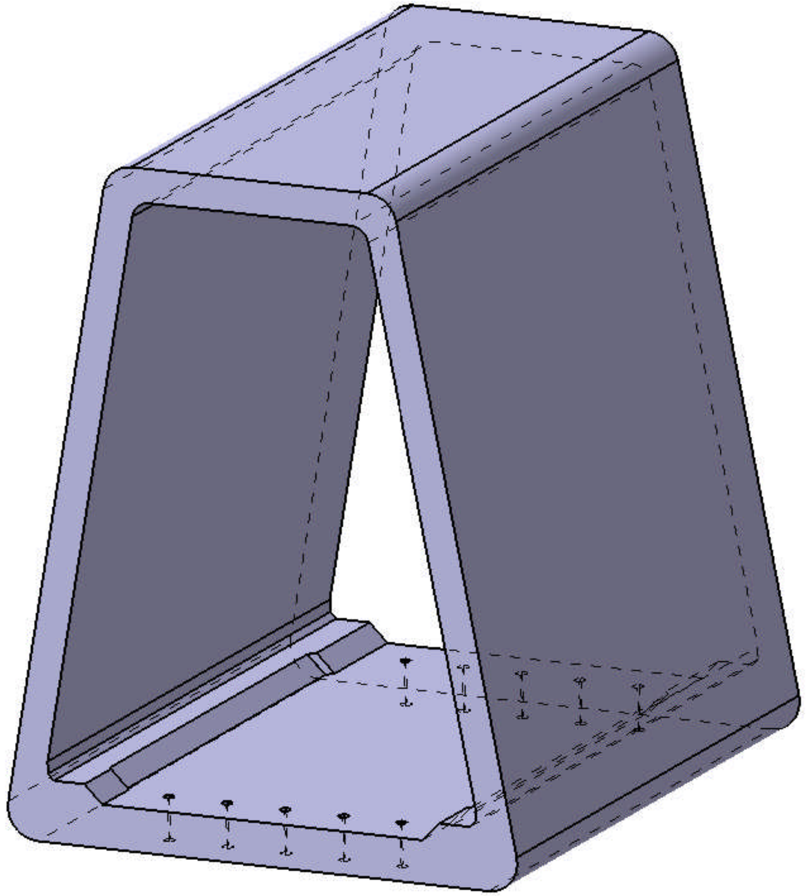
Manufacturing route can be proven by prototype tests.

Numerical analysis (FEM) must be in a position to satisfy QA requirements.



Status Prototyping UPP Single Wall 03-2009

MAN DWE
Apparatebau
Deggendorf www.man-dwe.de



Concept Single wall main frame

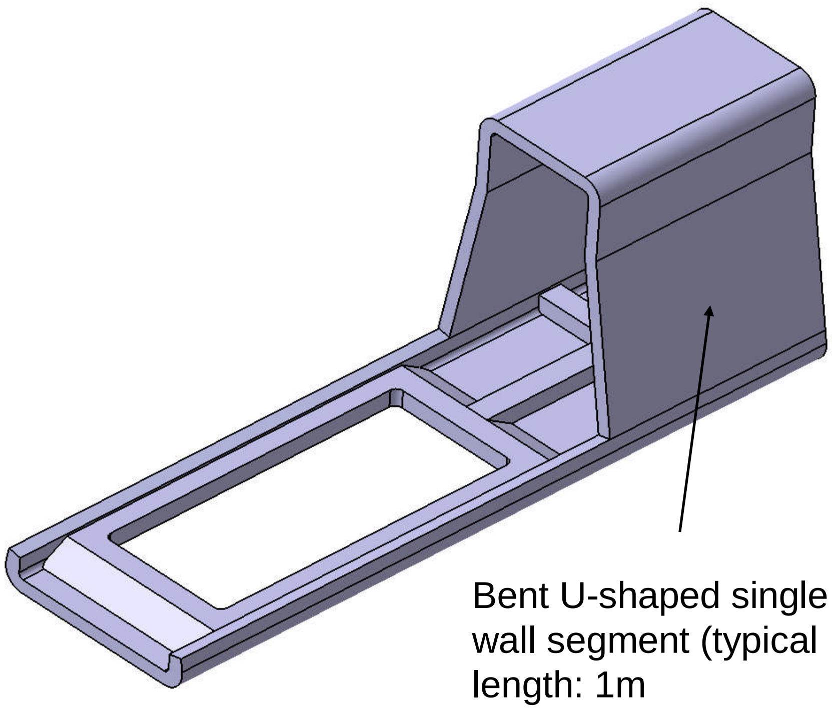
Main Frame:
Single Wall segment(s)

Manufacturing of single wall segments has to be investigated.

Manufacturing issues:

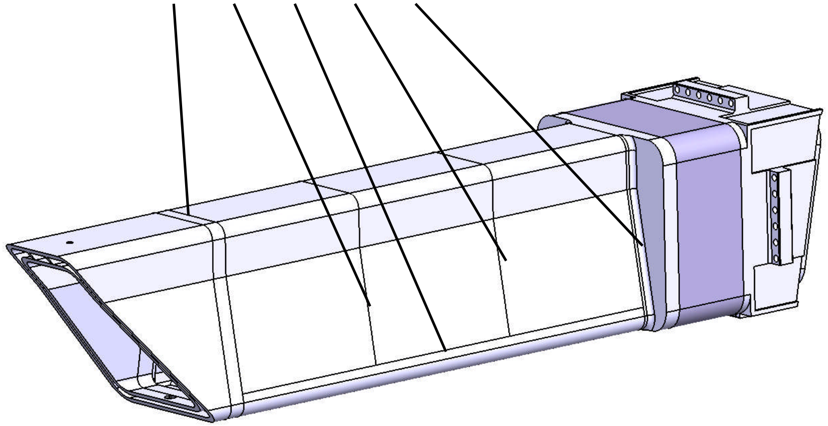
- Precise and strainless bending of steel plates with a thickness of 55-60 mm
- Investigation of Joints between segments and with associated plates

  (Bottom plate / Intermediate plate / Closure plate)



Bent U-shaped single wall segment (typical length: 1m

Joints single wall / associated plates:



Manufacturing of single wall main frame

Engineering topics on manufacturing analysis (completed):

- Evaluation of different manufacturing routes
- Evaluation of material
- Evaluation of mechanical processing
- Evaluation of raw-part shaping
- Evaluation of welding process
- Design adaptation with respect to RCC-MR
- Preparation of 3D-models and manufacturing drawings

Engineering topics on manufacturing (in progress):

- Material procurement
- Manufacturing
- Manufacturing inspection
- Reporting

Manufacturing routes

a) Assembly of two segments: U-shaped cover / Bottom plate

+ Only two welds

- Big plates (3 x 1 m²) to be bent → huge bending machines required

- Bending of 55 mm plates critical:

  - Limited length of parts to be bent (l > 1m doubtful)
  - Potential increase of wall thickness critical
  - Bending causes severe residual stresses to be mitigated by heat treatment
  - Hard to match precise geometry (angle of 10.5°)

b) Assembly of four segments: Bottom plate / Top cover / Side walls

+ No bending required

+ No additional heat treatment

+ Precise geometry easier to meet

+ Small raw materials (1x1 m²)

+ Length of frame-segments variable (1 – 3 m)

- Four welds (risk of distortion and residual stresses)

preferred solution

Manufacturing analysis

Material choice:

1.4404 (AISI SS 316 L)

This material is rather close with the AISI SS 316 L(N) IG in terms of chemical composition, why welding procedure and parameters are comparable.

However the mechanical properties of 1.4404 are slightly lower than for SS 316 L(N) IG, but sufficient for all prototyping issues.

AISI SS 316 L(N) IG is much more expensive, because it is not in the standard delivery programme of international steel markets

Raw part shaping:

For 1.4404 Material, rolled steel plates of divers thickness are available. (50 – 80 mm for walls and top-plate, 120 mm for bottom plate)

No additional forging (that was considered for SS 316 L(N) material) is required

Rolled steel is optimum for additional mechanical processing (machining, polishing, etc.)

Manufacturing analysis

Welding processing:

Two different welding processes are considered:

(a) TIG-welding (b) EB-welding

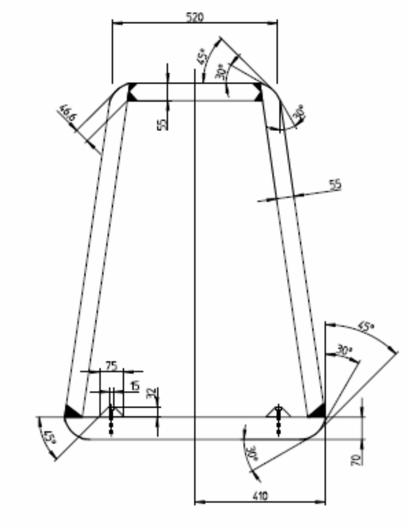
TIG-welding is a very sophisticated welding process and MAN-DWE is confident to fulfill all technical requirements on UPP-Main frame manufacturing with it.

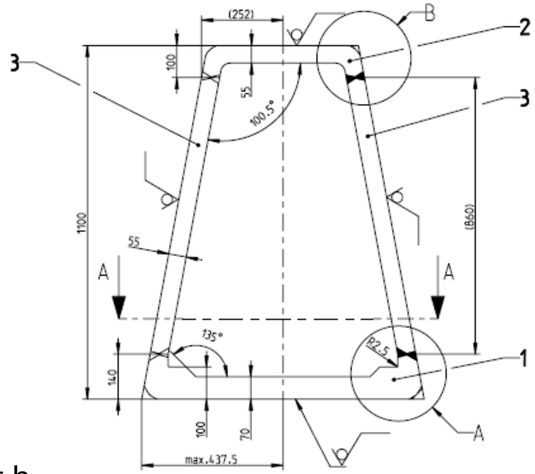
EB-welding reduces distortion and residual stresses because it reduces the zone of influence during the welding process. It requires higher accurateness and a more elaborated machinery.

