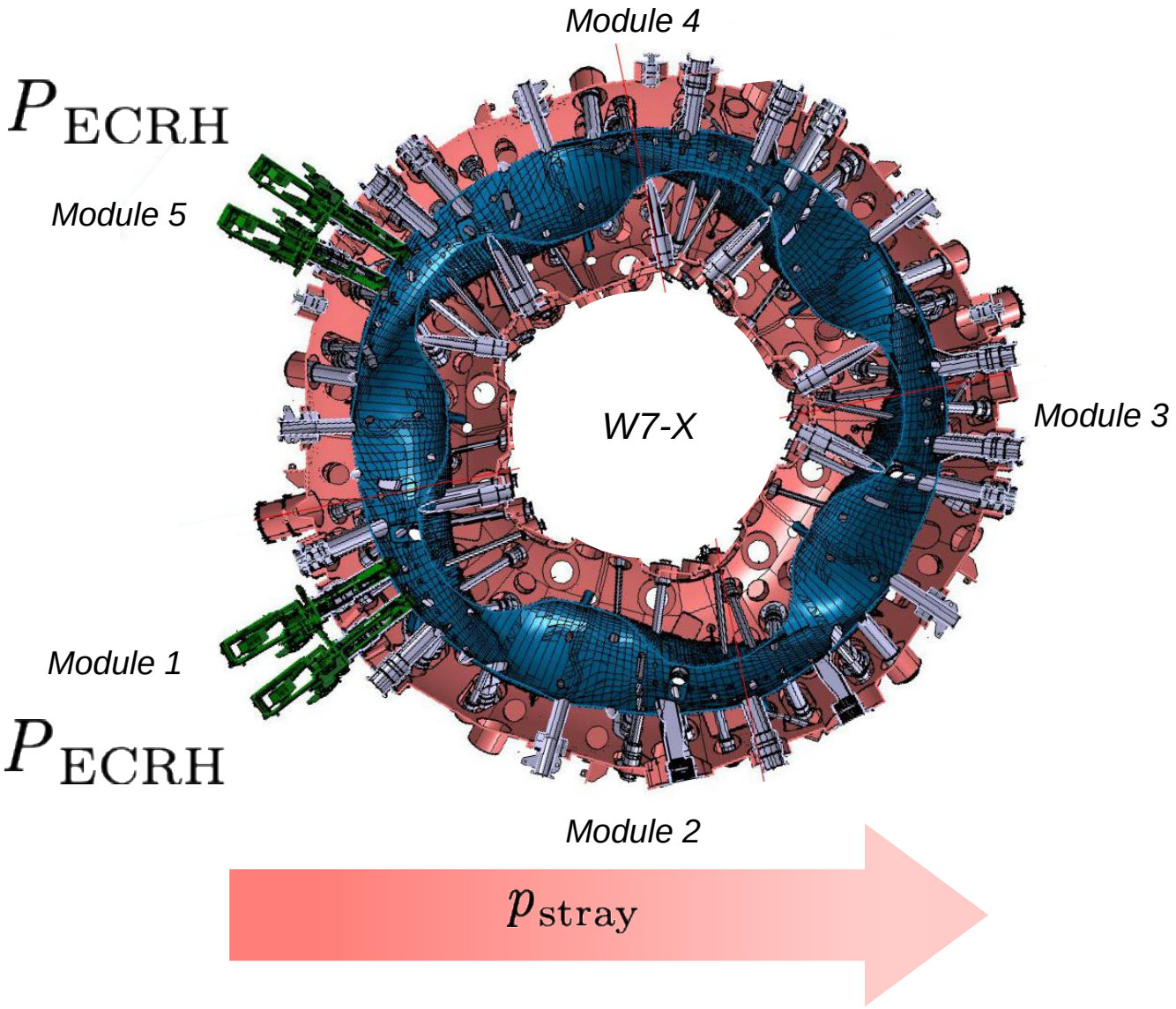
Update Stray Radiation activities W7-X in support of WPSA

