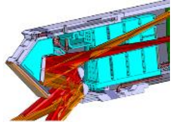


ECHULA (ECH Upper LAuncher) partners:
CNR Milano, CRPP Lausanne,
FOM Rijnhuizen, FZK Karlsruhe,
IPP Garching / IPF Stuttgart

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

Design and testing of the ITER ECRH Upper Launcher

PROTOTYPE TESTING OF THE BLANKET SHIELD MODULE AND TORUS WINDOW ASSEMBLY FOR THE ITER ECH UPPER LAUNCHER

T. A. Scherer, R. Heidinger, A. Meier, P.Spaeh, D. Strauss, A. Vaccaro
FZK, Karlsruhe

K. Sakamoto, K. Kajiwara, K. Takahashi
JAEA, Mito

Electron Cyclotron launcher at the ITER Upper Port

Key requirement:
Counteract plasma instabilities at the outer plasma location
("Neoclassical Tearing Modes - NTM")

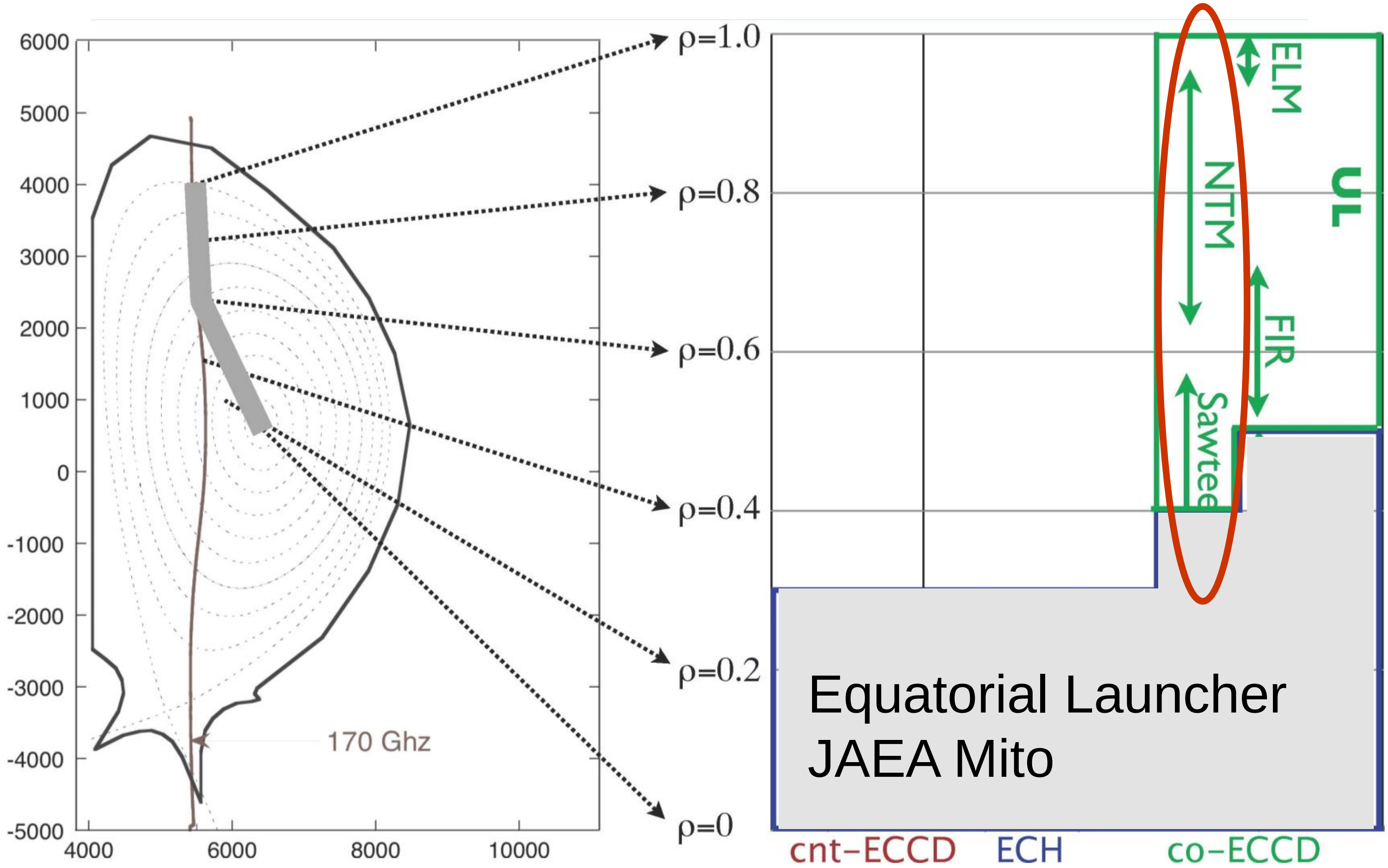
This requires:

- A mm-wave system, which extends from the interface to the transmission line up to the **target absorption zone** in the plasma performing as an **intelligent antenna**.

- A structural system, which integrates the mm-wave system, while ensuring sufficient thermal and nuclear shielding.

- Port plug remote handling and on-site testing capability, which ensure high port plug system availability.

Physics Mission of the Extended Physics Launcher for MHD control(@ Upper Port Plug: UL)

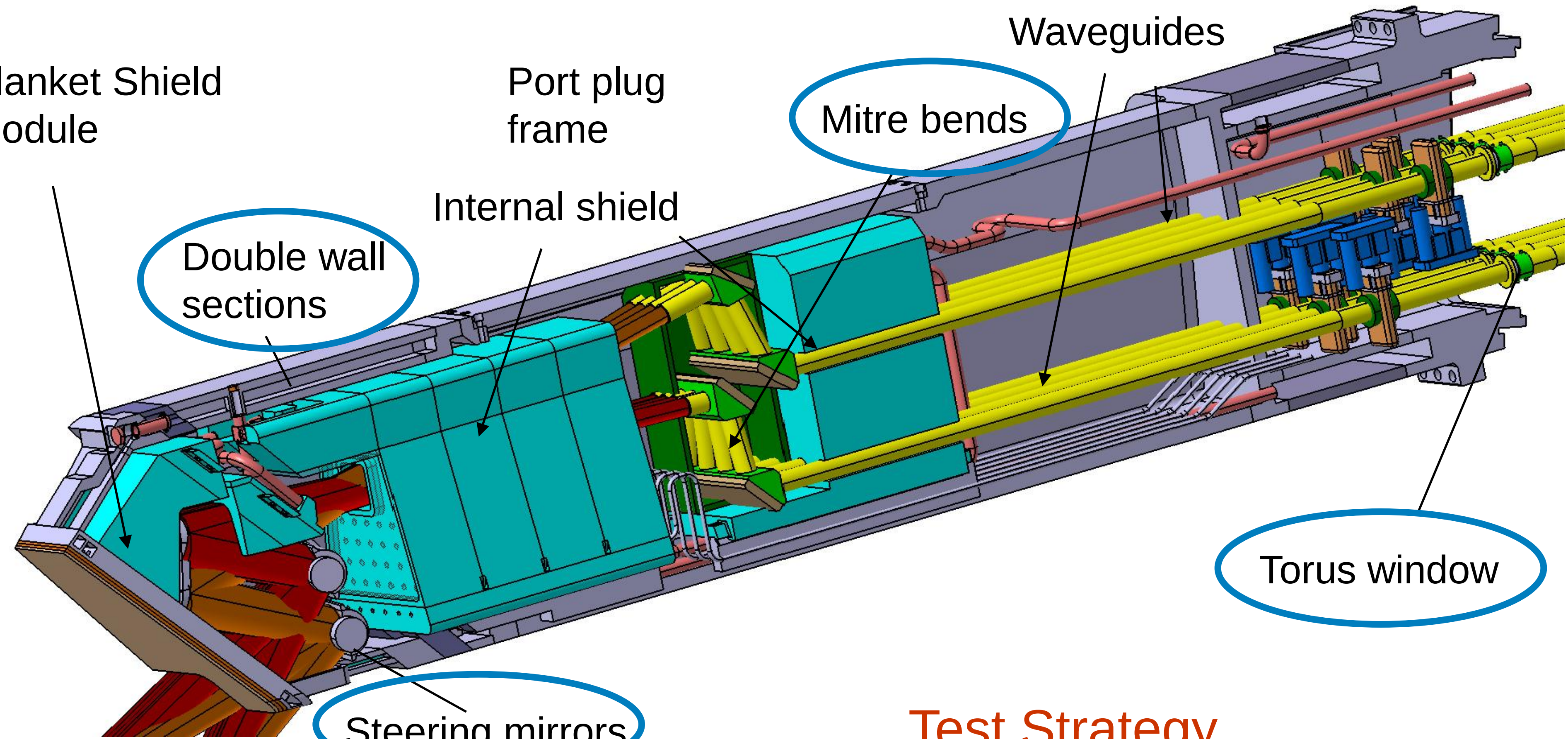


Study and Graphics by Mark Henderson ITER-IO

System Mission for Extended Performance Launcher: Port plug with integrated mm-wave beam lines