Due to lack of research and experience on EB-welding of heavy-constructions, it is foreseen to manufacture two UPP – single wall prototypes, using both variants to evaluate the optimum welding process.

To avoid the overlap of residual stresses and operational stresses, a optimized contour of the profile was investigated (variant b). It also allows welding from both sides and proper acess for mechanical finishing of the welds.

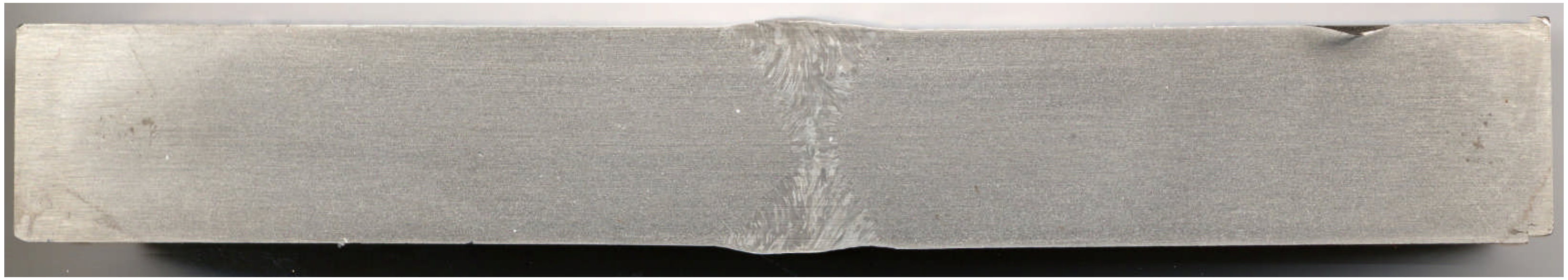
variant a





variant b
(preferred one)

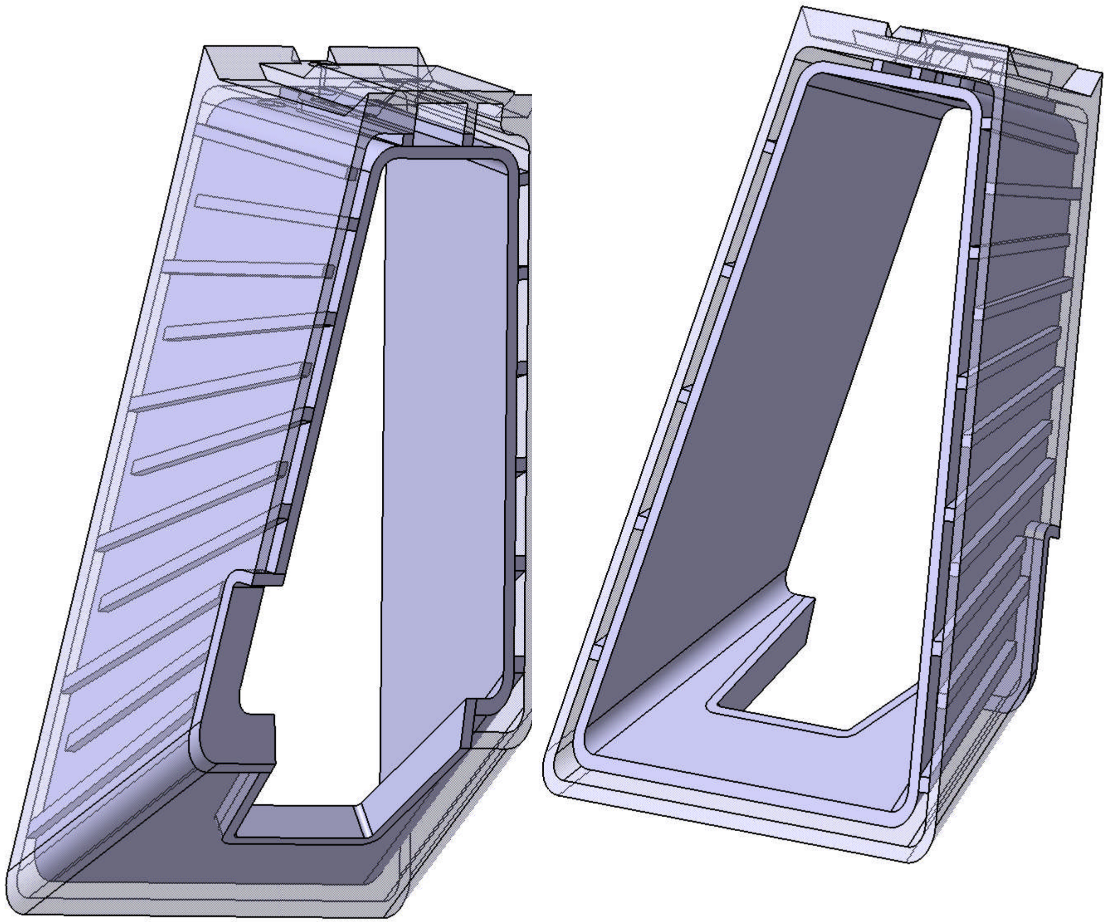
Different welding routes



a) TIG

b) EB

Manufacturing aspects of complex shaped double wall structures



QA criteria:

Visual inspection: Surface roughness, welds, interfaces, cooling connections

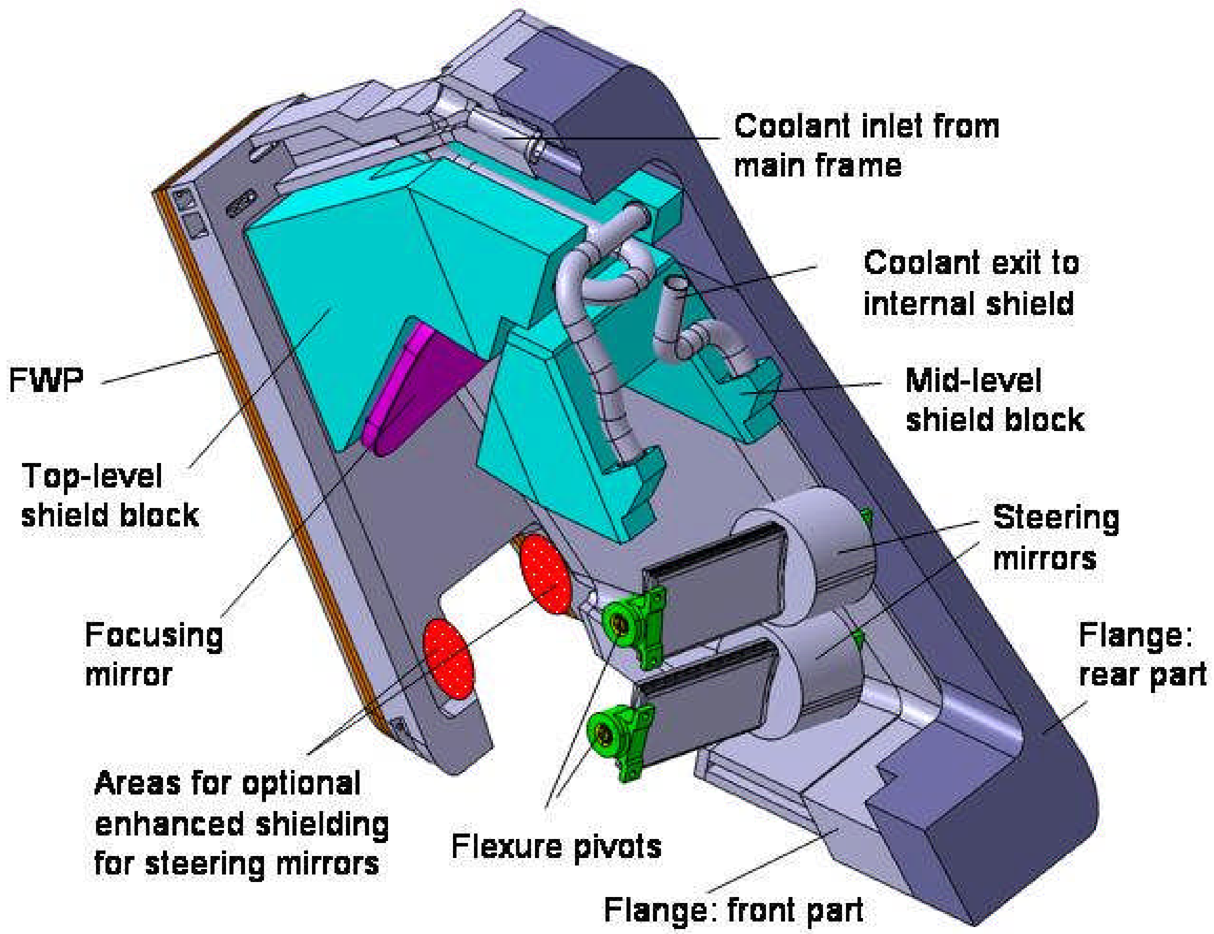
Dimension control:
Main dimensions by standard methods, skin scanning by 3-coordinate measuring position of flow ribs by US or x-ray

Pressure test: Water pressure of 6.3 MPa
Leak tightness: He leak test at RT

Ultrasonic tests of welds
Destructive metallurgical tests at sample welds

Material certification:
Composition, raw material fabrication route, heat treatment during assembly steps (If any)