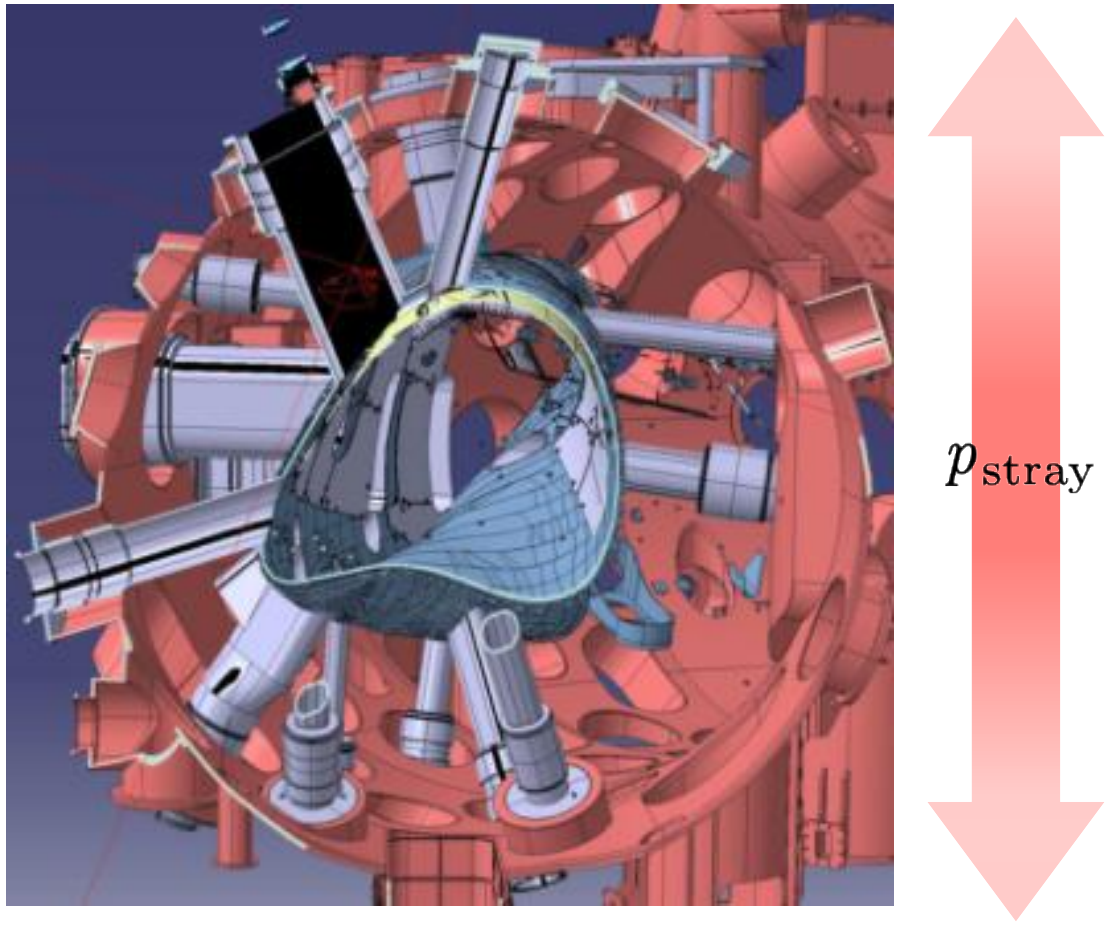
Hans Oosterbeek, Saul Garavaglia, Jakob Brunner, Heinrich Laqua, Mathias Stern, Torsten Stange, Jonas Zimmermann

Max-Planck-Institut für Plasmaphysik, Teilinstitut Greifswald, Wendelsteinstrasse 1, 17491 Greifswald, Germany

2025 WPSA Enhancement Projects Progress Meeting
Meeting 1 of 3, Thursday, 10th July 2025, per VC

Recap: non-absorbed ECRH *P* [W] ➔ Stray rad. *p* [Wm^{-2}]



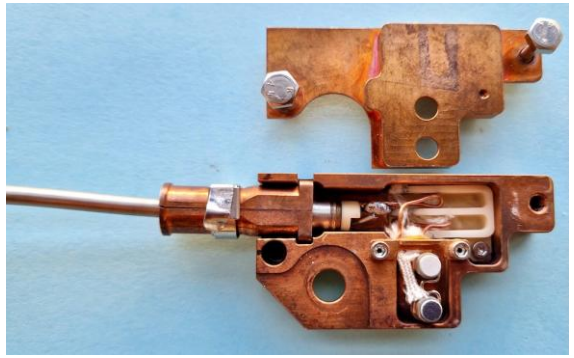


2025: EC Stray detection system design and procurement

WPAS activities at W7-X 2025

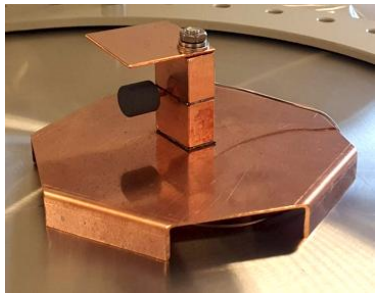
Collect and evalute bolometer sensor data on W7-X OP2.3(1)

(1) September 2024 – May 2025

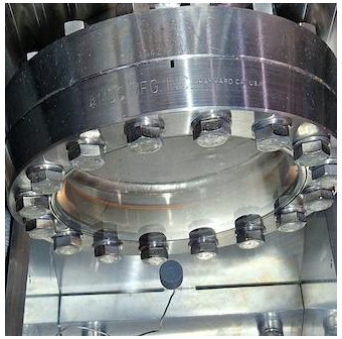


Outstanding practical issues with IO proto-type tested in MISTRAL 2023(2).
Not installed in-vessel OP2.3