Structural system

MM-Wave system



Feedback on target

Test Strategy

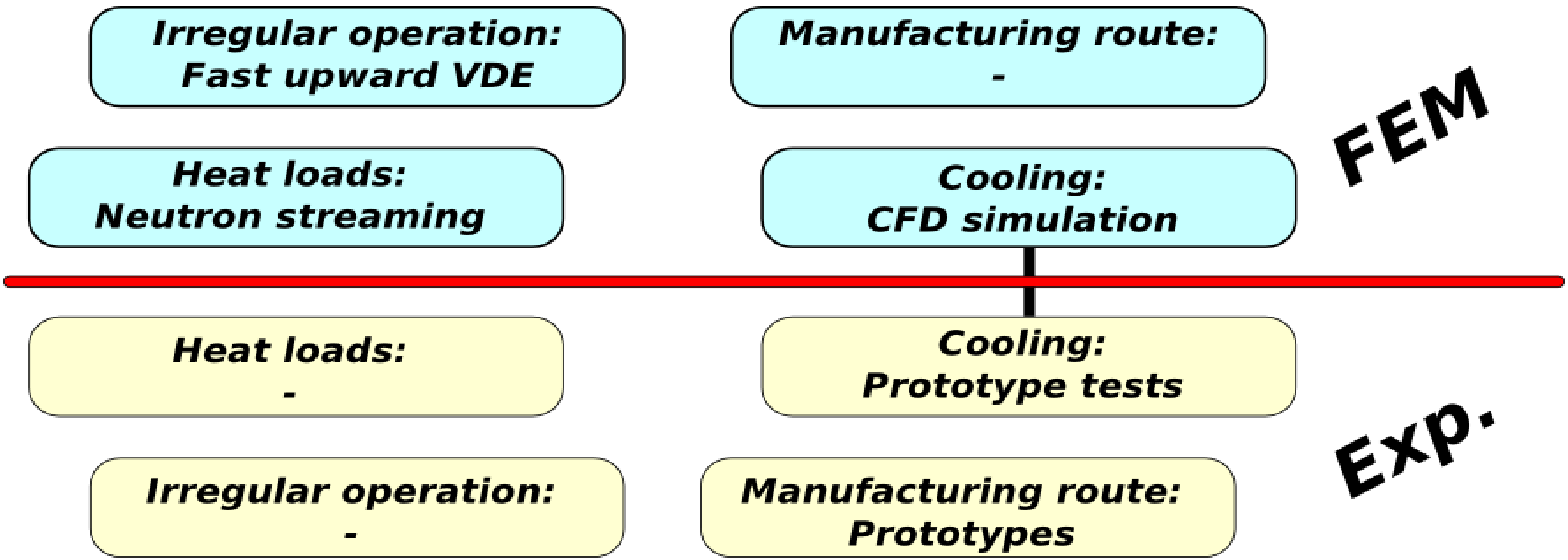
RH capability

Role of prototypes for design validation

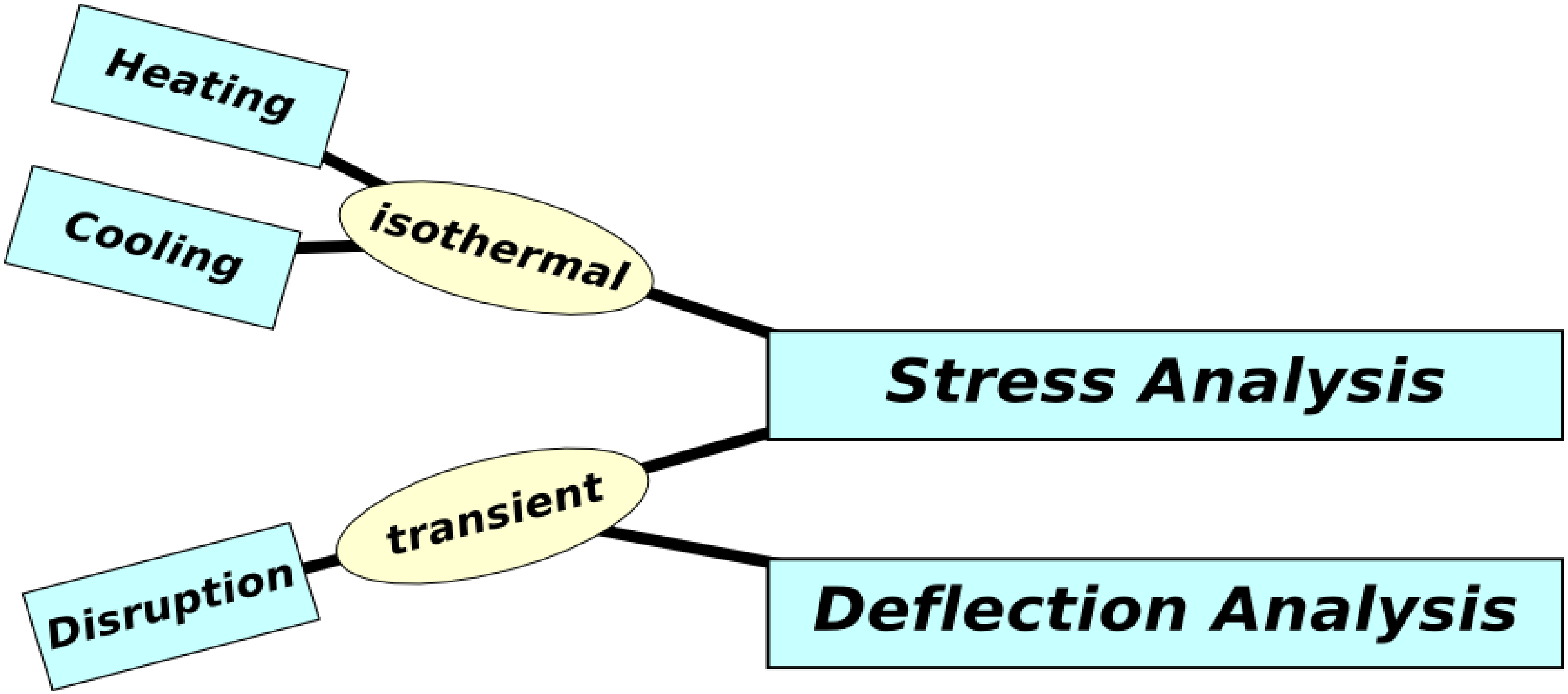
Only very limited load scenarios can be tested experimentally.

Manufacturing route can be proven by prototype tests.

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



Numerical analysis for design validation



<u>Combination of various simulations for proper design validation:</u>

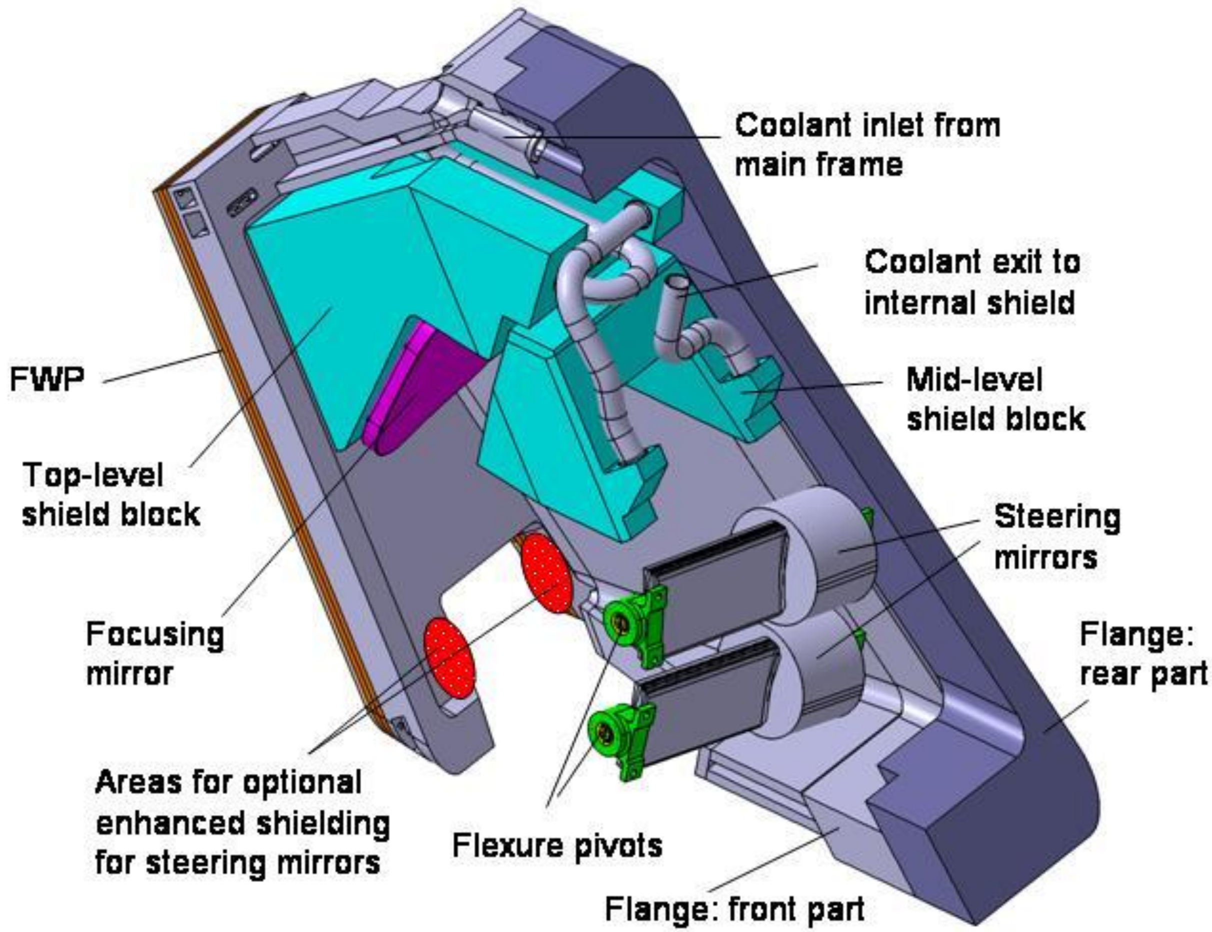
Heating: surface loads & volumetric heating (MC neutrons).

Cooling: CFD simulation.

Disruptions: the worst case scenario ("crash test").

Structural analysis: FEM stress/deflections.

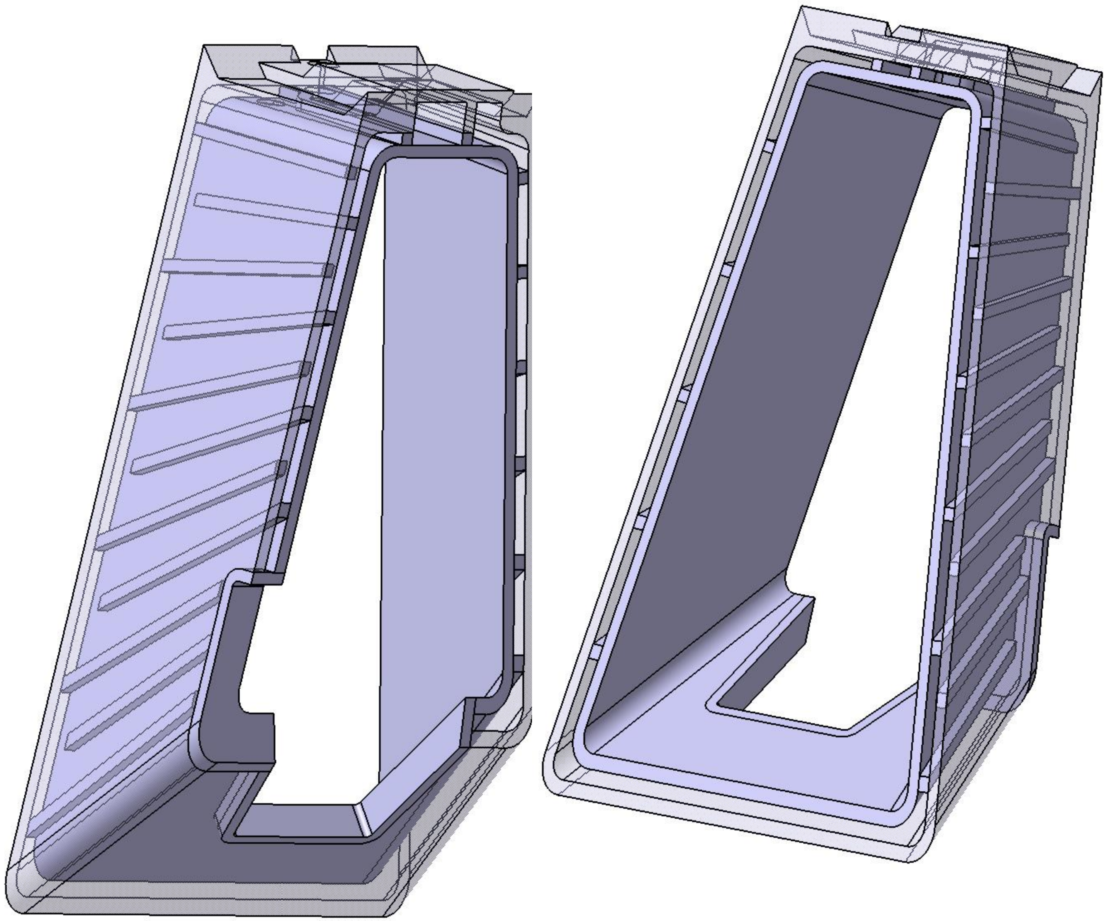
Design features of the blanket shield module



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)

Manufacturing aspects of complex shaped double wall structures



QA criteria:

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

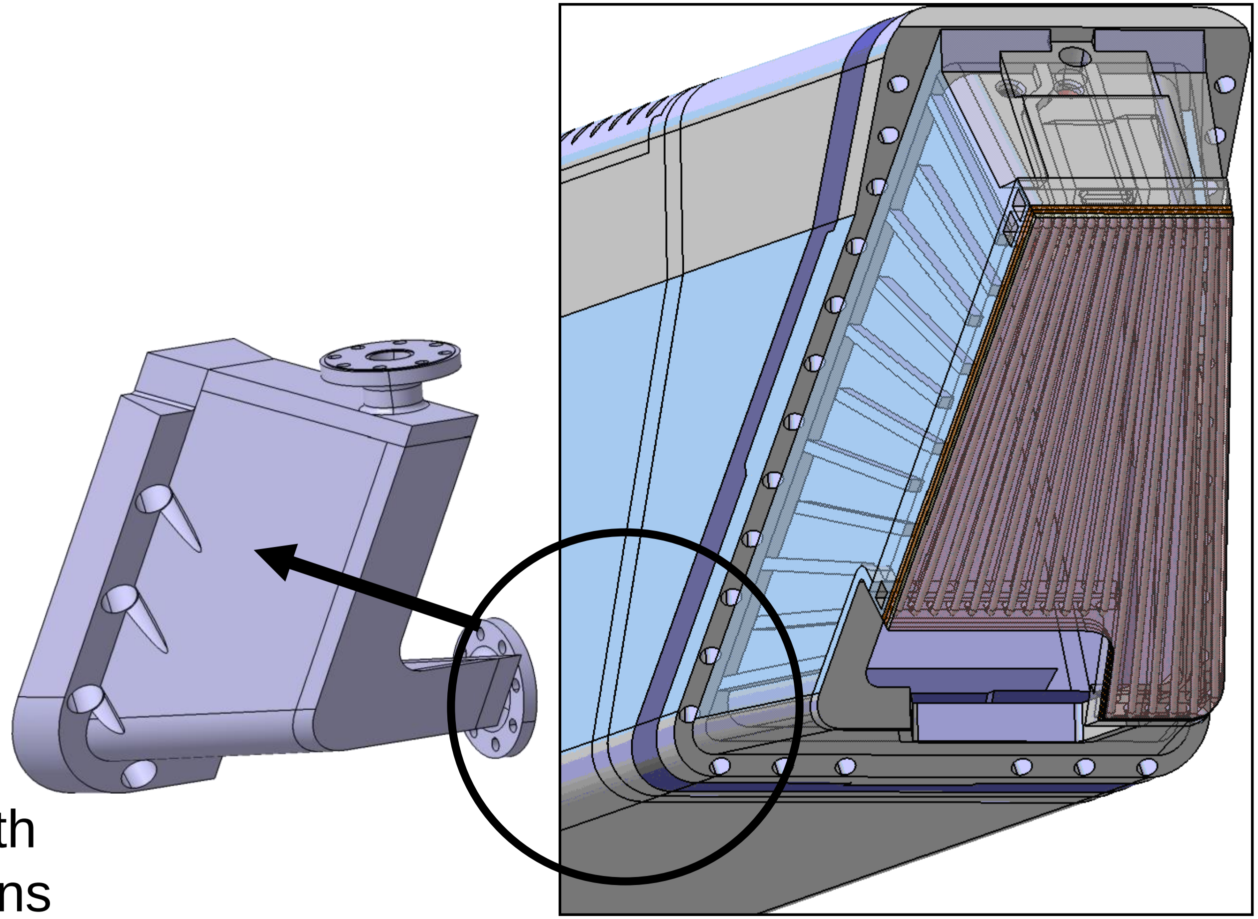
Dimension control:
Main dimensions by standard methods, skin scanning by 3-coordinate measuring position of flow ribs by US or x-ray

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)

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

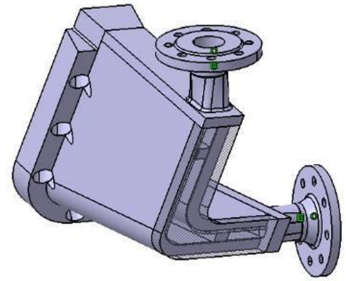
Prototypes:

- 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	✓

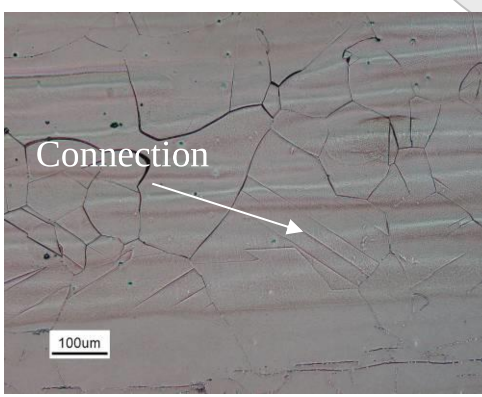


Step A: 3D-CAD Model

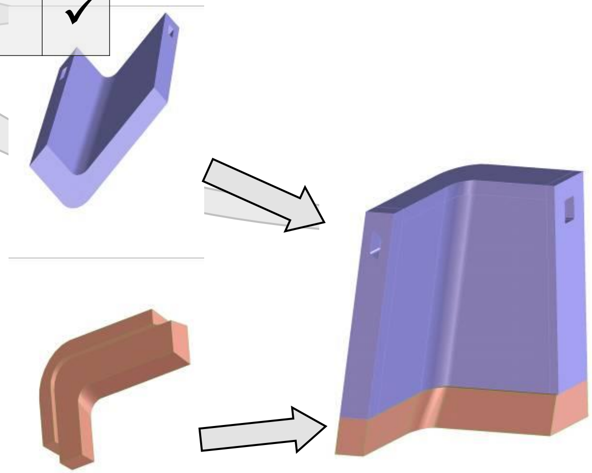
Step B: Capsule forming and filling

Step C: HIPped body of the double wall structure

View into the cooling channel



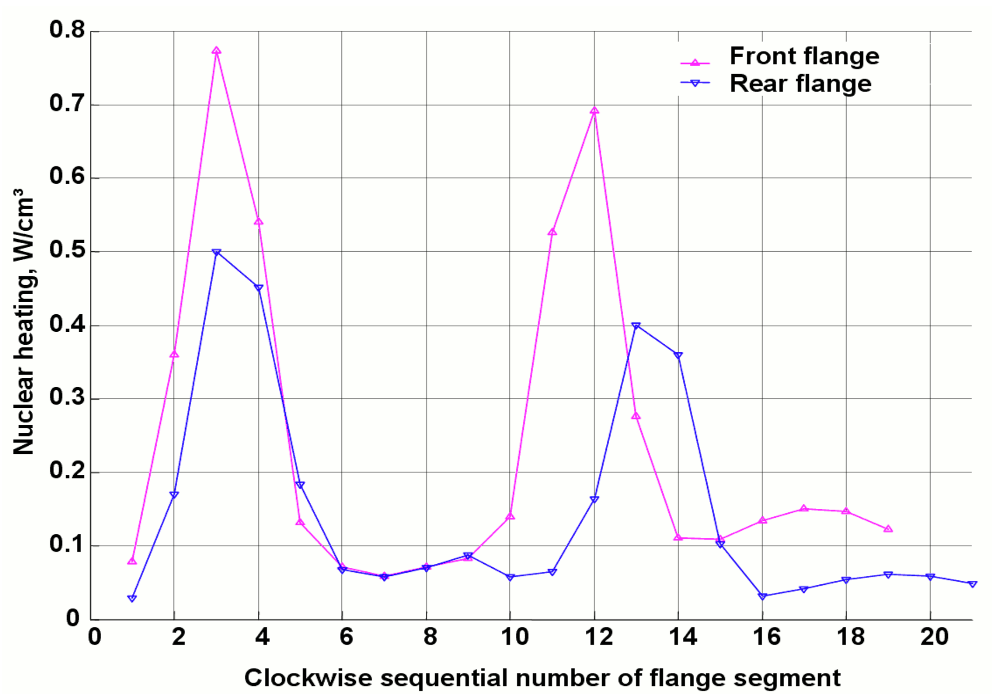
Microstructure of diffusion welded tensile specimen

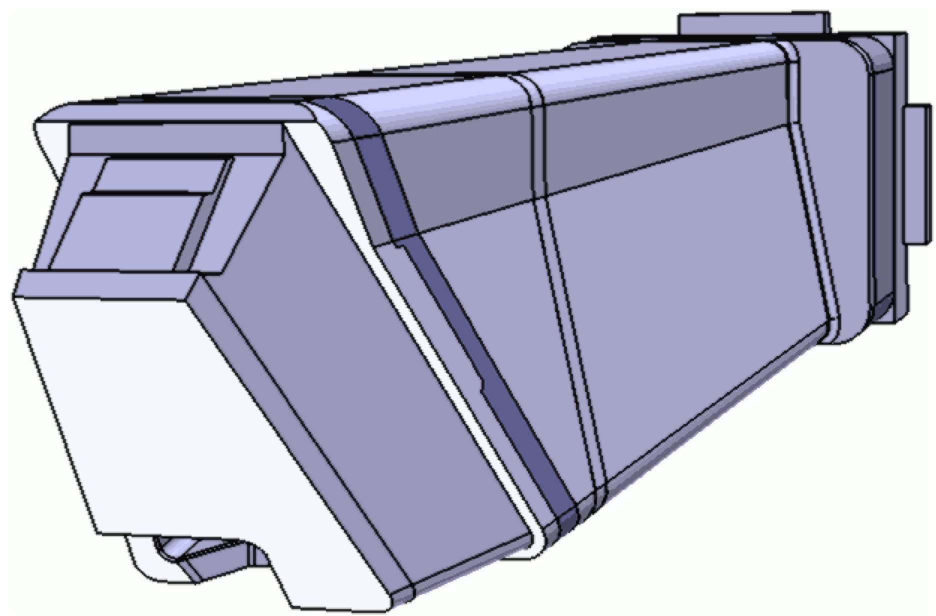


Step D: Flange connection by diffusion welding

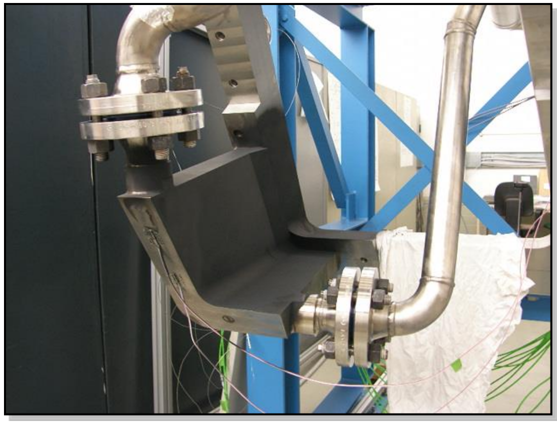
Particular concern of thermal loads on structural components

- Surface loads on First Wall Panel (FWP).
- Volumetric heat load distribution by neutron heating.
- Cut out in FWP causes hot spots especially at the passively cooled flange between BSM and main structure.



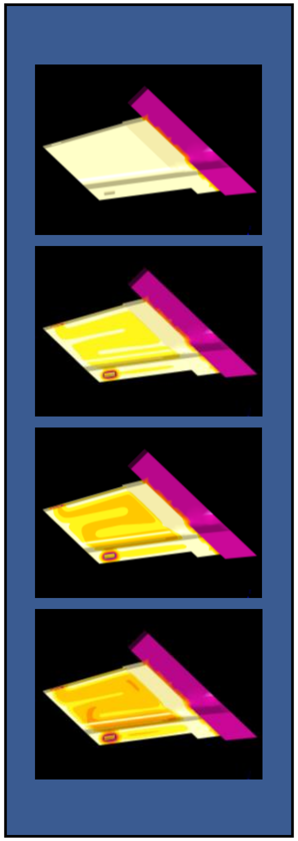


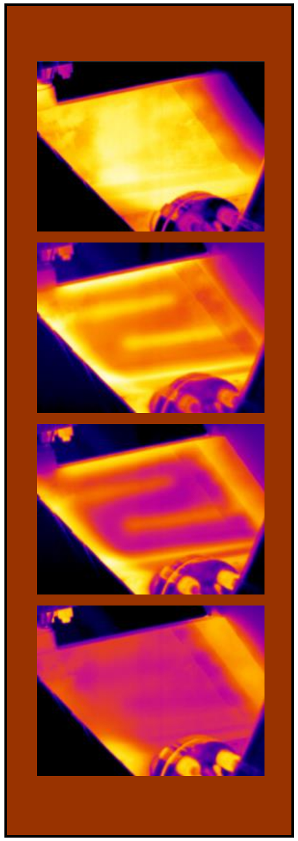
BSM corner prototype: Results + Outlook



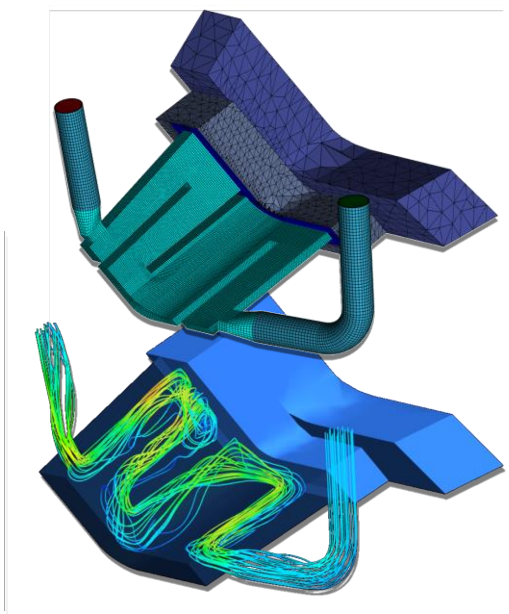
Double wall HIPped corner prototype.
Shock cooling from 100°C to 20°C.