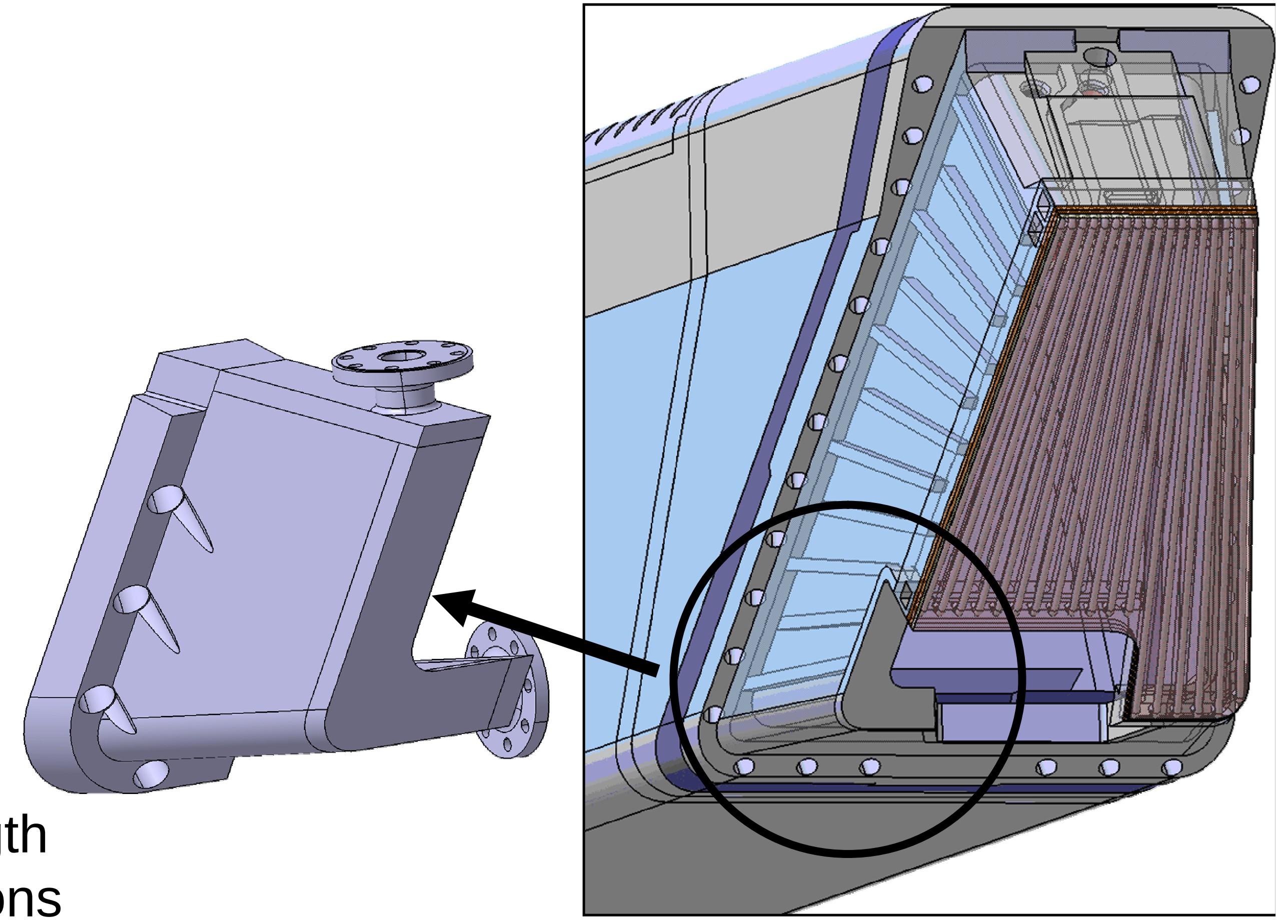
Design features of the blanket shield module



The blanket shield module (BSM)
closes the gap formed by the port in the regular blanket structure

Plasma-facing element is the first wall panel (FWP):
configuration of a regular blanket module
but welded attachment
(open space for mm-waves)

Prototyping and testing of the BSM



Cooling Test facility:

- Up to 240°C
- Up to 45 bar

Mechanical tests

- Yield/ultimate tensile strength
- Microstructure of the junctions

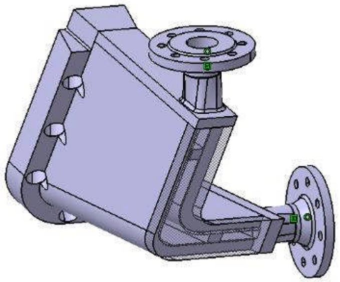
Prototypes:

- Sintered (HIP)
- Brazed
- Machined compacts (deep drilling + e-welded)

BSM Corner Prototype manufactured by “HIP route”

Arguments for the HIP route

Mechanical strength	✓
Water pressure (6.3MPa / 30min)	✓
Complex geometry	✓
Calculated shrinking	✓

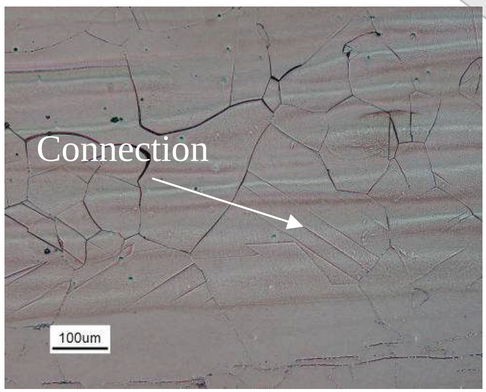


Step A: 3D-CAD Model

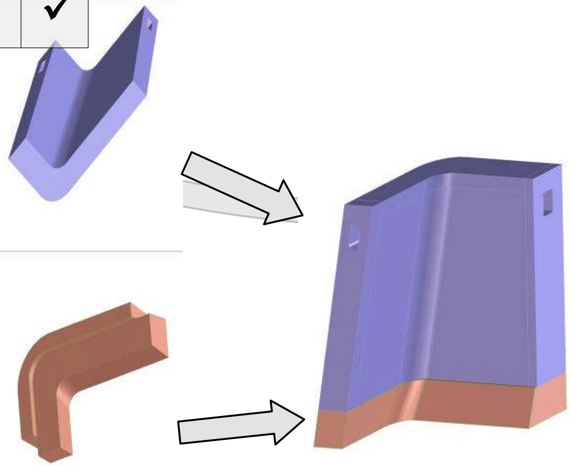
Step B: Capsule forming and filling

Step C: HIPped body of the double wall structure

View into the cooling channel

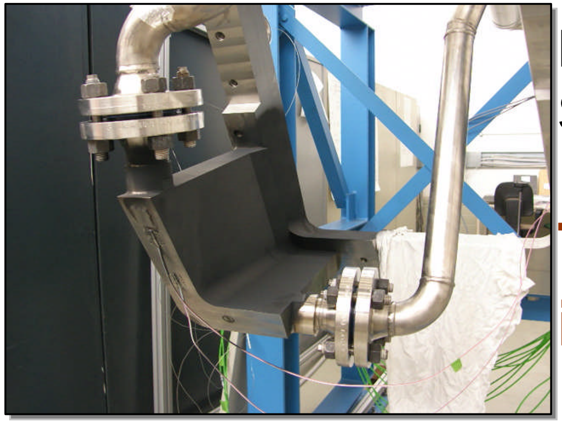


Microstructure of diffusion welded tensile specimen



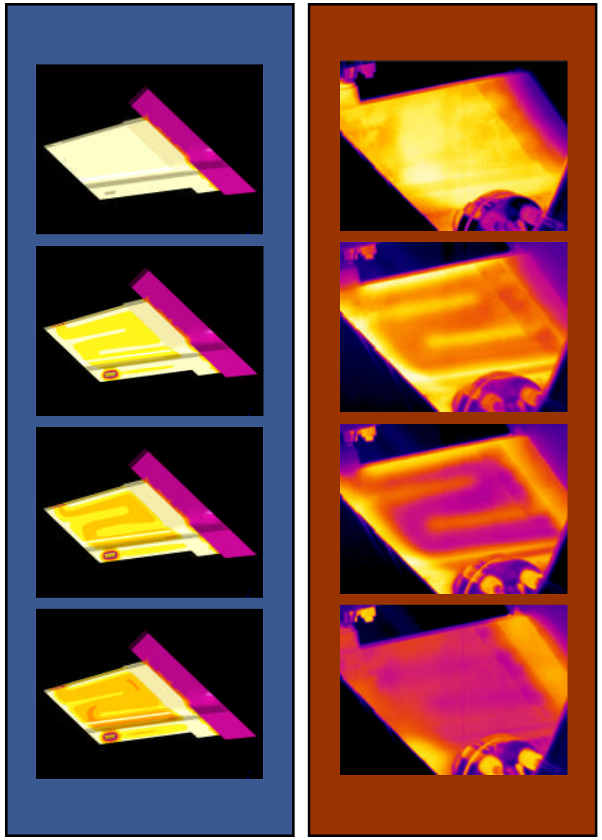
Step D: Flange connection by diffusion welding

BSM corner prototype: Results + Outlook

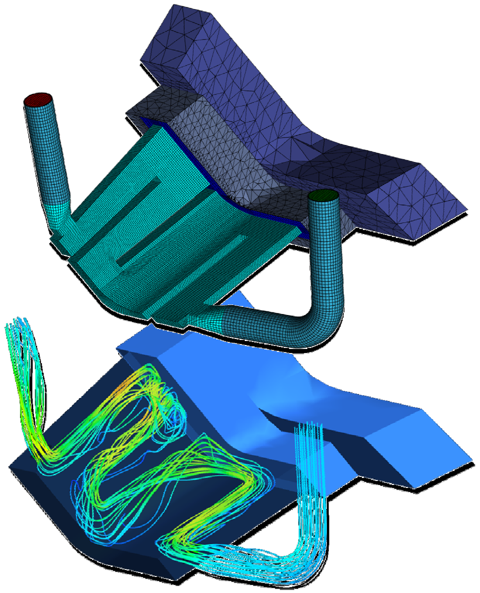


Double wall HIPped corner prototype.
Shock cooling from 100°C to 20°C.

Temperature profile by infrared camera.