Alternative: single bolometer bodies inside and outside W7-X



Microwave bolometer **inside** AEM51

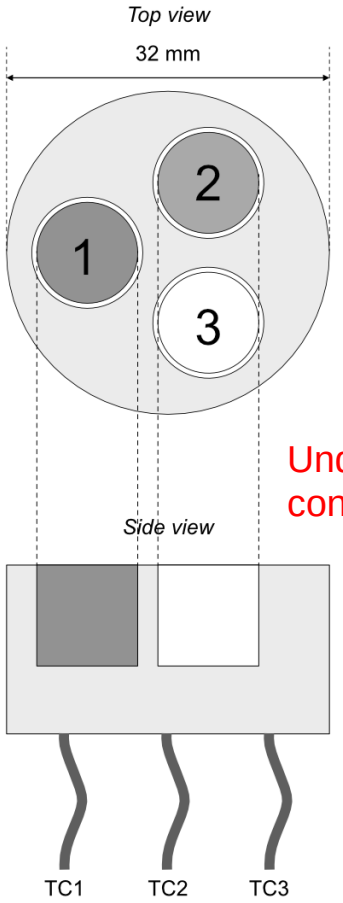


Microwave bolometer **outside** AET10

Microwave bolometer **outside** AEN40

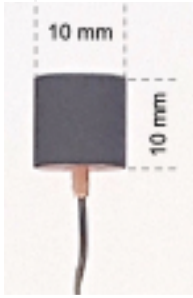
(1) J.W. Oosterbeek et al., Microwave stray radiation measurement techniques, Fusion Engineering and Design Volume 215, June 2025, 114967

Holder with 3 separated bodies: MISTRAL 2026



Coatings AlO_3/SiO_2 (87%/13%):
1. 150 µm (140 GHz)
2. 120 µm (170 GHz)
3. none (‘cold bolometer’)

‘Standard’ microwave bolometers used.



Under review: tune response using conduction term. Bonus: fixture

In FPGA obtain:
- TC1 – TC3: stray rad. at 140 GHz
- TC2 – TC3: stray rad. at 170 GHz,

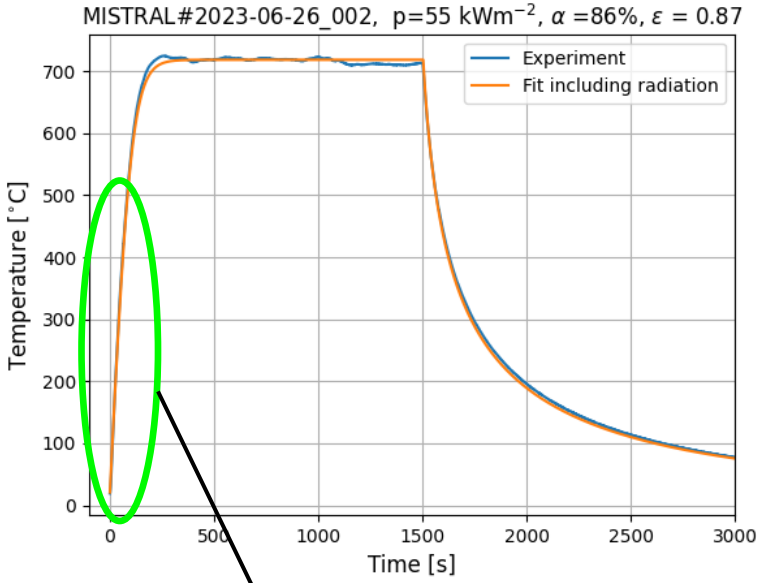
while correcting for calibration

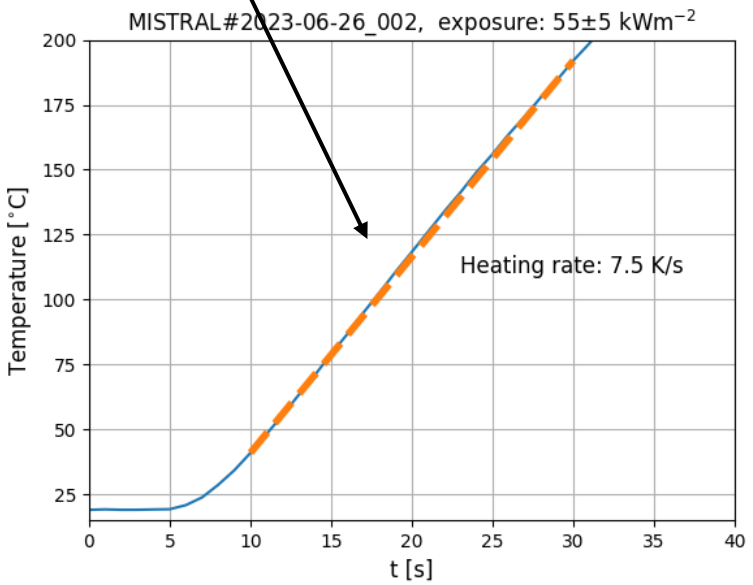
Recap: microwave bolometers

$$\frac{\Delta T}{\Delta t} = \frac{p\alpha S}{mc_v}$$

Absorbed power

Heat capacity





Including radiation[1]:

$$\frac{\Delta T}{\Delta t} = \frac{p\alpha S - \sigma S\epsilon\left(T^4 - T_s^4\right)}{mc_v}$$