Temperature profile by infrared camera.





CFD analysis verified.

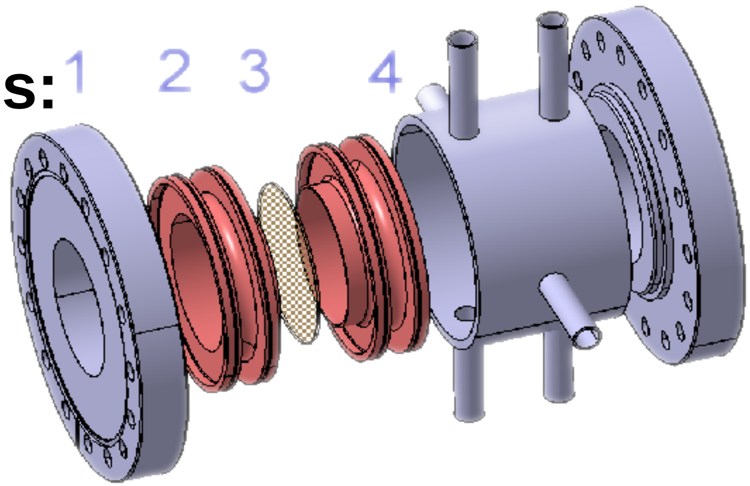


Extended validation + testing:
Model extension to full BSM + flange + main double wall.

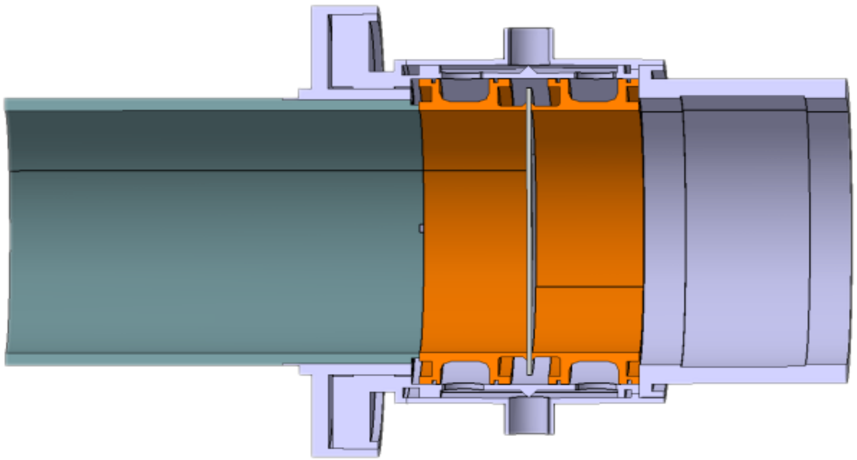
QA impact: Numerical analysis of
- Temperature profile at flange.
- Bolt pretensions.

Diamond Window Prototypes for the ITER Front Steering (FS) Upper Launcher

Targets for initial (pre-)prototyping steps:



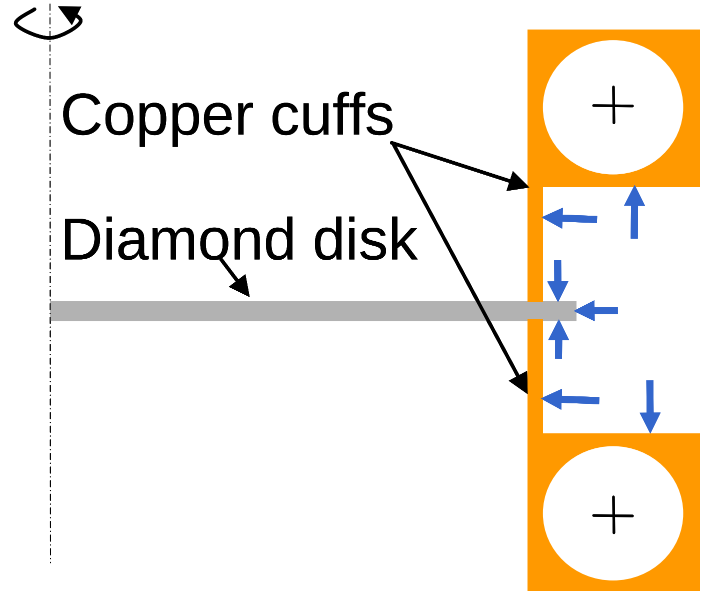
- Validation w.r.t. input parameters for numerical design development and performance analysis bead on FEM
- Decision on cooling principles: direct vs. indirect cooling.
- Demonstrate in-situ maintenance
- Quantify parameters and capabilities for semi-automated (dis-)assembly



Cooling principles

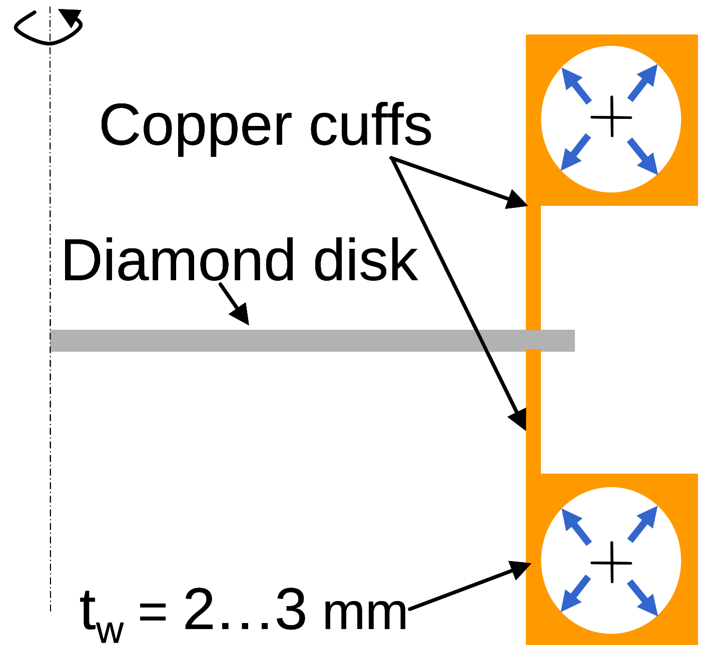
Direct Cooling:

- Lower peak and average temperatures
- Risk of cooling water intrusion at failure
- Enhanced failure safety by electroplating Cu at the diamond edge and at the brazing



Indirect Cooling:

- Optimized safety: cooling water separated by strong Cu structure.
- Higher cooling water pressure possible.
- Lower cooling efficiency due to the longer heat flow path.

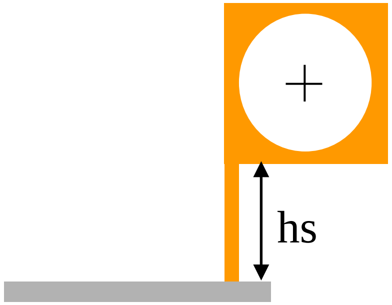


Thermal analysis: Impact of mm-wave loss for 2 MW

- window aperture: 2a [mm] = 60
- water temperature: T [°C] = 40
- water consumption: w [l / min] = 20

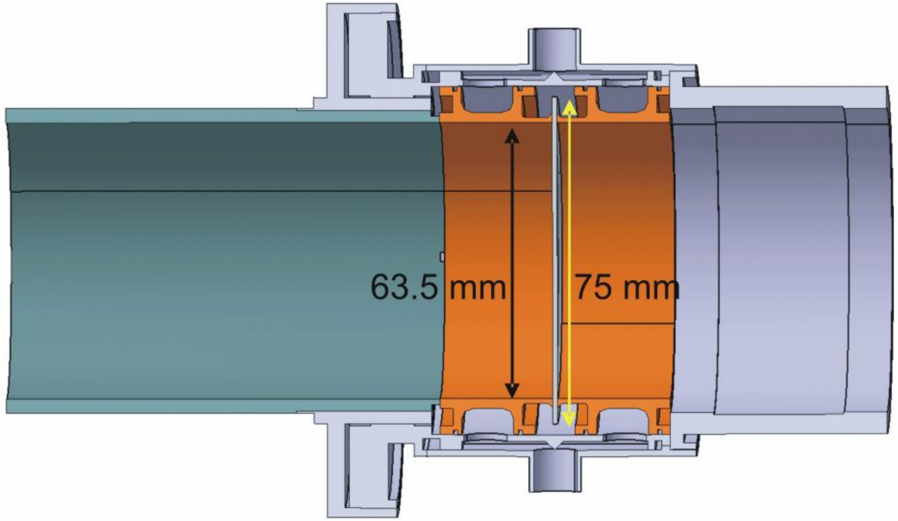
⇒ film coefficient: α_T [W/(m²K)] = 19700

- separation: hs [mm] = 5/10



P_{abs}	Cooling		T_{center}, [°C]	T_{edge}, [°C]	ΔT, [°C]
530 W	Direct (edge)		97	50	47
$\tan\delta = 2 \cdot 10^{-5}$	Indirect	hs = 5	114	66	48
		hs = 10	133	83	50
1060 W	Direct (edge)		162	60	102
$\tan\delta = 4 \cdot 10^{-5}$	Indirect	hs = 5	202	92	110
		hs = 10	248	127	121
265 W	Direct (edge)				<25
$\tan\delta = 10^{-5}$	Indirect hs = 10				<25

EU CVD diamond torus window concept



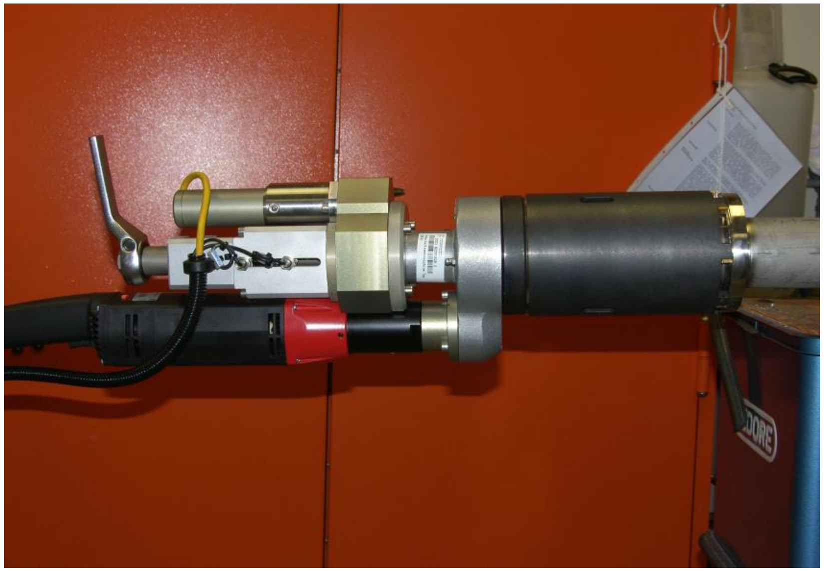
Diamond disk Diameter: 75 mm
Thickness: 1.11 mm

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

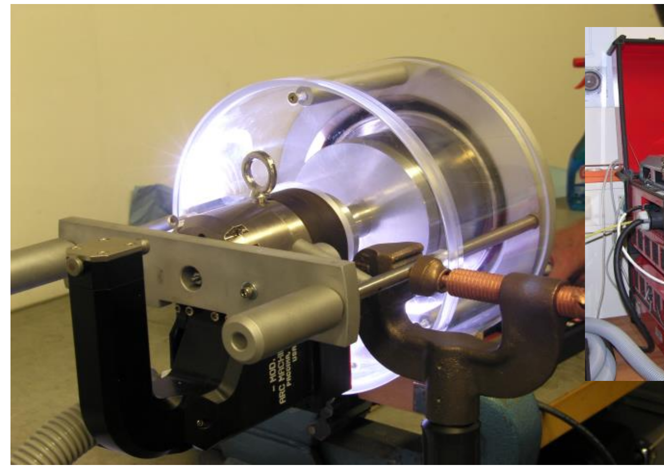
Semi-automated handling processes and tools