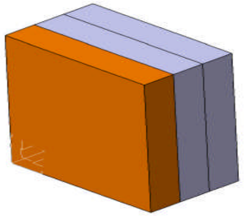


CFD analysis verified.

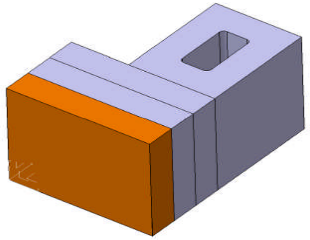


Extended validation + testing:
Model extension to full BSM + flange + main double wall.

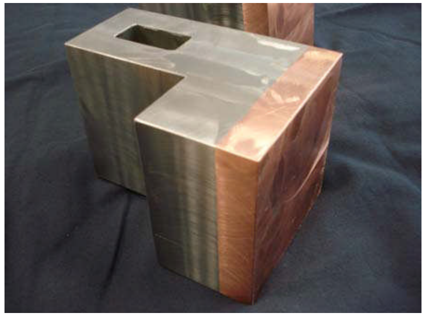
QA impact: Numerical analysis of
- Temperature profile at flange.
- Bolt pretensions.



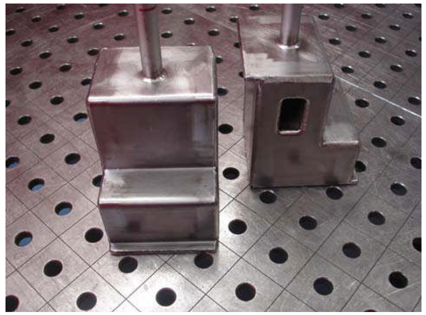
CuCrZr –SS



Doppelwand

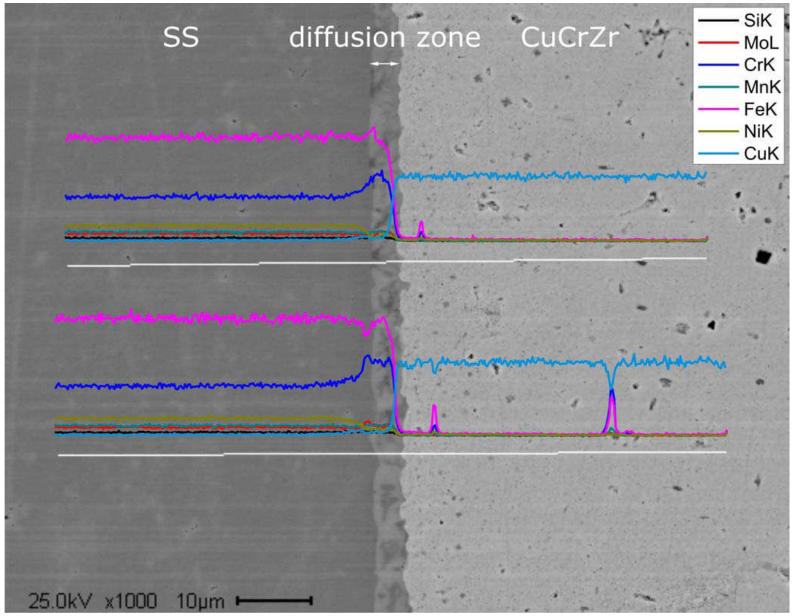


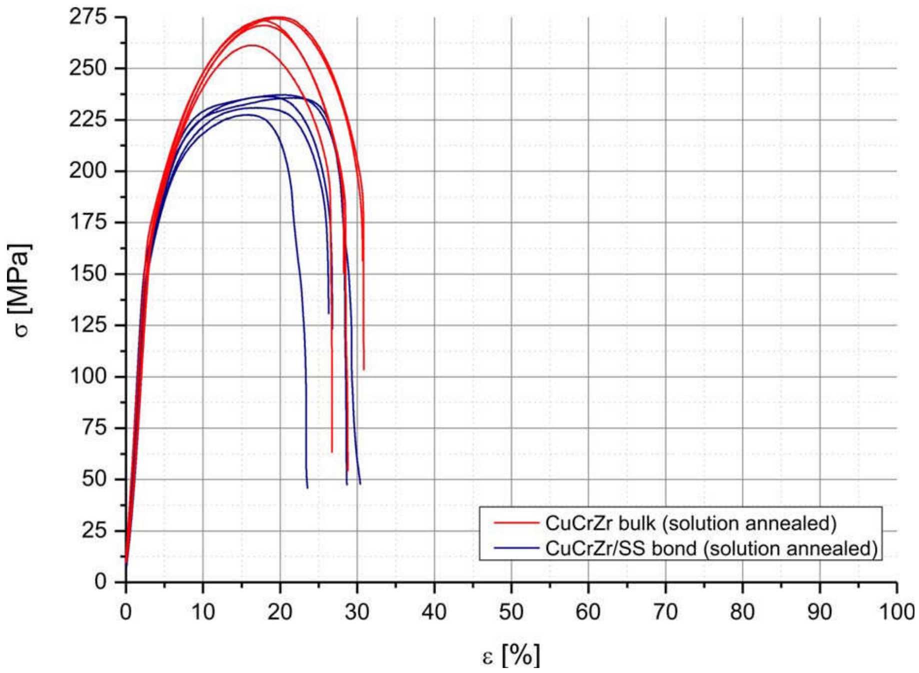
HIP



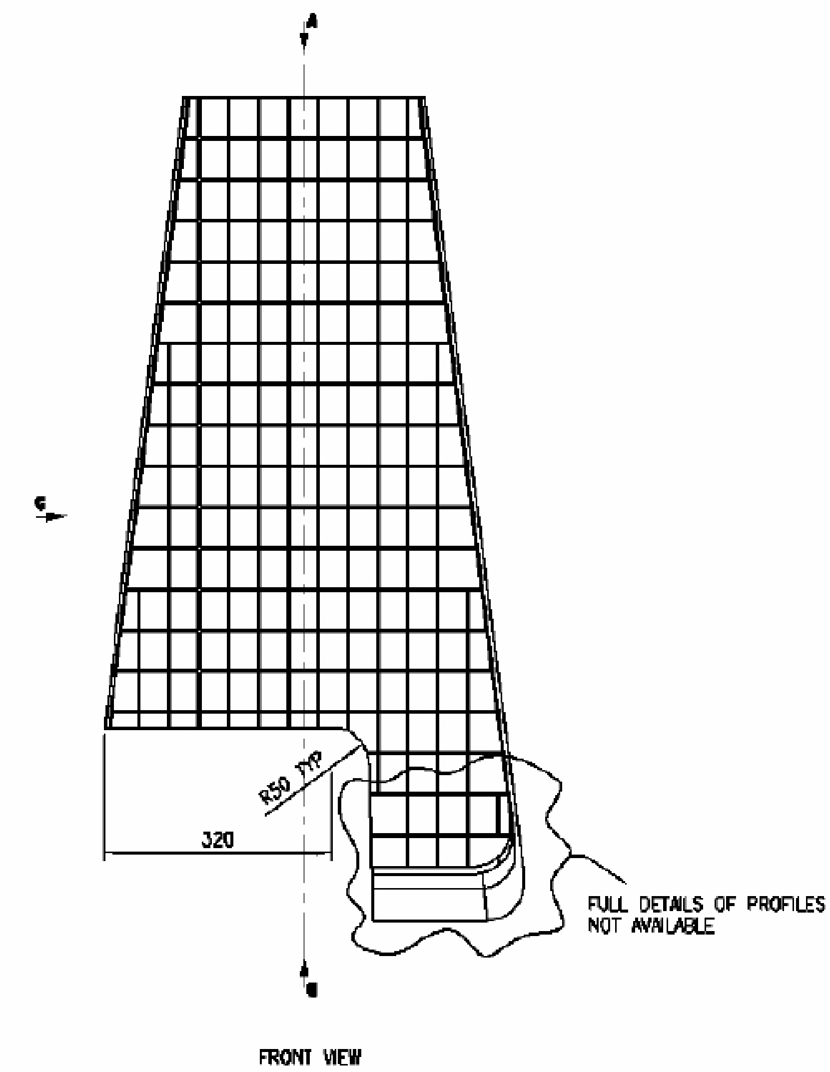
HIP route

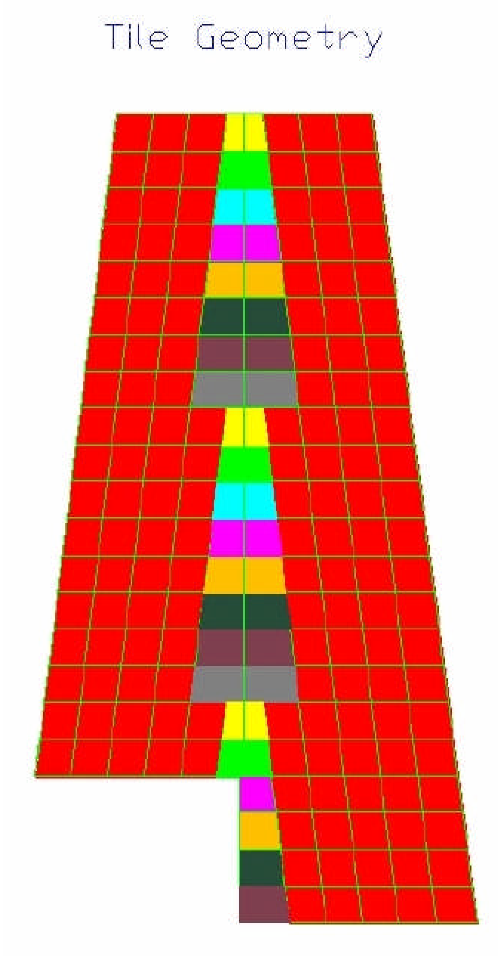
E2-176-MFZ-CuCrZr/SS-
06 07 08 09 10





Beryllium

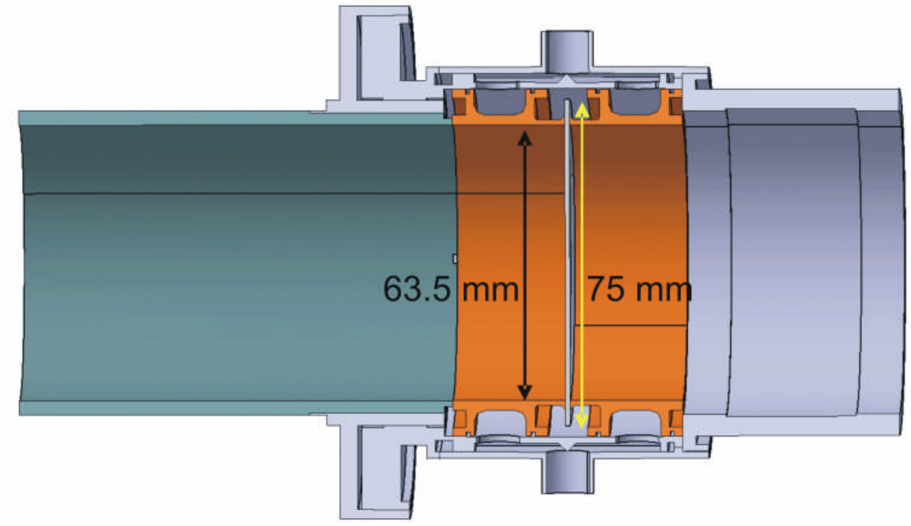

R50 TYP
320
FULL DETAILS OF PROFILES
NOT AVAILABLE
FRONT VIEW


Tile Geometry

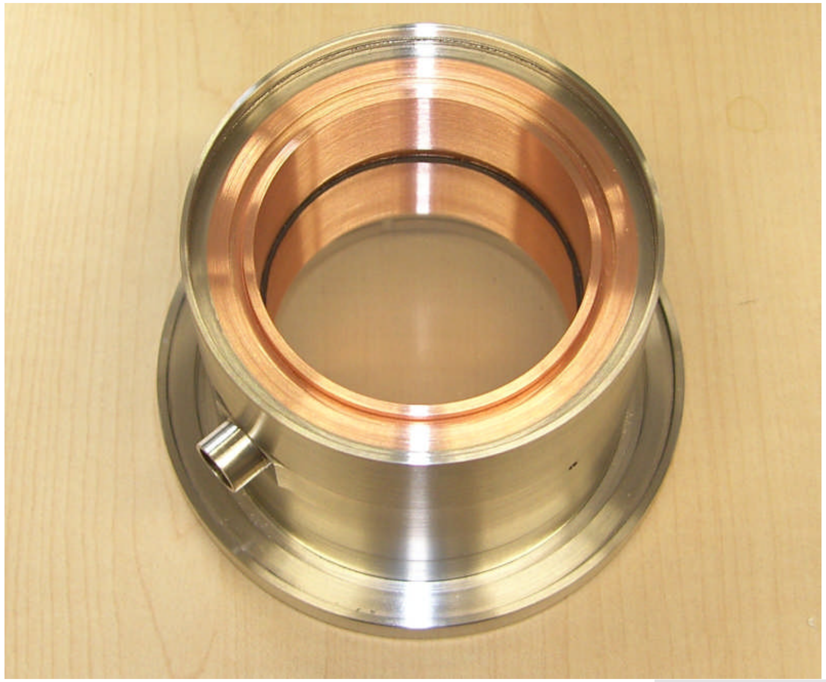
Conclusion