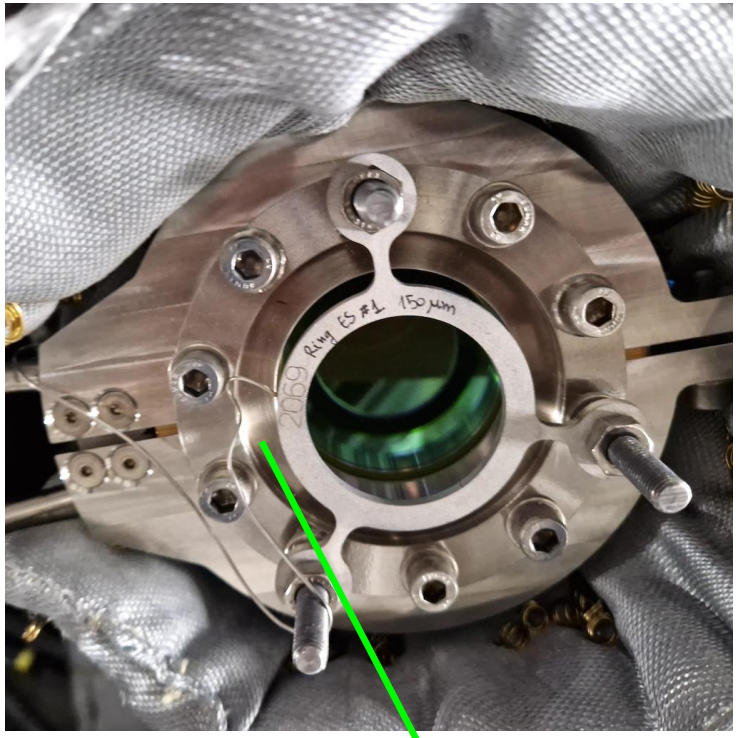
[1] N. Maassen et al., Microwave detector: design for ITER. Technische Universiteit Eindhoven, 2014.

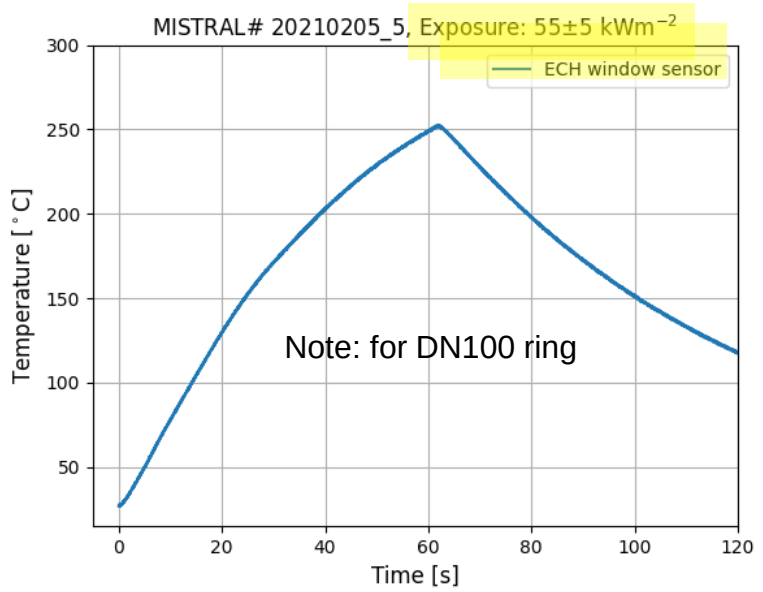
Exposure: $55\ kWm^{-2}$
Heating rate: $\dot{H} = 7.5$ K/s

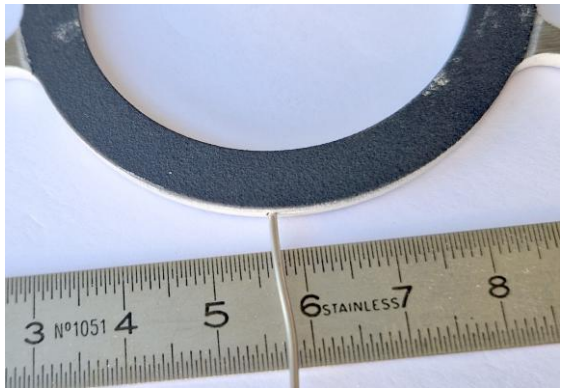
Calibration this bolometer:
$C = \frac{55}{7.5} \approx 7.3\ \left[\frac{kW \cdot s}{m^2 \cdot K}\right]$