Cutting



- Cut Diameter: 110 .. 118 mm
- Outer Diameter: 123 mm
- Protem / France

Welding



Weld head for RS window

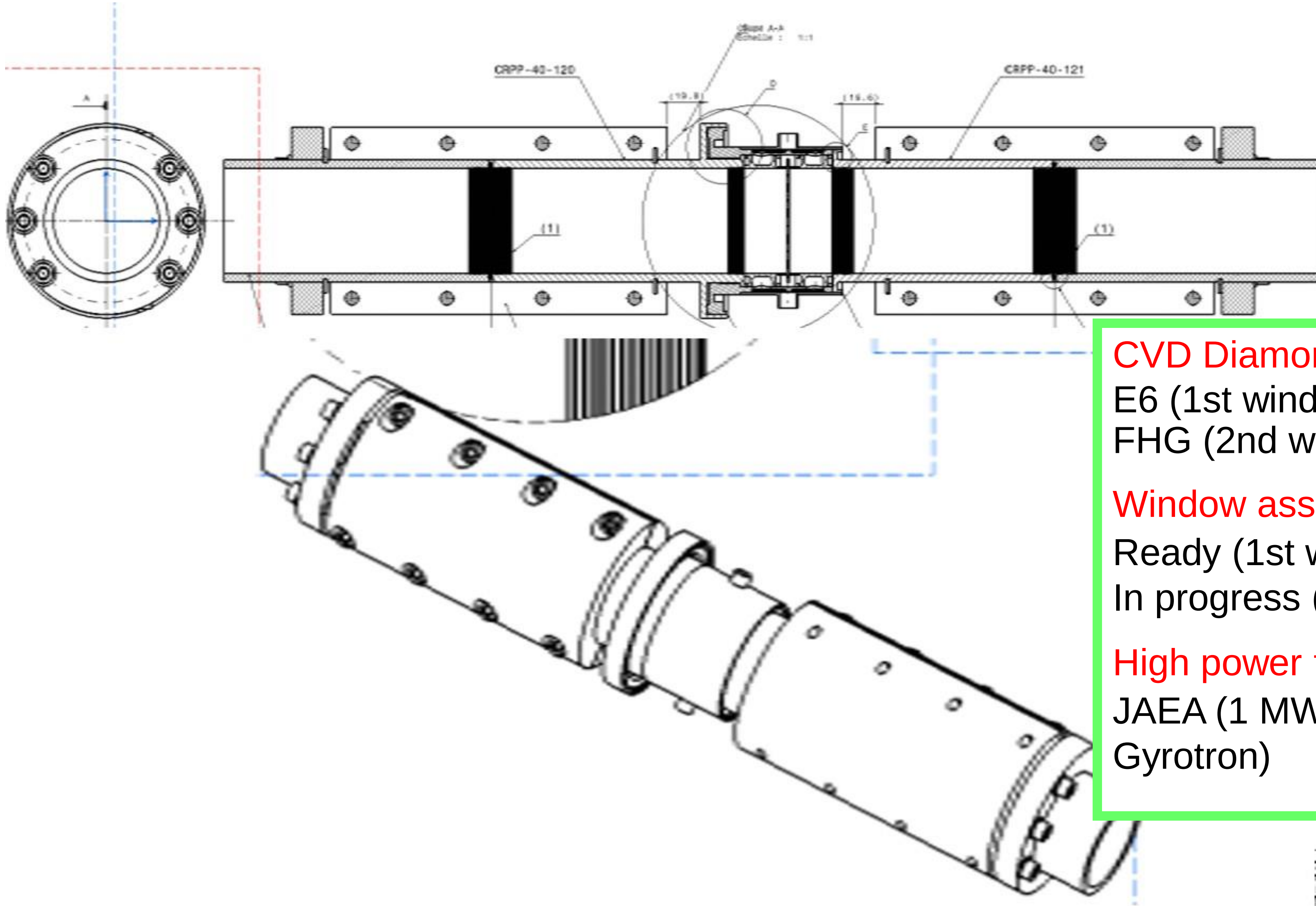
Power supply

→ RS - weld Head adaptation:

Outer Diameter: 230 mm → 130 mm

Weld Diameter: 144 mm → 114 mm

AMI / USA

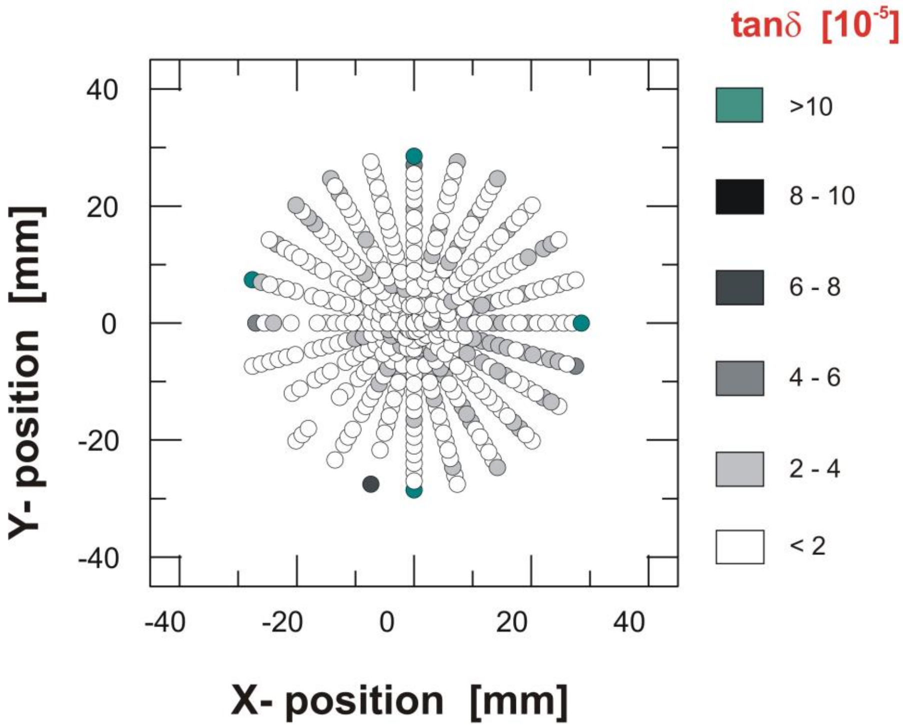


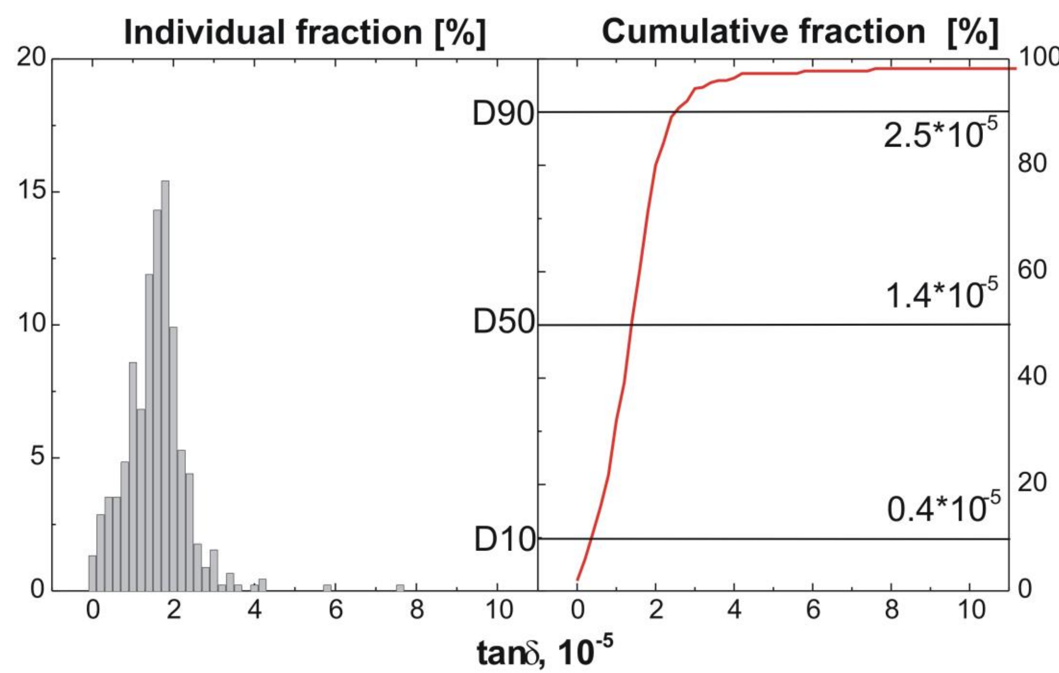
CVD Diamond disk:
E6 (1st window)
FHG (2nd window)

Window assembly:
Ready (1st window)
In progress (2nd window)

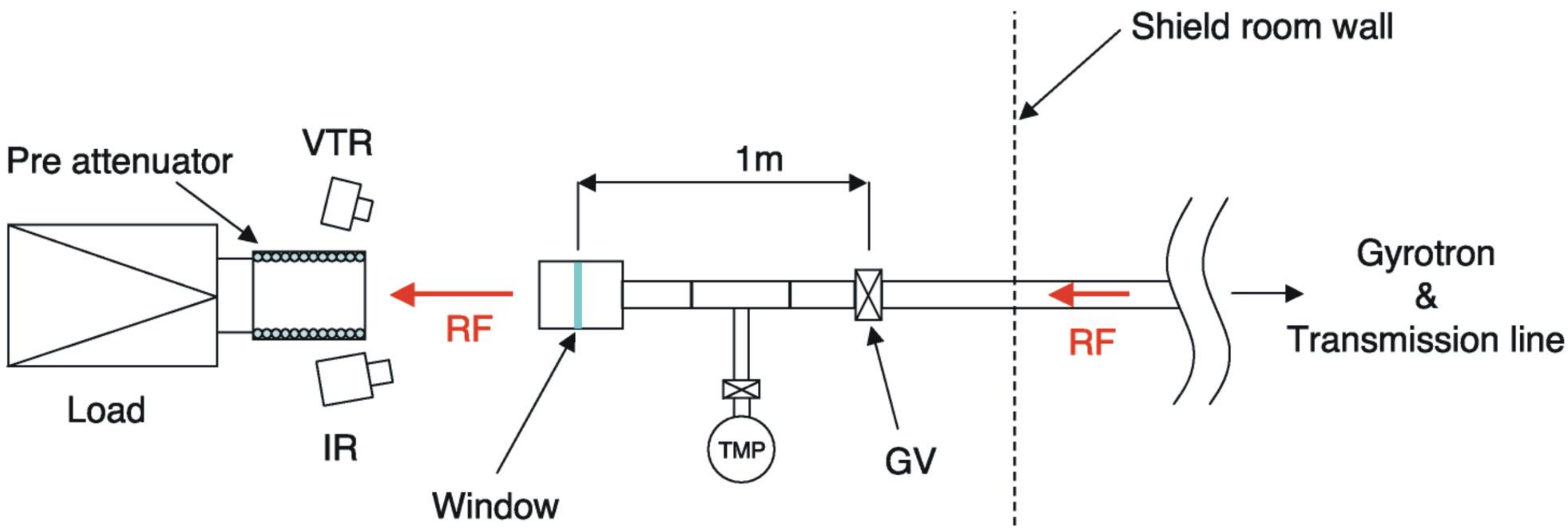
High power tests
JAEA (1 MW/170 GHz – Gyrotron)