- BSM corner prototypes / manufacturing routes
- FWP mock ups
- Manufacturing concept for a UPP-Single wall prototype developed and completed
- Manufacturing of 2 prototypes under progress
- Expected Finalisation until end of June 2009
- Extensive tests (weld analysis, residual stress analysis, contour and alignment tests) will follow
- Double wall structure prototype development
- Open: Shield modules

EU CVD diamond torus window concept



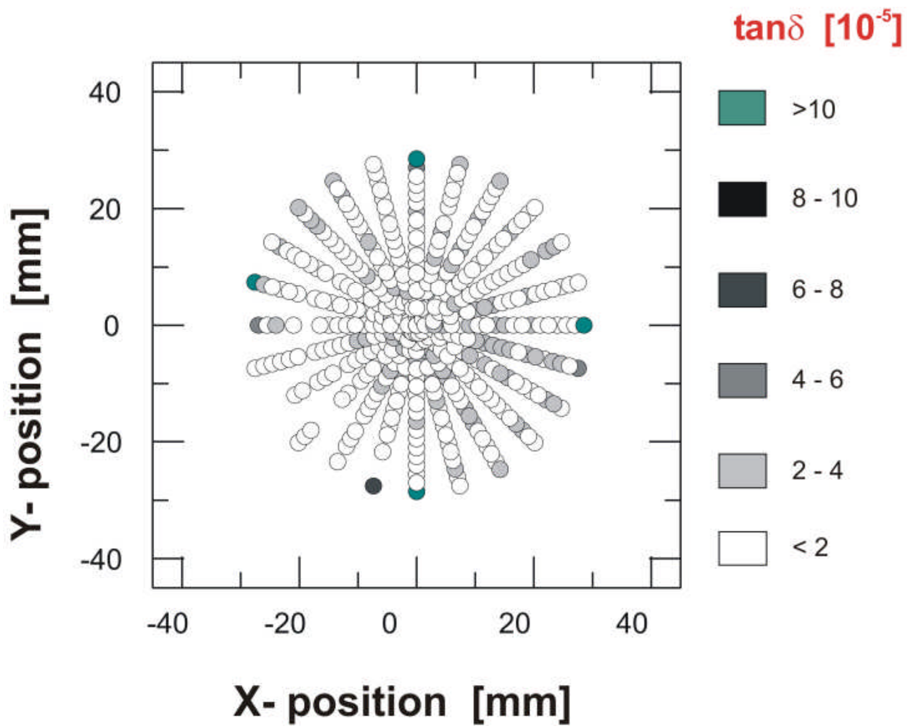
Diamond disk Diameter: 75 mm
Thickness: 1.11 mm

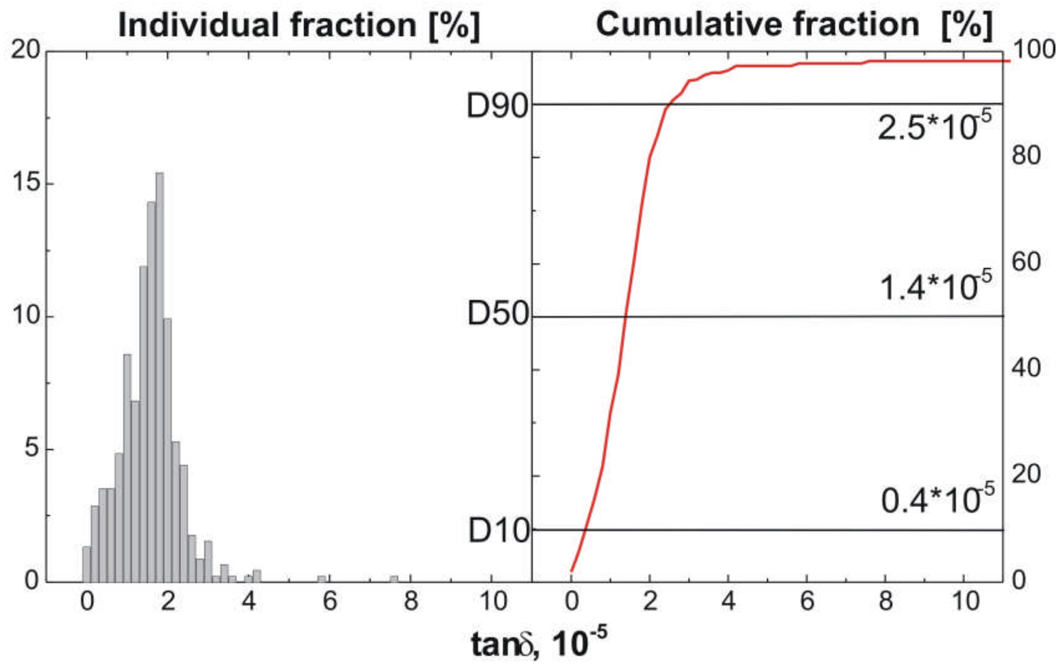


Demonstrator disk by ElementSix:
Loss measurements at 170 GHz:
$\tan\delta_{eff} = 0.9 \times 10^{-5}$
(central area)

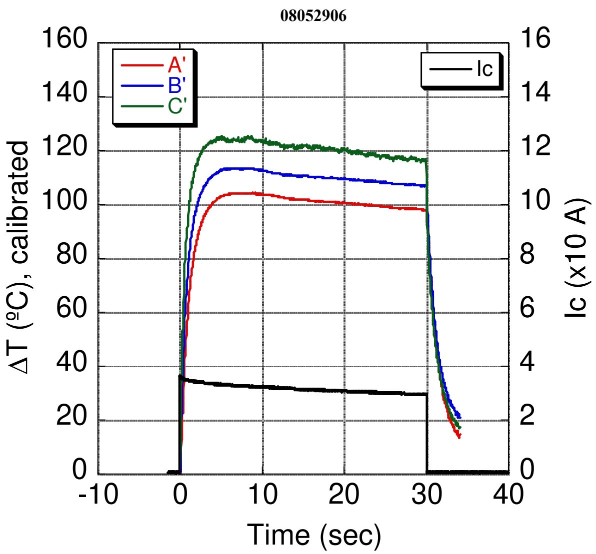
Smaller disk for torus window
Much lower $\tan\delta$ than guaranteed loss for gyrotron windows