$p = 7.3\dot{H}\ [\mathrm{kWm^{-2}}]$

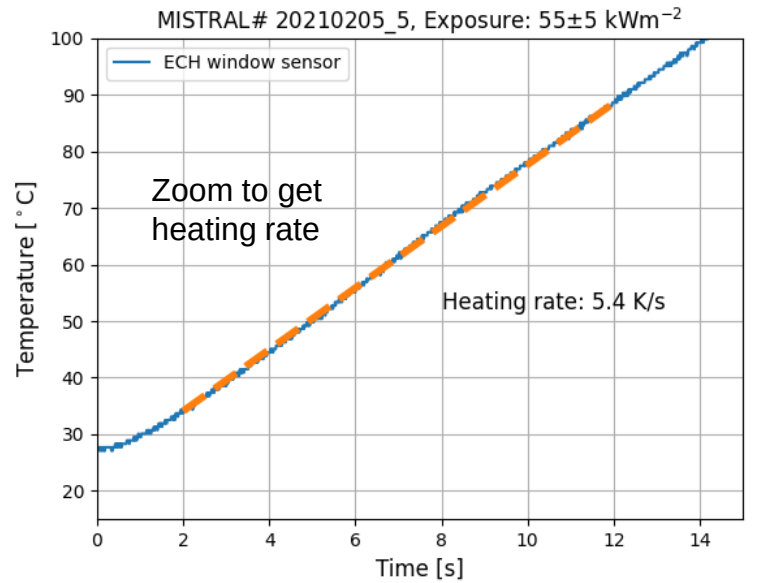
Recap: ECH window sensors[1]







Heating rate measured with thermo-couple ~ 4 mm inserted as with bolometer

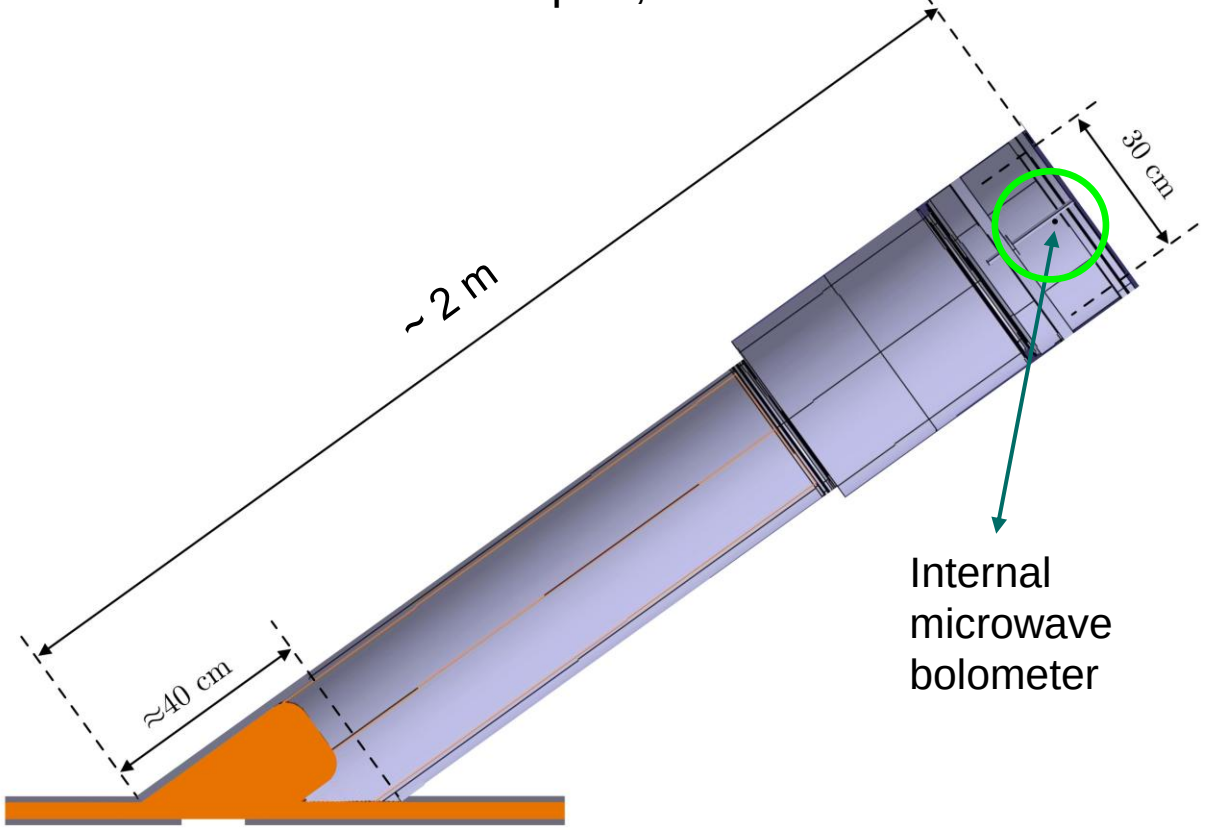


[1]*Conceptual design by ITER: S. Pak and R.J. Zubieta-Lupo.*

Gratitude to Beate Kursinski and Jens Knauer for manufacture and integration at W7-X

