The WEST IR machine protection system

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on behalf the
WEST Team

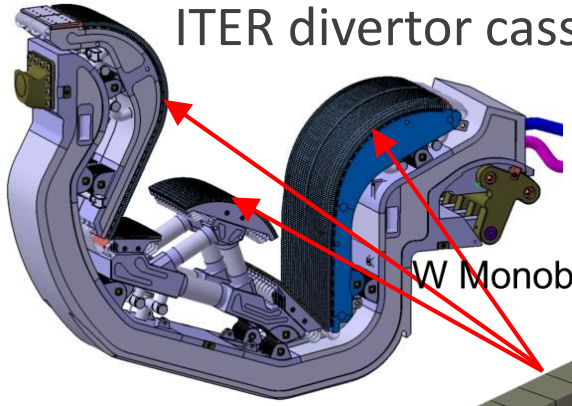
29/03/2022

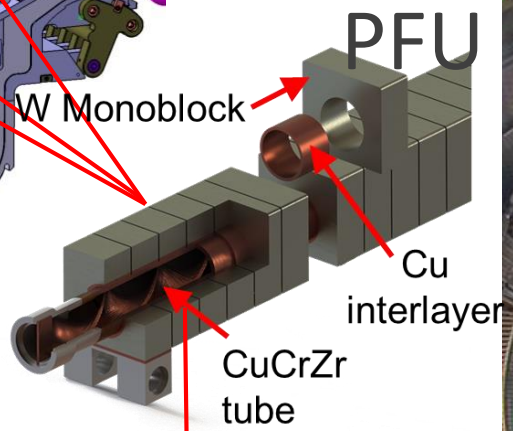
Outline

- Context
- IR system of WEST
- Wall monitoring system
- Prediction/experiments and Machine Protection
- Preliminary summary of the WEST IR machine protection
- Next steps

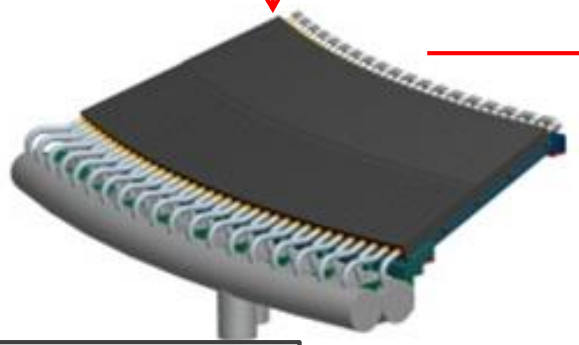
WEST: Actively cooled ITER-like Tungsten divertor