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

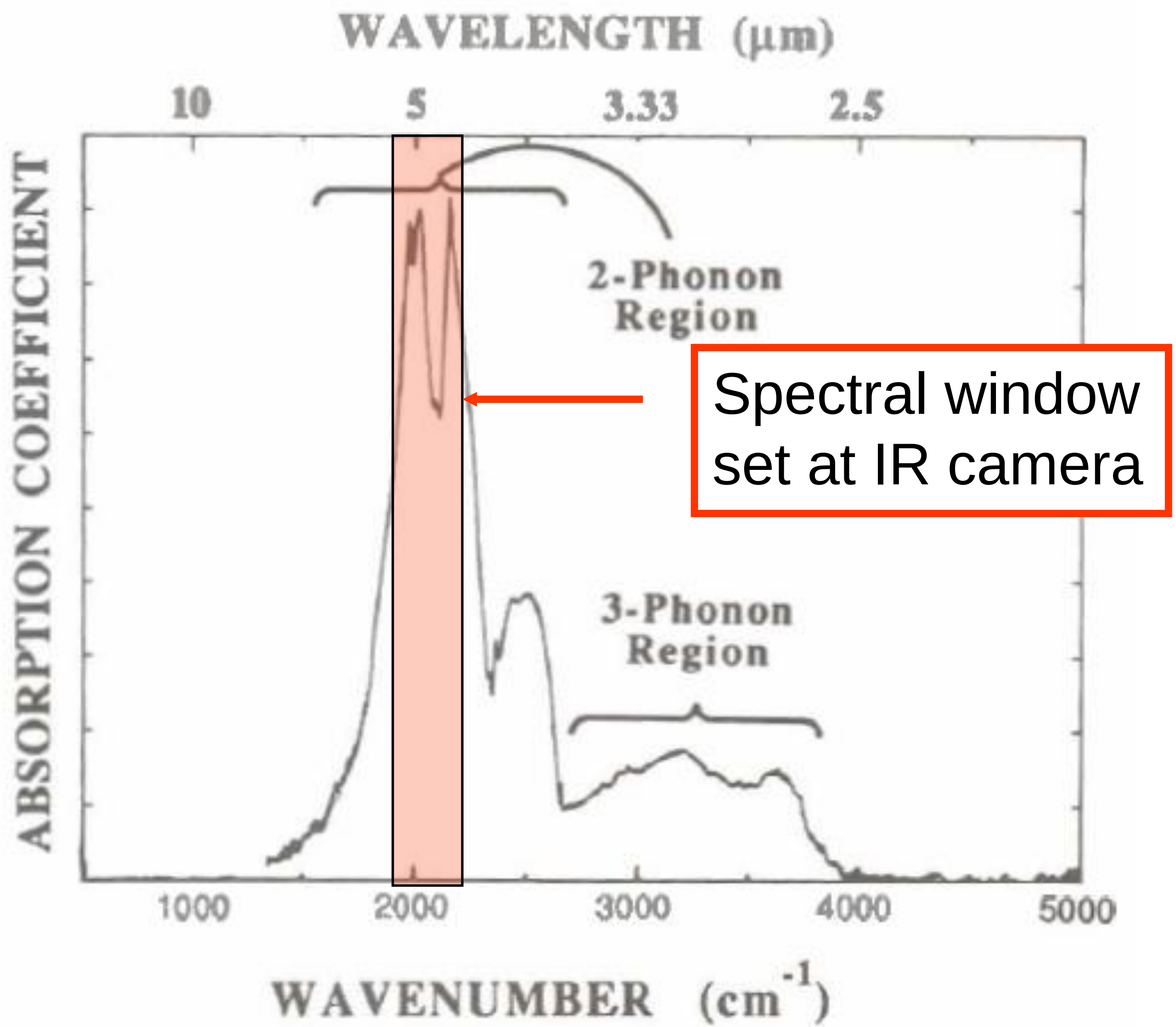




Setup for short-pulse CVD diamond window testing at 170 GHz/1MW gyrotron

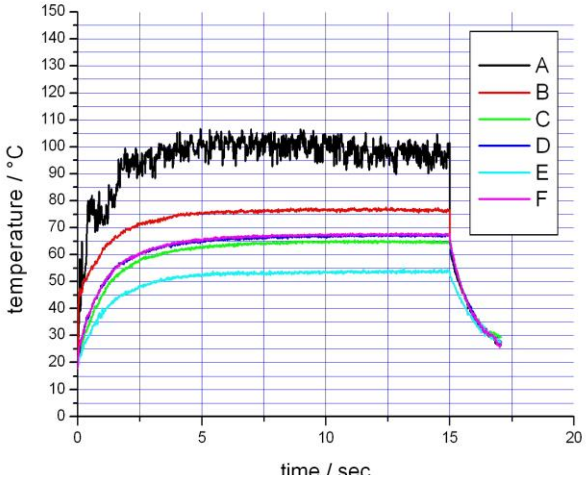


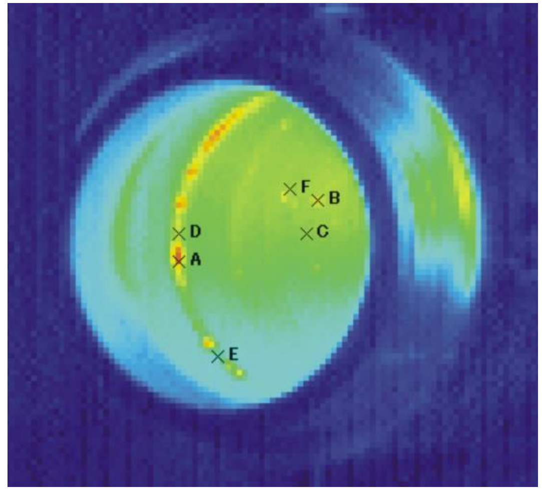
Wavelength aspects for IR window diagnostics



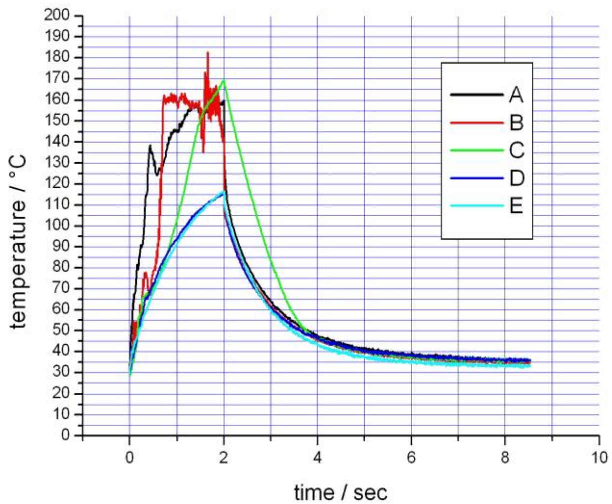
D. C. Harris, „Infrared Window and Dome Materials“, Vol. TT10, 1994

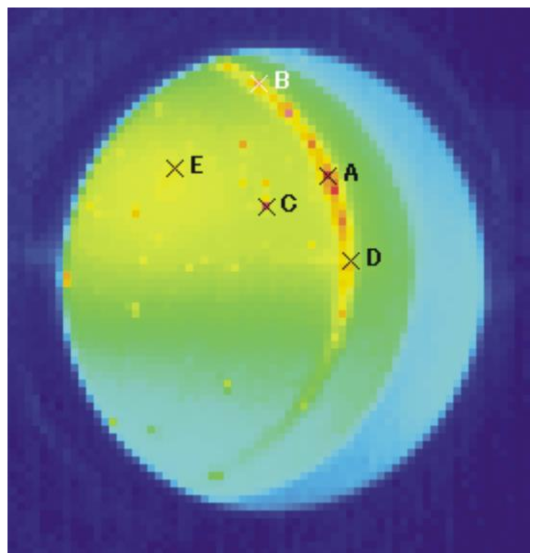
First window high power measurements at the 1 MW gyrotron facility in Japan (JAEA)





15.0 s
320 kW



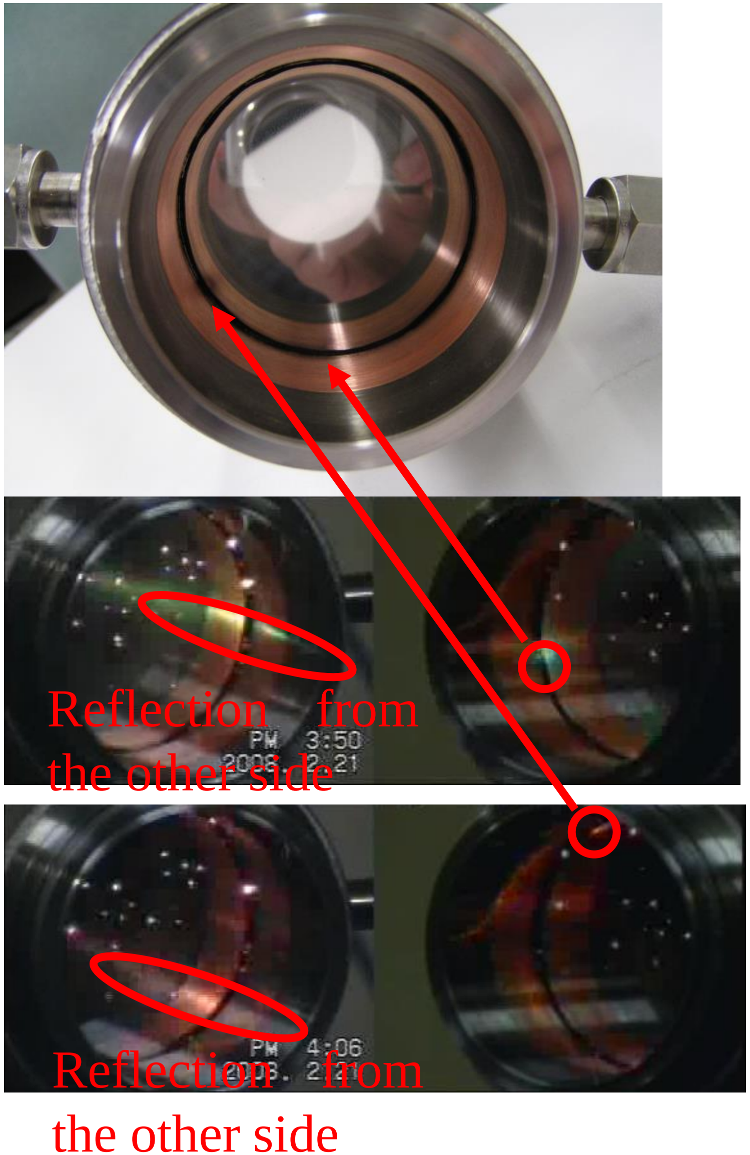


2.0 s
600 kW

Tests stopped

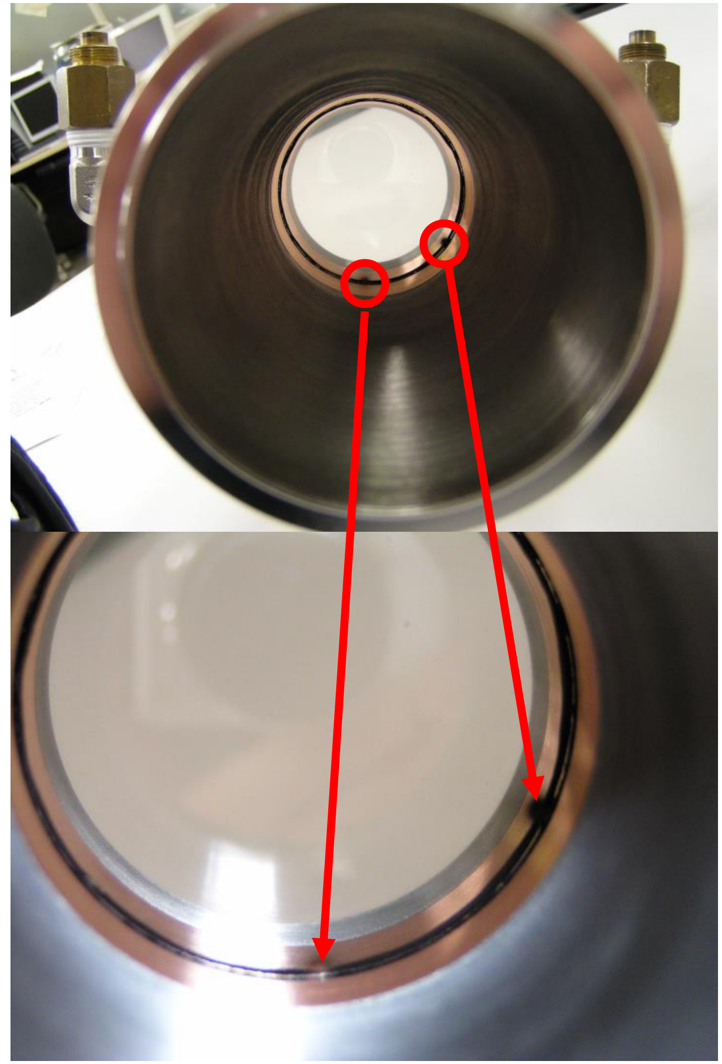
to re-work braze
to mitigate risks for
higher power failure