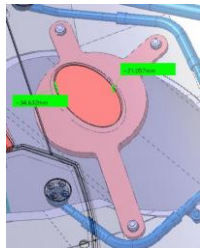
Ports close to ECRH launchers

AEM51: non-used port, INTERNAL bolometer



Internal microwave bolometer

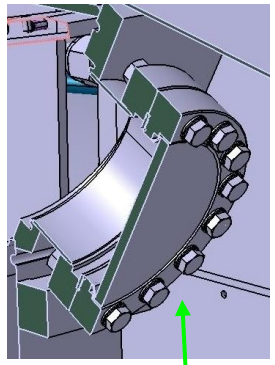
Plasma

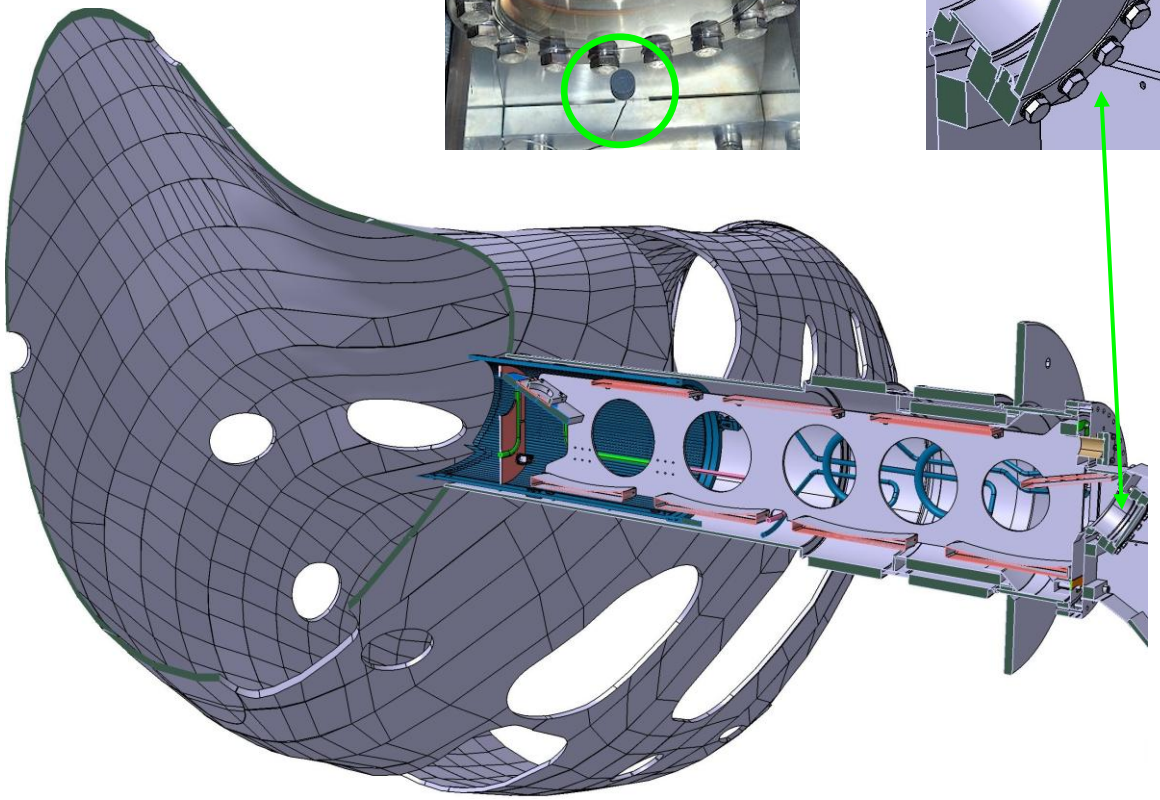


Cover plate with spacing: Measurement effectively behind tiles and vessel wall

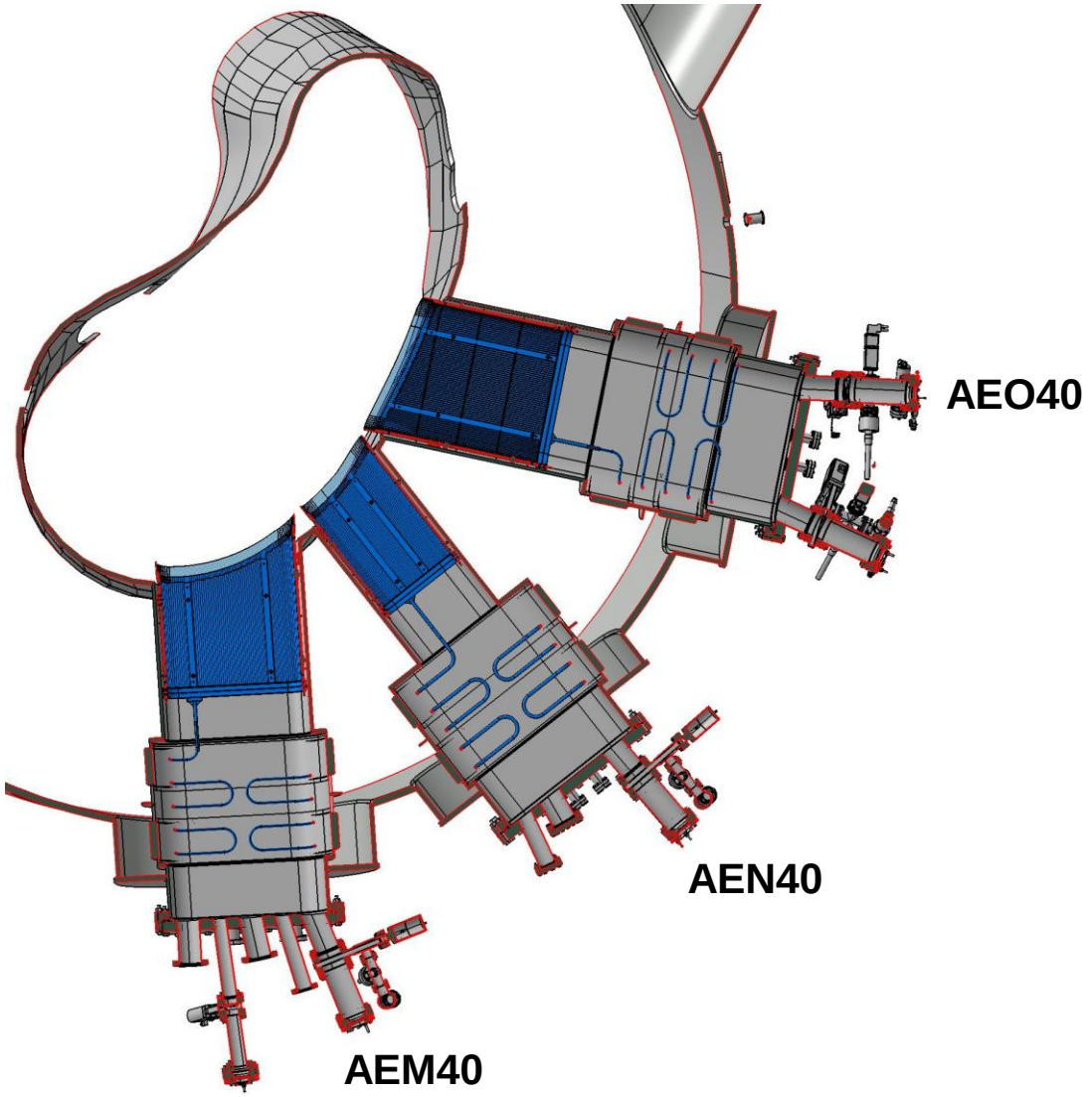
AET10: CTS Antenna, EXTERNAL bolometer

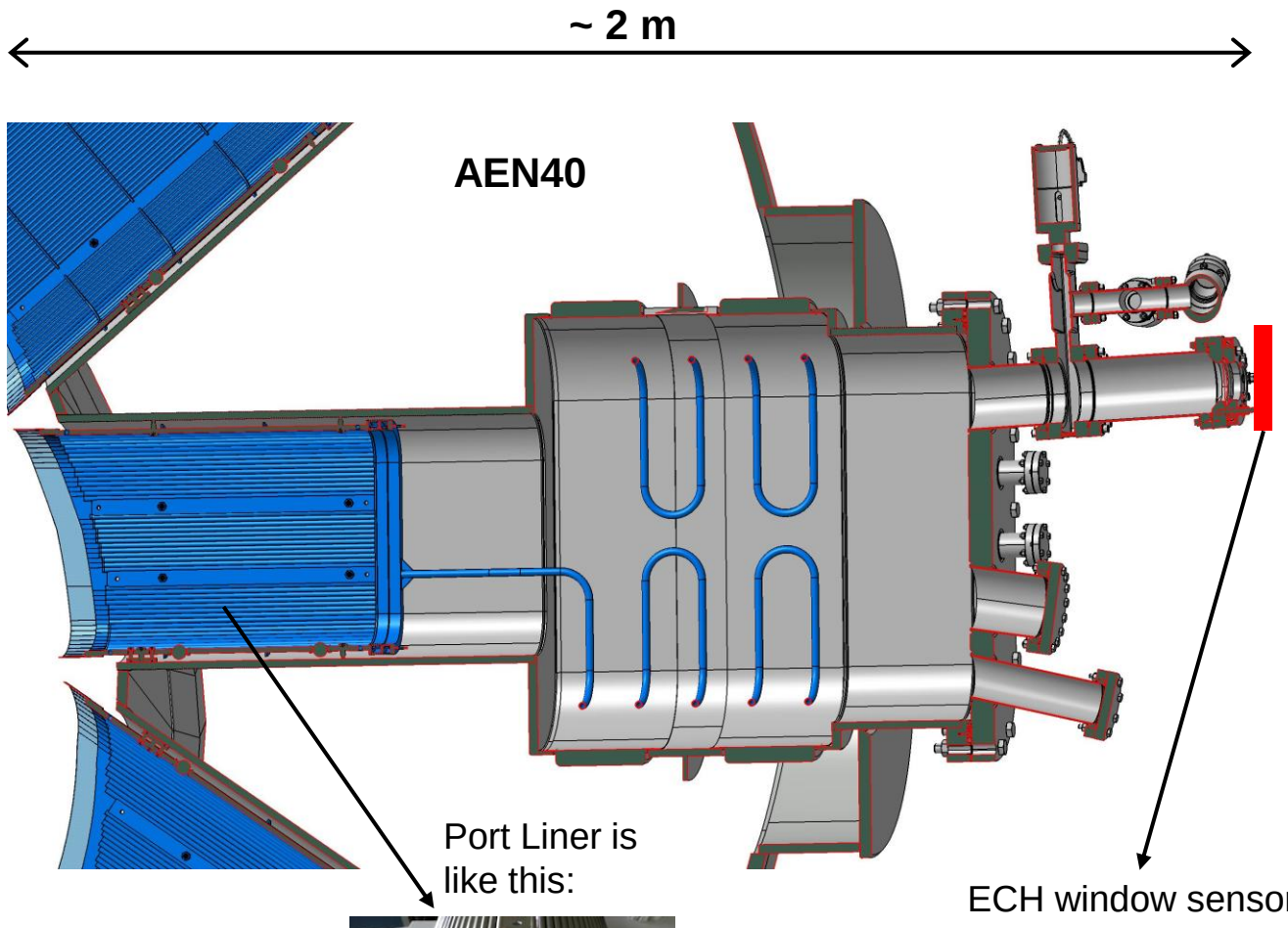
External microwave bolometer





Ports away from ECRH launchers





Measurements 22.05.2025: AEM51, AET10, AEN40, AEM40

- TO BE UPDATED

Plasma parameters for 20250522.047

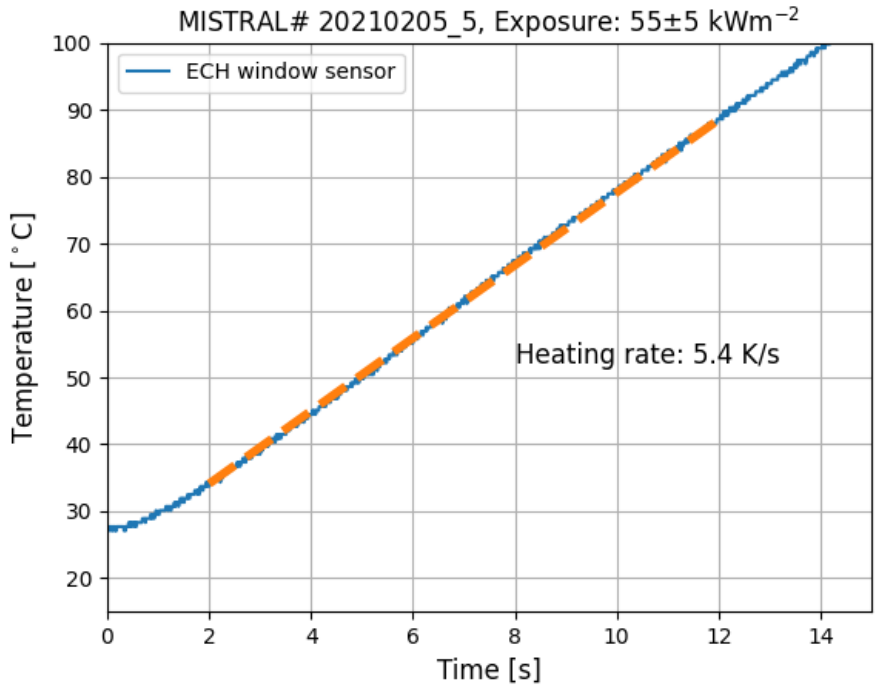
- TO BE UPDATED

Stray rad. from bolometers AEM51 and AET10 for #47

- TO BE UPDATED