ITER divertor cassette

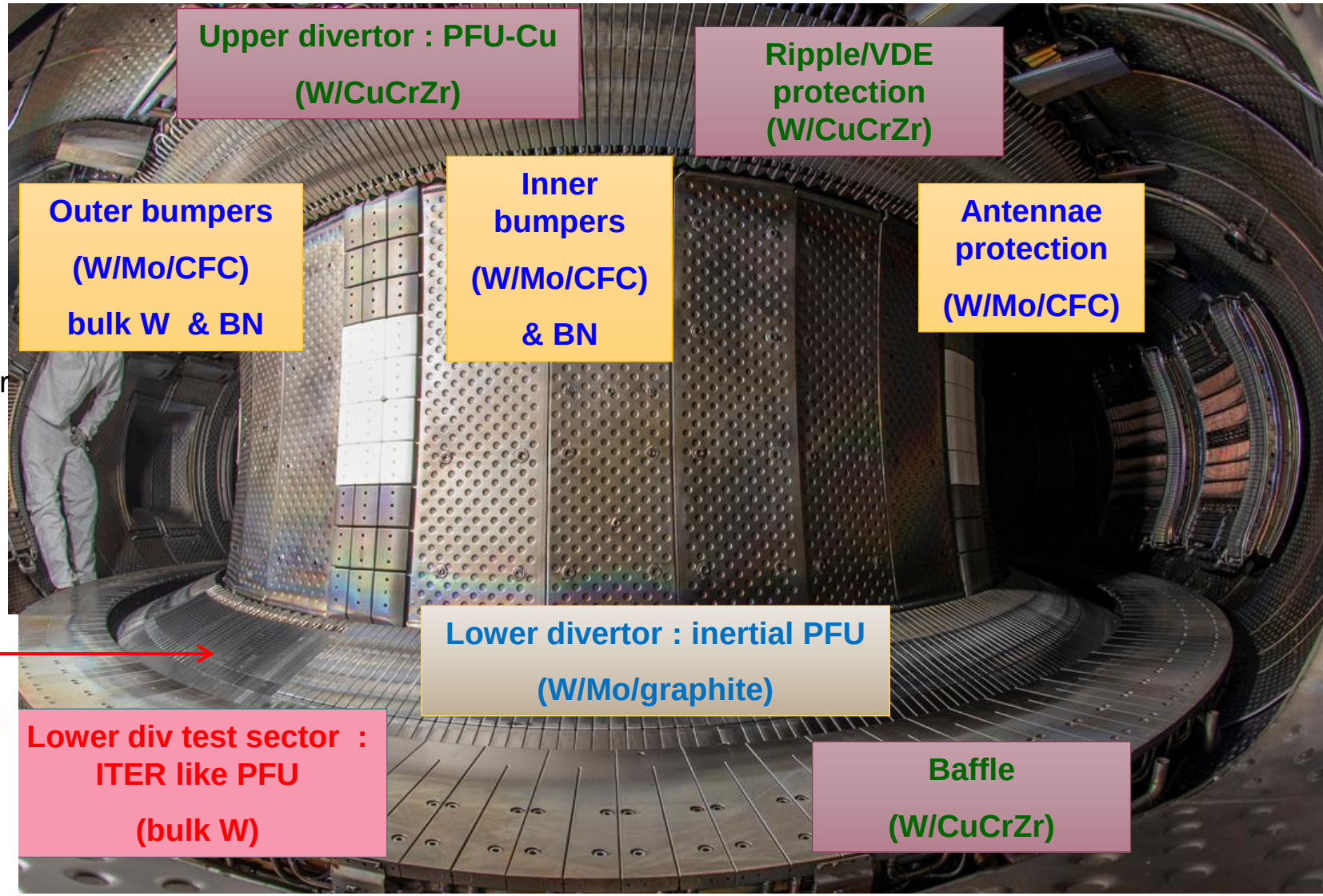




- 54 cassettes
- Actively cooled
- Should handle ~100MW
  - 10MW.m^{-2} Steady state
  - 20MW.m^{-2} Transient



WEST ITER-like divertor



Reliable power exhaust control scheme and wall protection system for fusion devices

Wall protection system for **Safety**
- Prevent PFC damage (Critical heat flux…)
- Detection of melting, Hot spots, deposits…
- Monitor PFC ageing (fluence, cracks…)

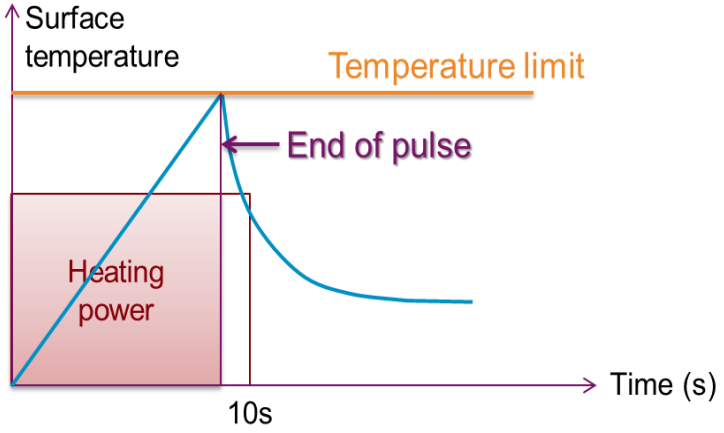
Physics activities: and consequently a reliable **Safety**
- Scenario developments: High heat flux high energy
- Heat load pattern, λ_q, ..
- Power deposition: W monoblocks, gaps, shaping…

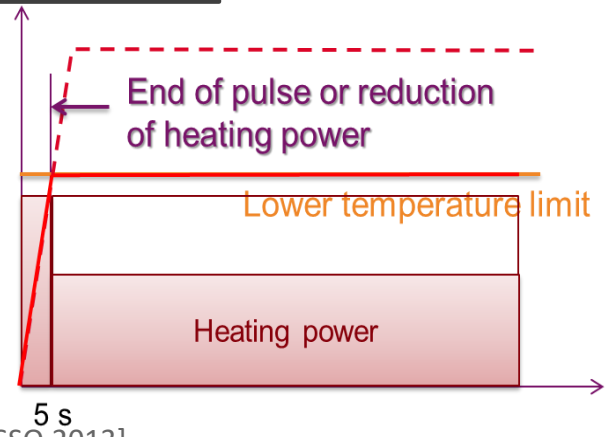
T_{surf}: Key parameter

- If T_{surf} is overestimated, ”safe” for machine, but no performance scenario
- If T_{surf} is underestimated, high performance but major risks for the device.