Brazing problem in the first window prototype

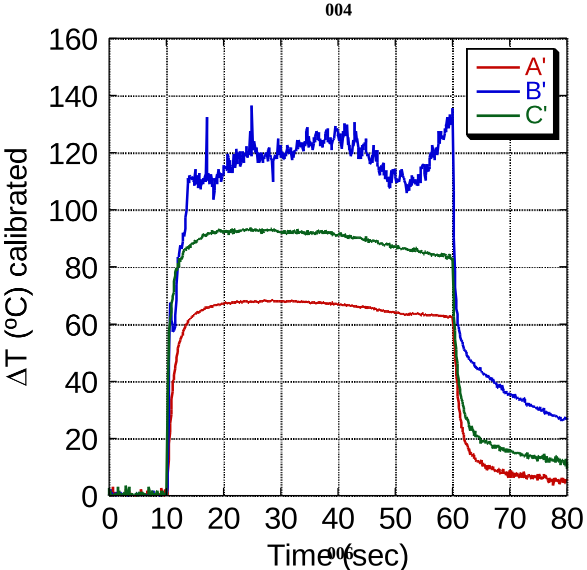


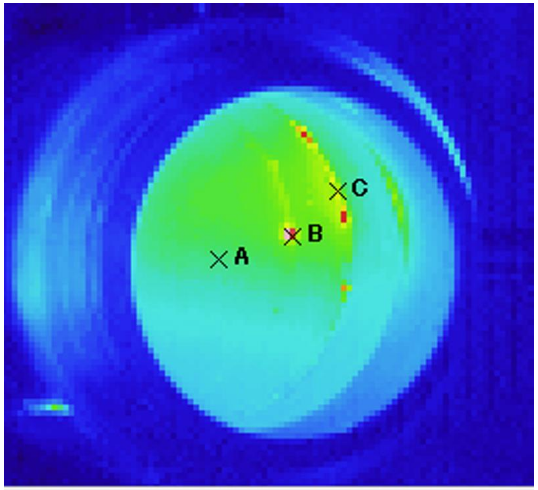
1.5 s

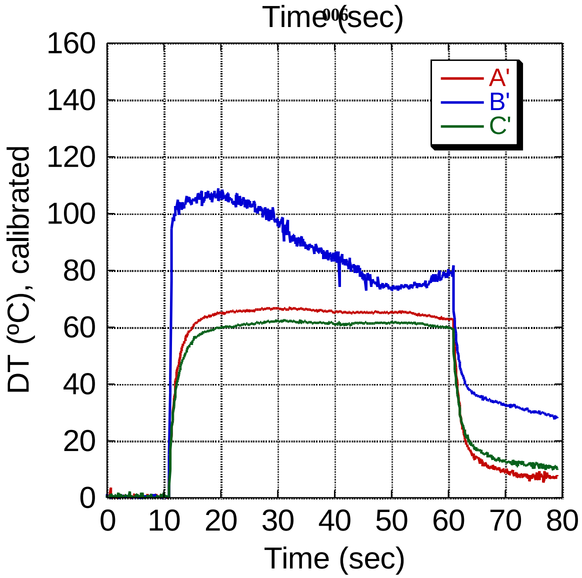
2.0 s

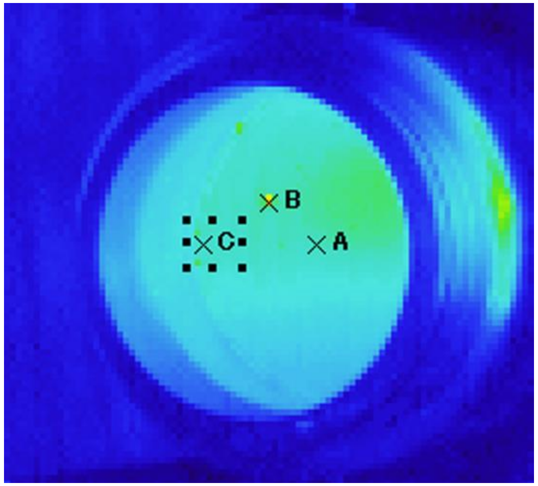


2nd sequence of high power measurements at the 1 MW gyrotron facility at JAEA





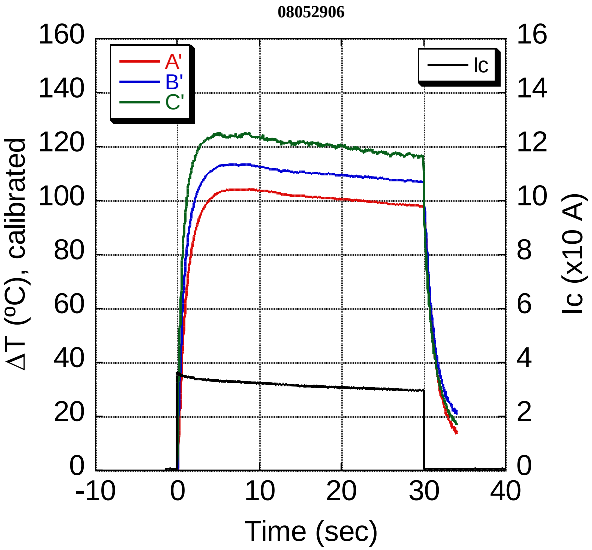


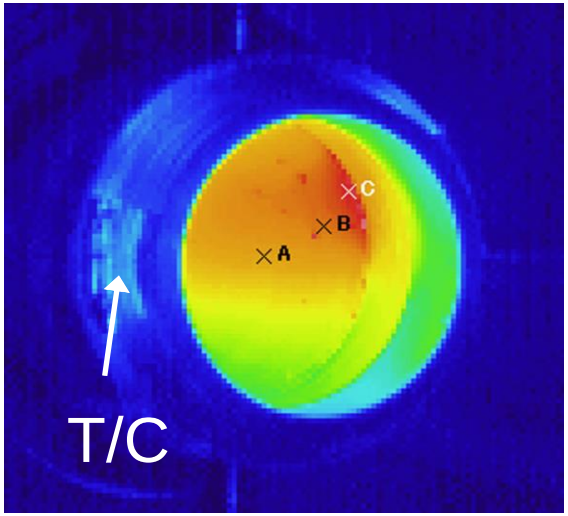


320 kW
50 s

Steady state regime attained

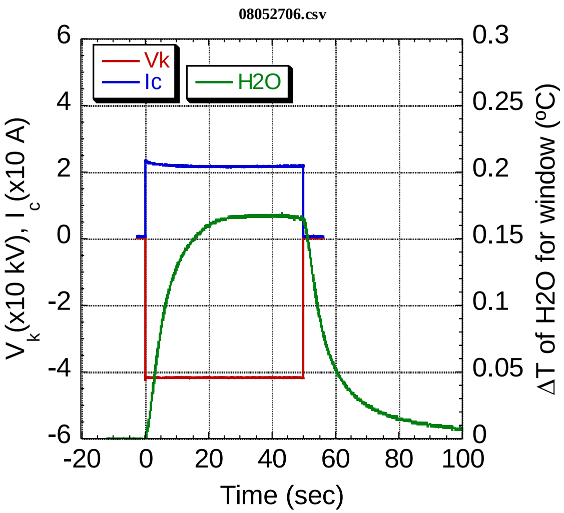
High power measurements at the 1 MW gyrotron facility in Japan (JAEA)





520 kW
30 s
T-Saturation

T/C measurement: housing

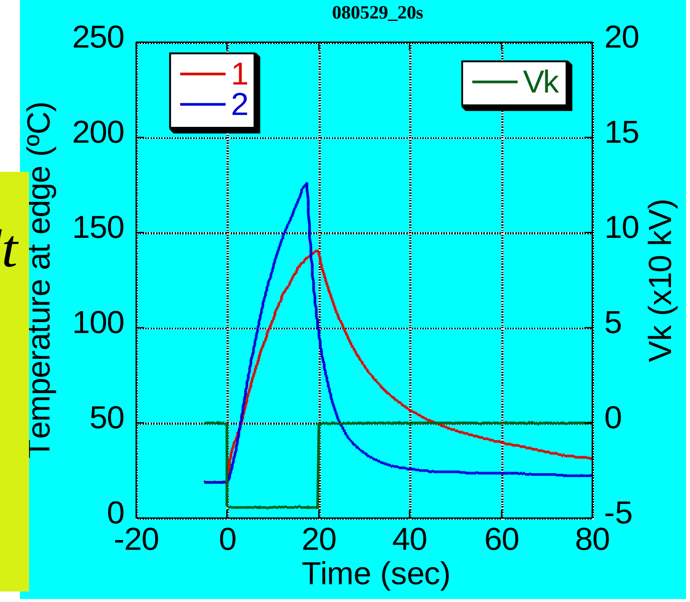


$$P_{diss} = 4.18 \cdot Q_{aq} \cdot \frac{dT}{dV \cdot \tau} \cdot \int_0^{\tau} \Delta V \cdot dt$$