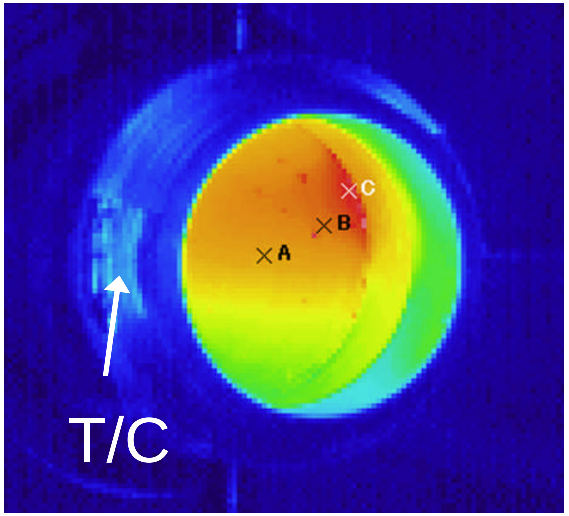
Diel. loss mapping of E6 diamond demonstrator disk (@ 100 GHz)





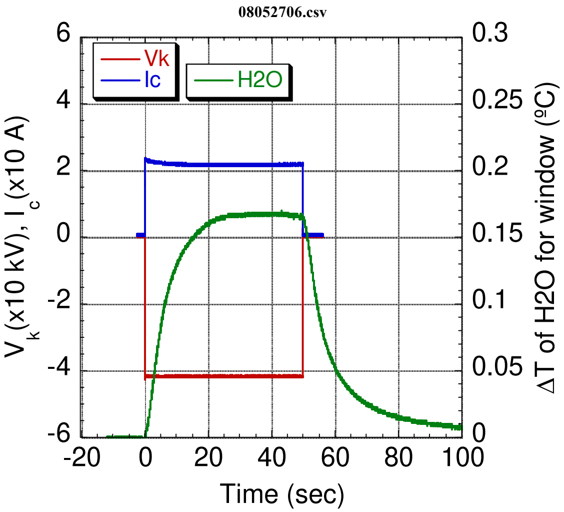
High power measurements at the 1 MW gyrotron facility in Japan (JAEA)





520 kW
30 s
T-Saturation

T/C measurement: housing

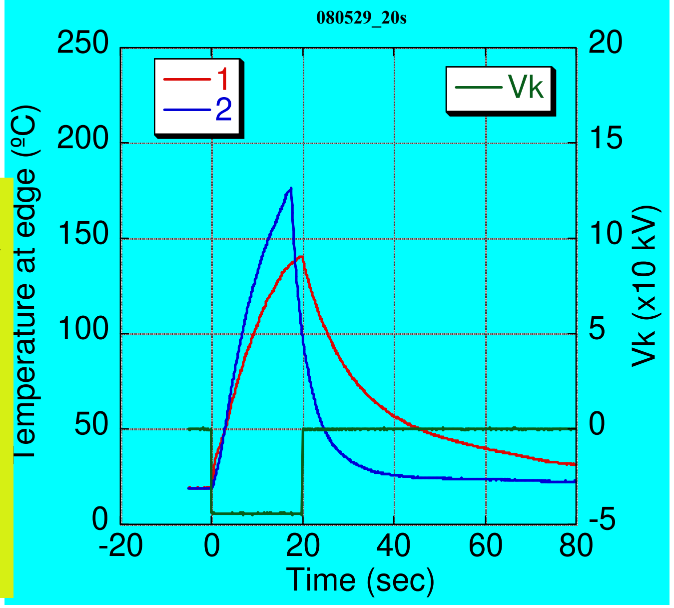


$$P_{diss} = 4.18 \cdot Q_{aq} \cdot \frac{dT}{dV \cdot \tau} \cdot \int_0^{\tau} \Delta V \cdot dt$$

$$= \dot{m} \cdot c_{aq} \cdot \Delta T$$

$$P_{diss} \approx 100\ W \quad ;$$

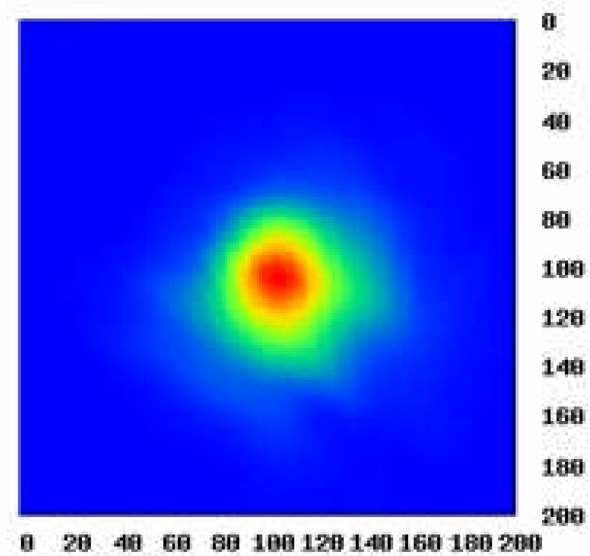
$$for:\ Q_{aq} = 7.7\ l/\min$$

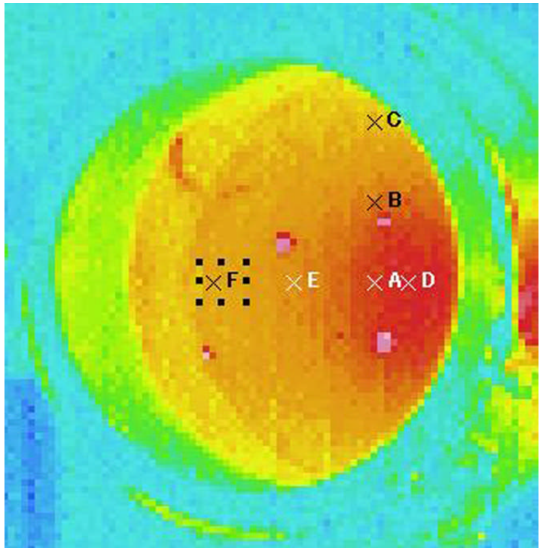


Impacts

Temperature distribution :

The region of high temperature increase shifted toward the center compared to the previous experiment!

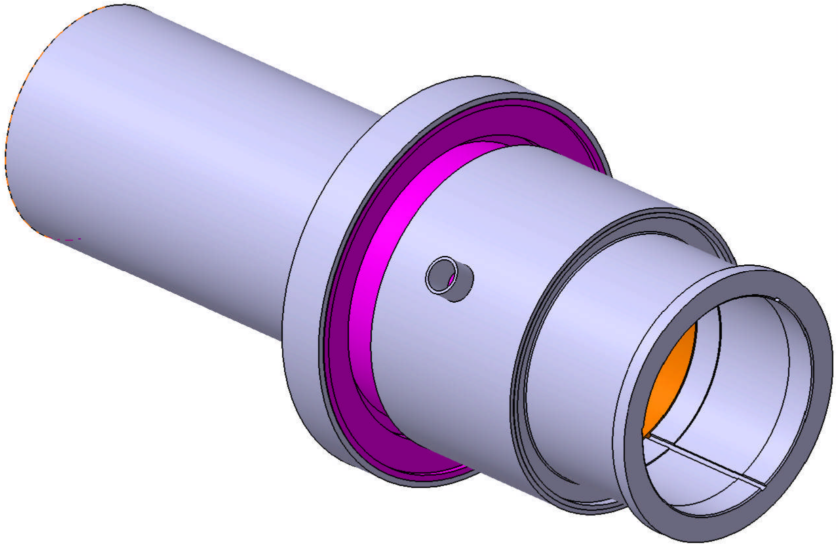


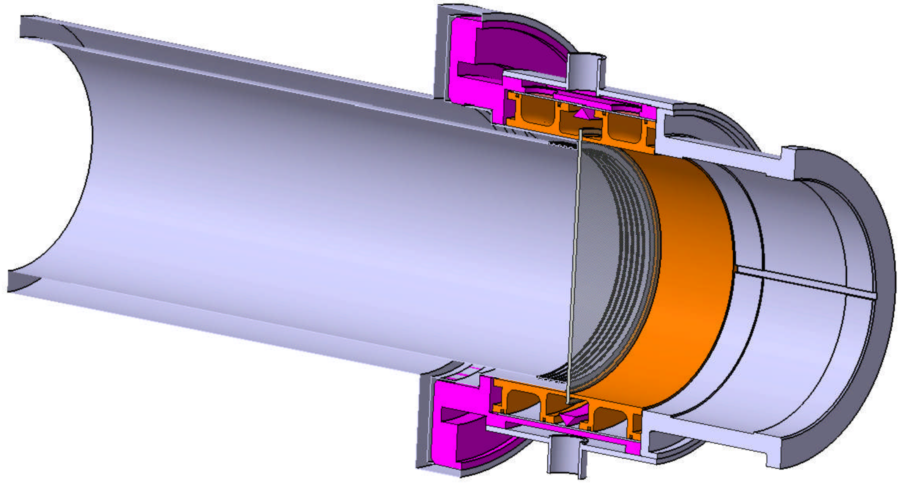


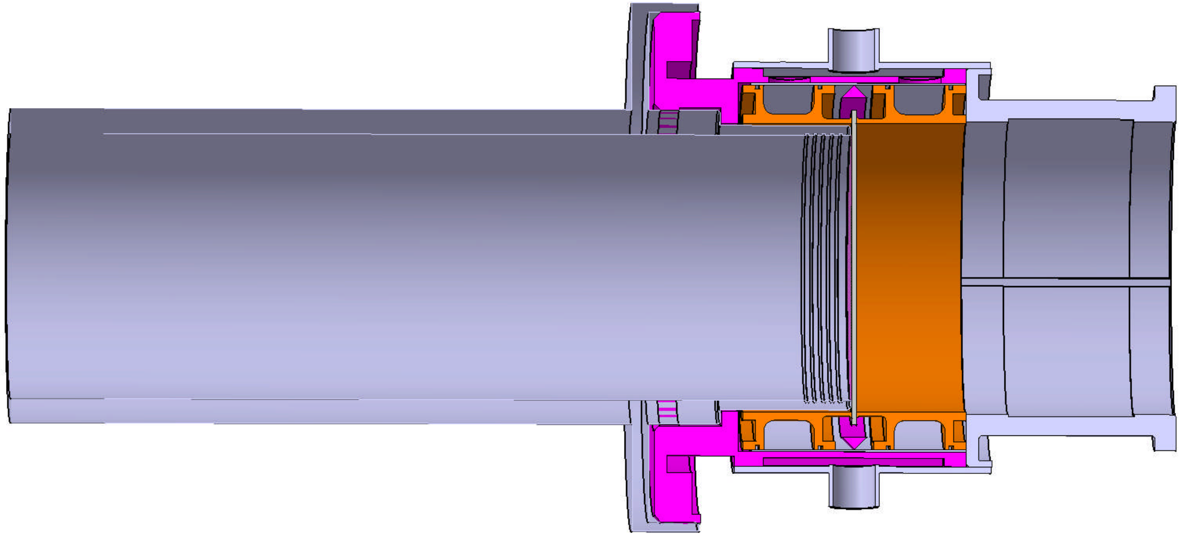
Beam correction (MOU)