Stray radiation from ECH window sensor AEN40 for #47

- TO BE UPDATED



Exposure: $55\ kWm^{-2}$
Response: $\dot{H} = 5.4\ \mathrm{K/s}$

Calibration this bolometer:
$\mathrm{C} = \frac{55}{5.4} \approx 10\ [\frac{kW \cdot s}{m^2 \cdot K}]$

$\mathrm{p} = 10\dot{H}\ [\mathrm{kWm^{-2}}]$

Note:

Curve above is for DN100 sensor, while DN64 was used. But as local bolometer surface is similar: expect small error only.
Exit calibration of DN64 sensor in MISTRAL 2026 campaign.

Summary WPSA activities 2025 – update summer

- **Evaluation of bolometer sensor data on W7-X during campaign OP2.3**
  - Microwave bolometer data inside vessel as well as on the outside of vessel: Good data, S/N fine, fully acceptable interference
  - ECH-window sensor data: data quality as for bolometers.
  - Dynamic range on W7-X:
    - Minimum detection ~ 100 Wm^{-2}
    - Maximum as tested on MISTRAL 55 kWm^{-2}, but could possibly be higher (no data set).
  - OBSERVATION: significant reduction of stray radiation at the end of long ports, in modules away from ECRH launchers. Example presented: modules 1,5 versus module 4. Ratio ~ 1:50

- **Differential ECH-sensor development**
  - Sensor holder for 3 ‘standard’ bolometer bodies.
  - Each bolometer has its own thermo-couple:
    - The difference signal between two bodies with different coatings is proportional to stray radiation only, other heating terms cancel.
    - Absolute temperature available: allows correction for radiated power.
    - To be tested in MISTRAL 2026