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

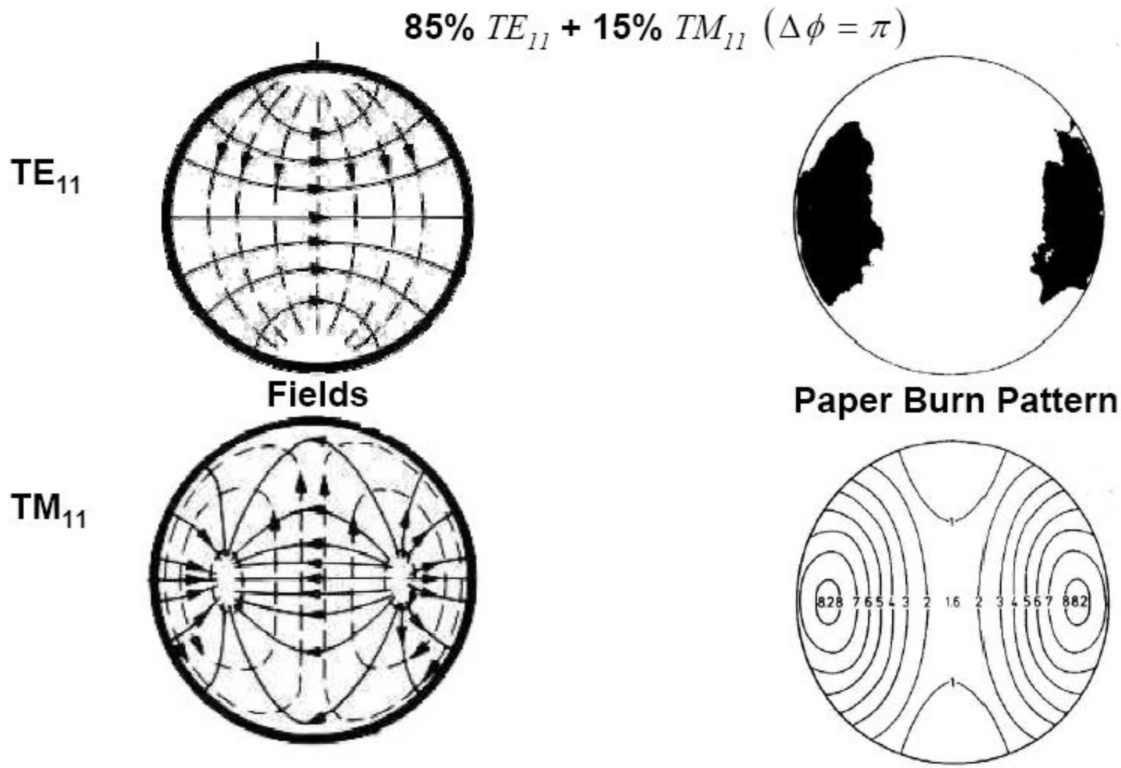
$$P_{diss} \approx 100\,W \quad ;$$

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



Extrapolation limits for ITER window operation

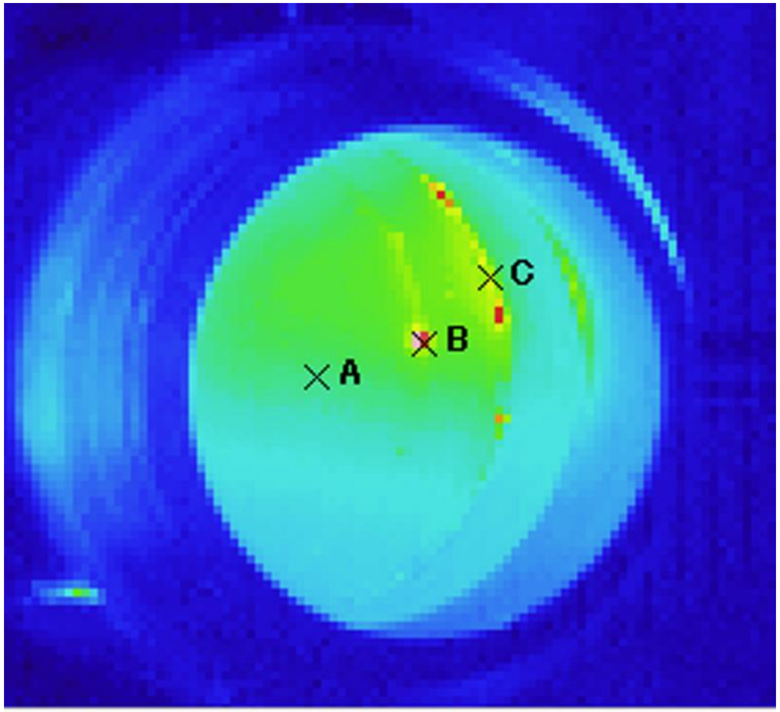
Example for Asymmetry caused by higher mode contents

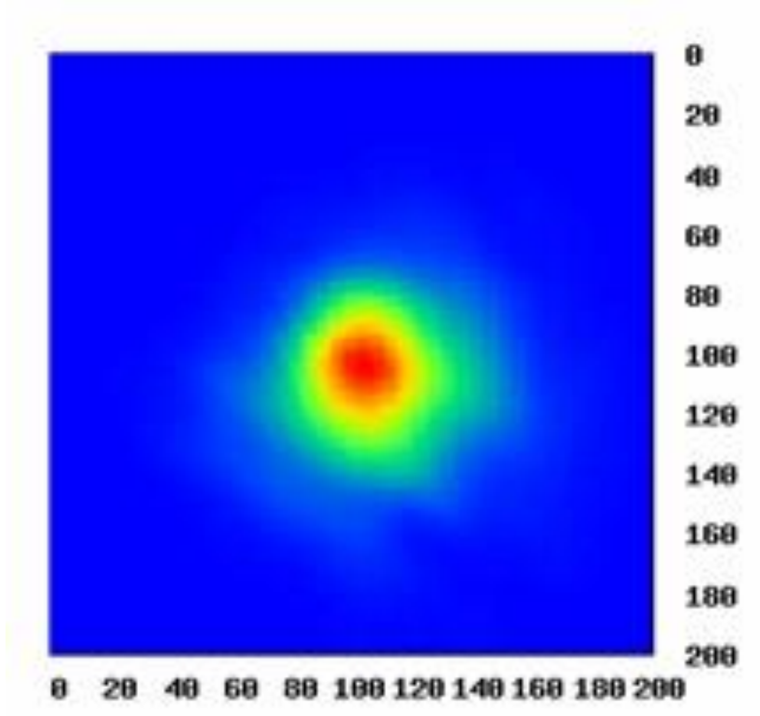


By courtesy of Prof. Thumm (IHM-FZK)

- Beam profile not purely Gaussian (several miter bends in TL)
- Non radial symmetric temperature distribution
- Non radial symmetric distribution of the electrical field

Impacts



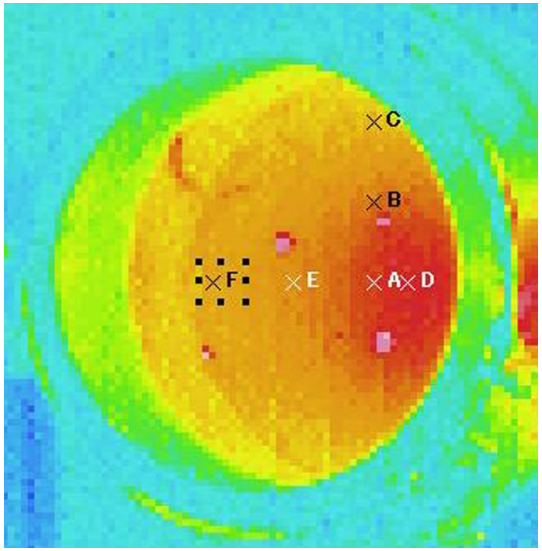


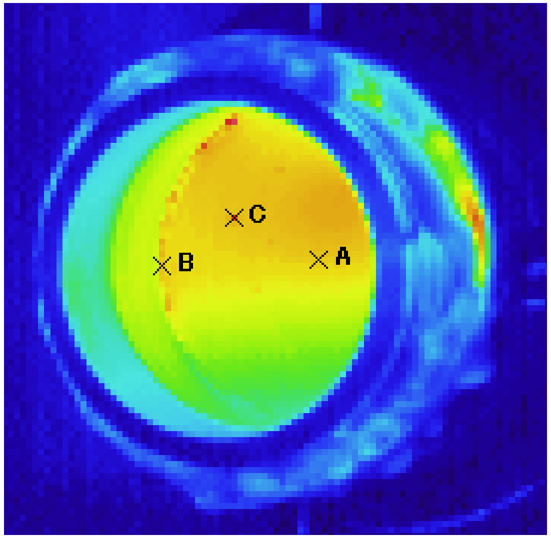
Observation of „Parasitic cavities"

Beam correction (MOU)

Impacts

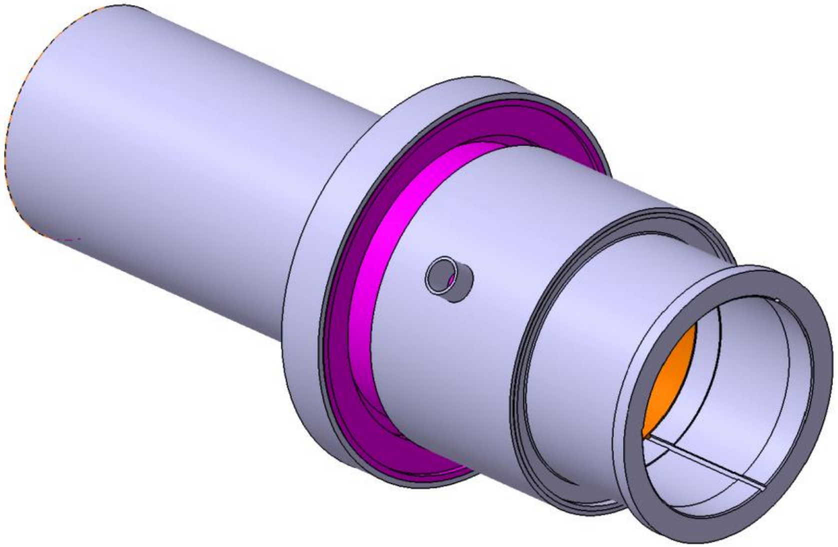
Temperature distribution:
The region of high temperature increase shifted toward the center compared to the previous experiment!

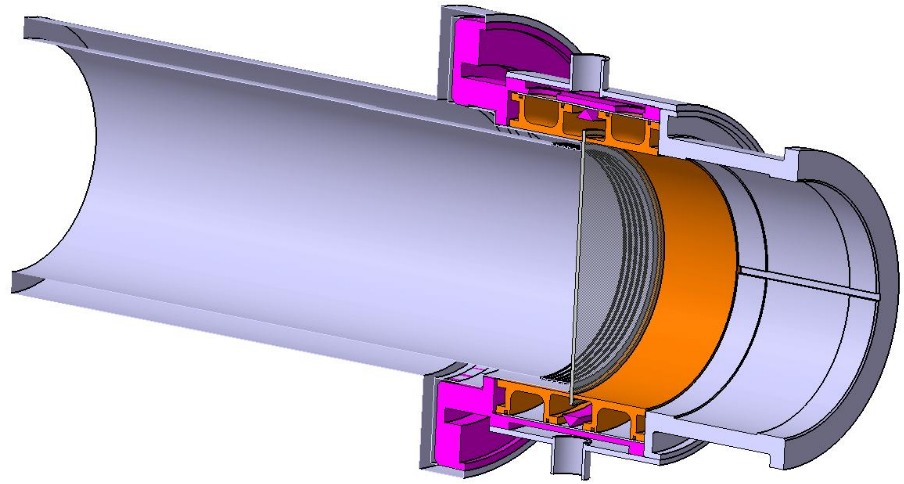


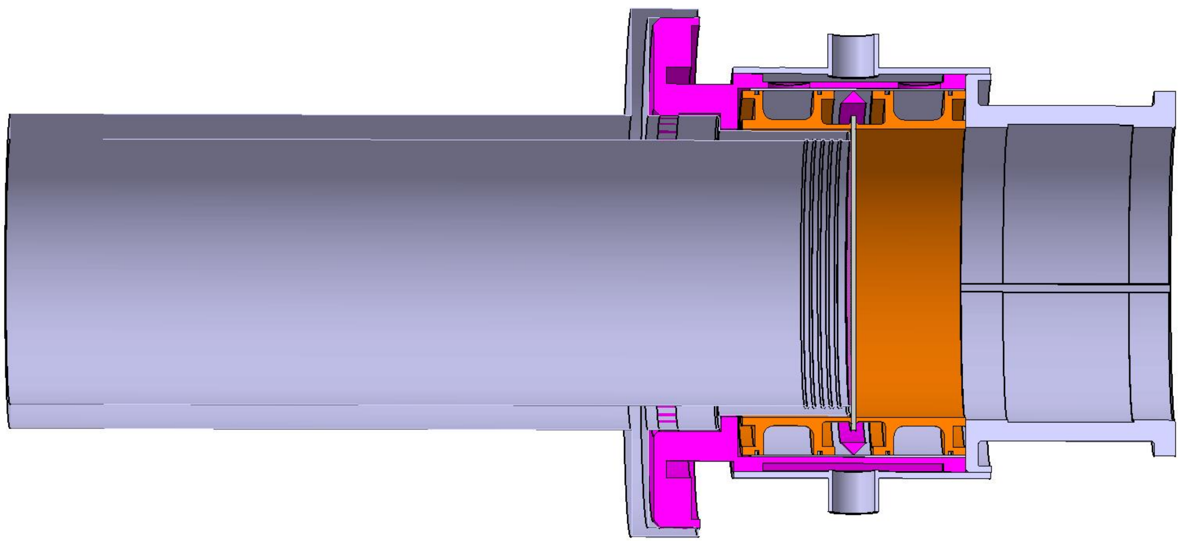


245 kW at 15 sec **320 kW at 20 sec**

Window with WG insert







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