245 kW at 15 sec

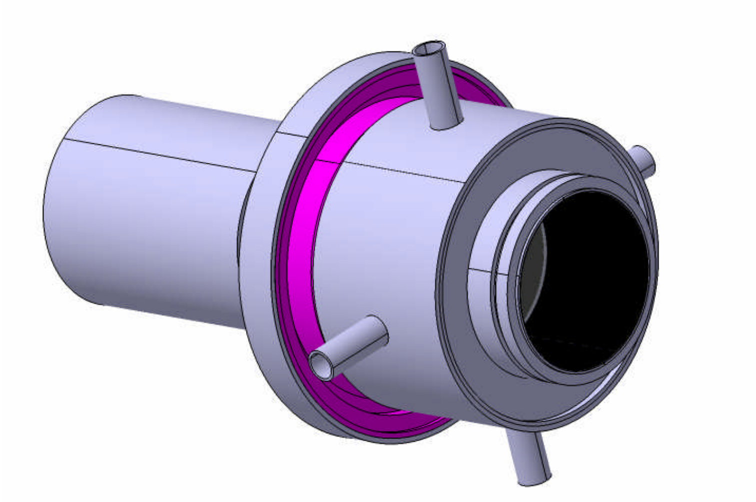
Window with WG insert

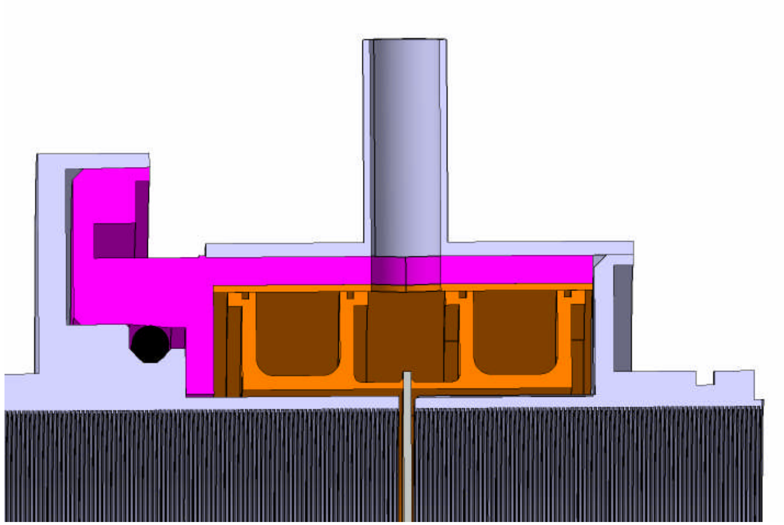


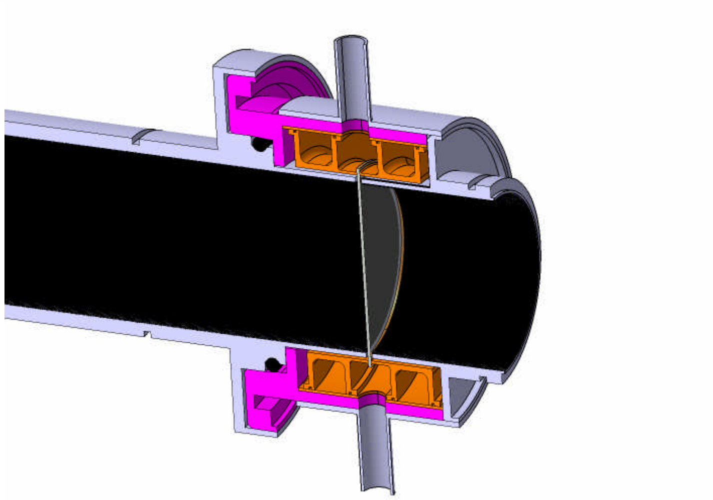




Window with WG insert (matching)





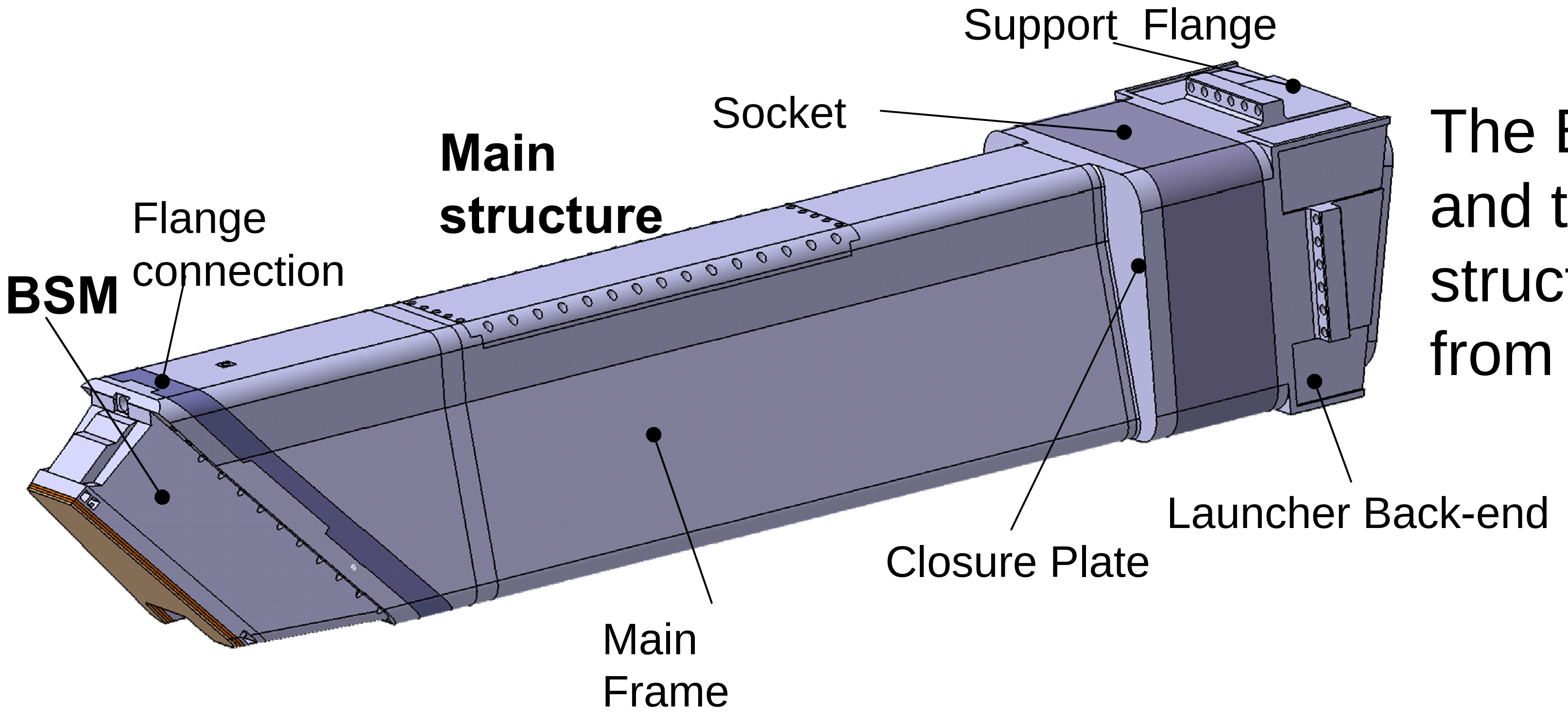


Window prototyping outlook and summary

- Aim: Common window assembly for EL and UL (EU / JA)
- Short and long pulse measurements up to 520 kW / 170GHz
- Optimization of brazing
- Temperature saturation on diamond disk
- No arcing observed
- Heating of housing by mixed modes (gaps and parasitic cavities)
- Optimization of beam profile (JAEA)

- Investigation of the influence of non-Gaussian field distributions on the window (How many “wrong” modes are allowed?)
- Impact on window design? 2nd prototype / waveguide insert (matching)

The Upper Launcher in ITER



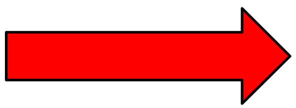
The BSM housing and the main structure is made from SS 316 LN IG

Normal ITER condition:

• T = 120-150 ^{o}C

Outbaking

• T = 240 ^{o}C



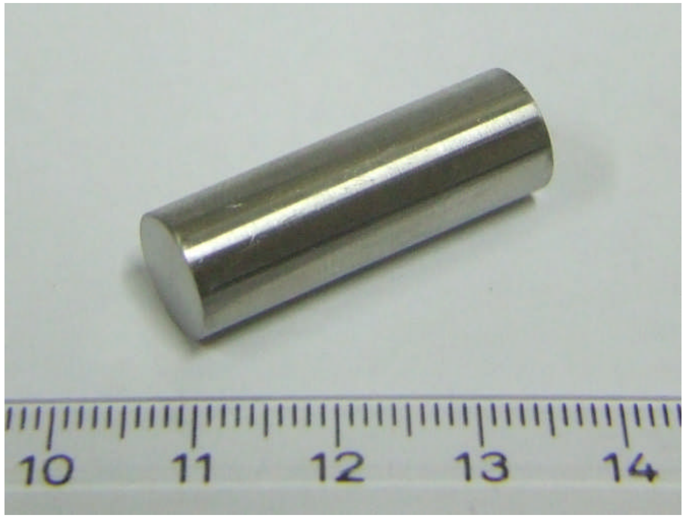
Gas released from the structural material poisons the ITER plasma

Outgassing

- Outgassing is the evolution of gas from a solid or liquid in a vacuum.
- The outgassing rate of a solid or liquid is the quantity of gas leaving per unit time and per unit of exposed surface at a specified time after the start of evacuation, so it is measured in Pa m^3 s^{-1} m^{-2} (Pa m s^{-1}).

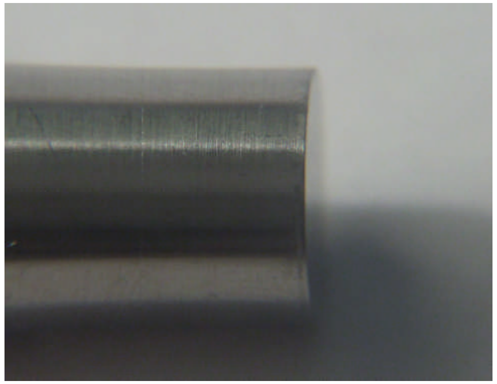
Measurements of total and partial outgassing rates are *in progress* for several SS-samples made from different fabrication techniques.

SS-samples

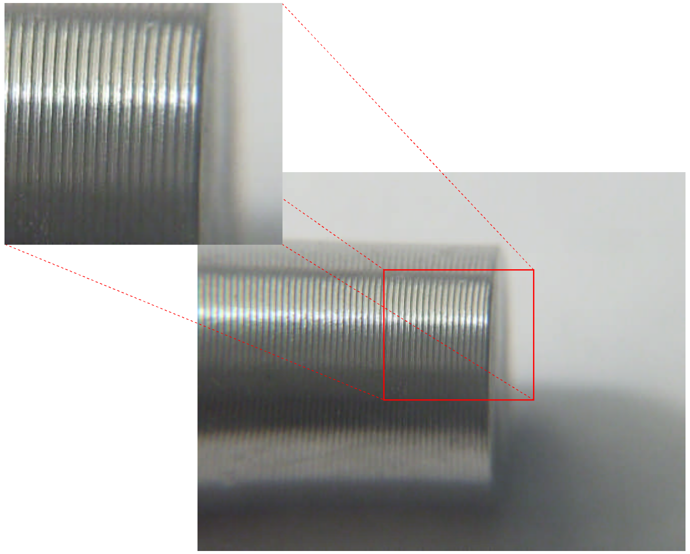


3 pairs → SS 316 LN IG by P HIPing
→ SS 317 LNM by Rolling
→ SS 317 LNM by Rolling + HIPing

In each pair:

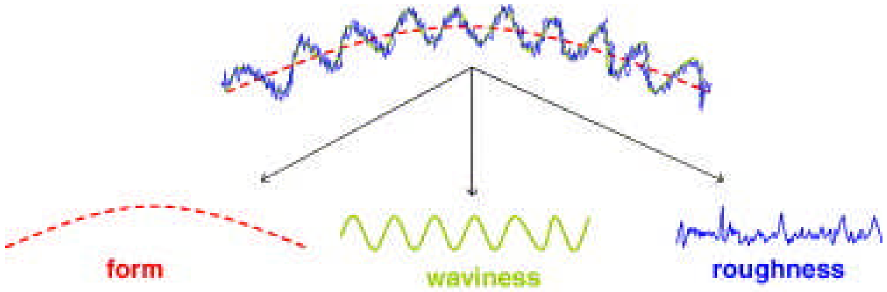


Polished sample

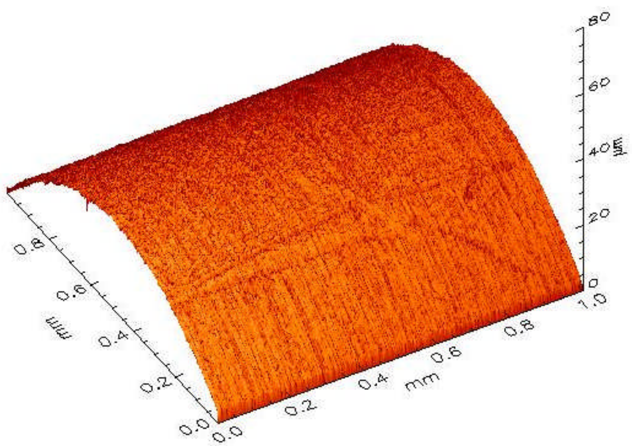


Sample with rills

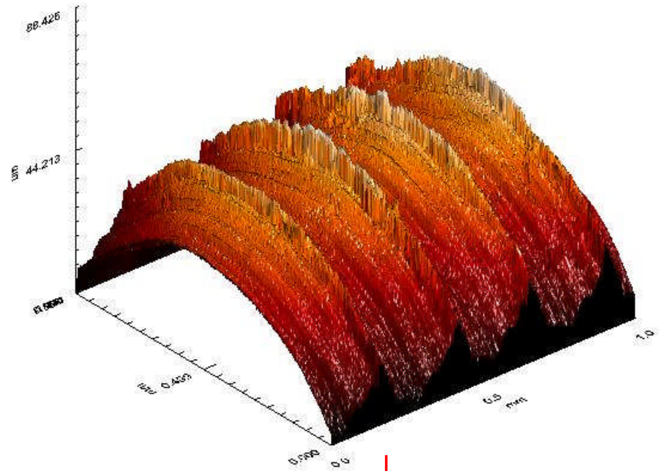
Roughness measurements



Roughness and waviness are distinguished by the cut-off length λ_c, whose value is suggested by the normative.



By optical method, raw data related to an area of 1 mm^2 are obtained.



Roughness profile:

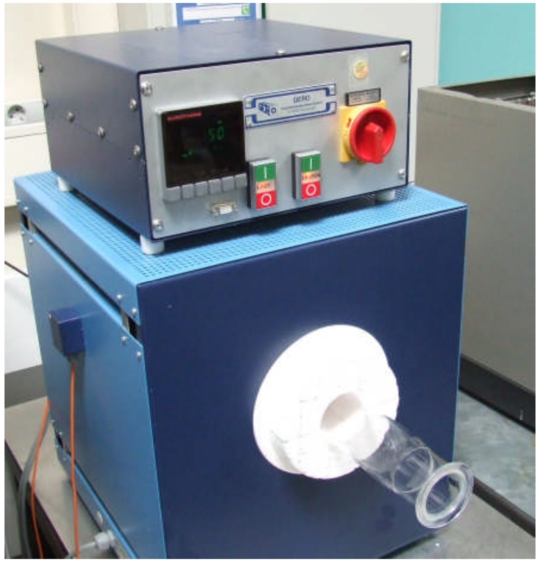
$f_s \approx 1.2$

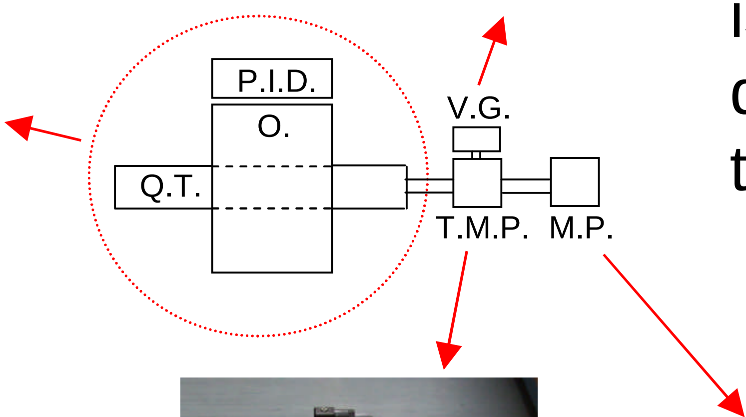
Determination of the real surface of the samples

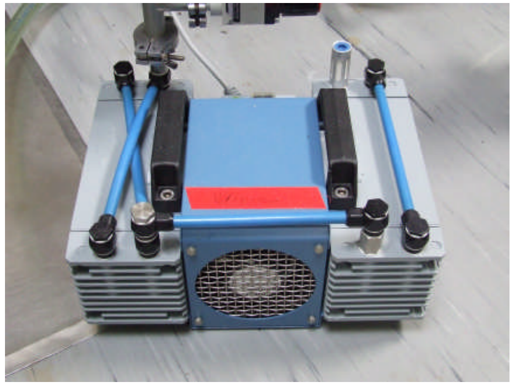
Roughness and waviness profiles:

$f_s \approx 1.8$

Vacuum test







Vacuum test setup: a pressure of $5*10^{-7}$ mbar is reached inside the quartz tube, at room temperature.

New steps

- Temperature calibration under vacuum.
- Total and partial outgassing measurements:

$$Q = (P_1 - P_2) * \frac{C}{A}$$

- Comparison with the ITER requirements. The required outgassing rates at 100°C for hydrogen isotopes and impurities are respectively $1*10^{-7}$ and $1*10^{-9}$ Pa m s^{-1}.

At 200°C, the measured Q for steel is $1.1*10^{-5}$ Pa m s^{-1}.

It is difficult to satisfy these requirements!!!