Active cooling brings specific issues :
- Limitation on performance, not only on discharge duration
- More severe consequences (water leaks, shutdown time)

Inertial PFCs

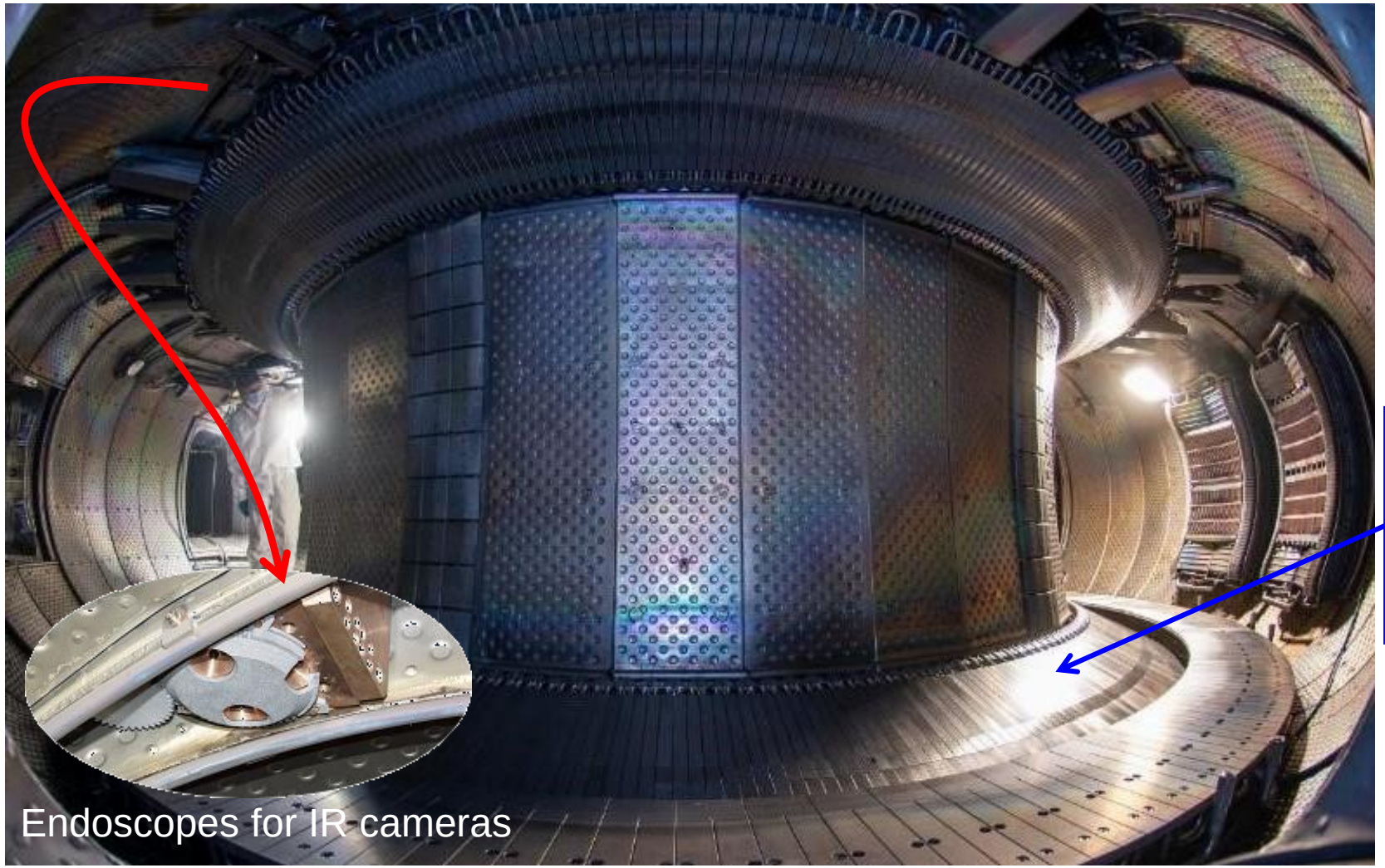




Actively cooled PFCs

[J. Bucalossi, IAEA TM SSO 2013]

WEST Phase 2: Full actively cooled lower divertor

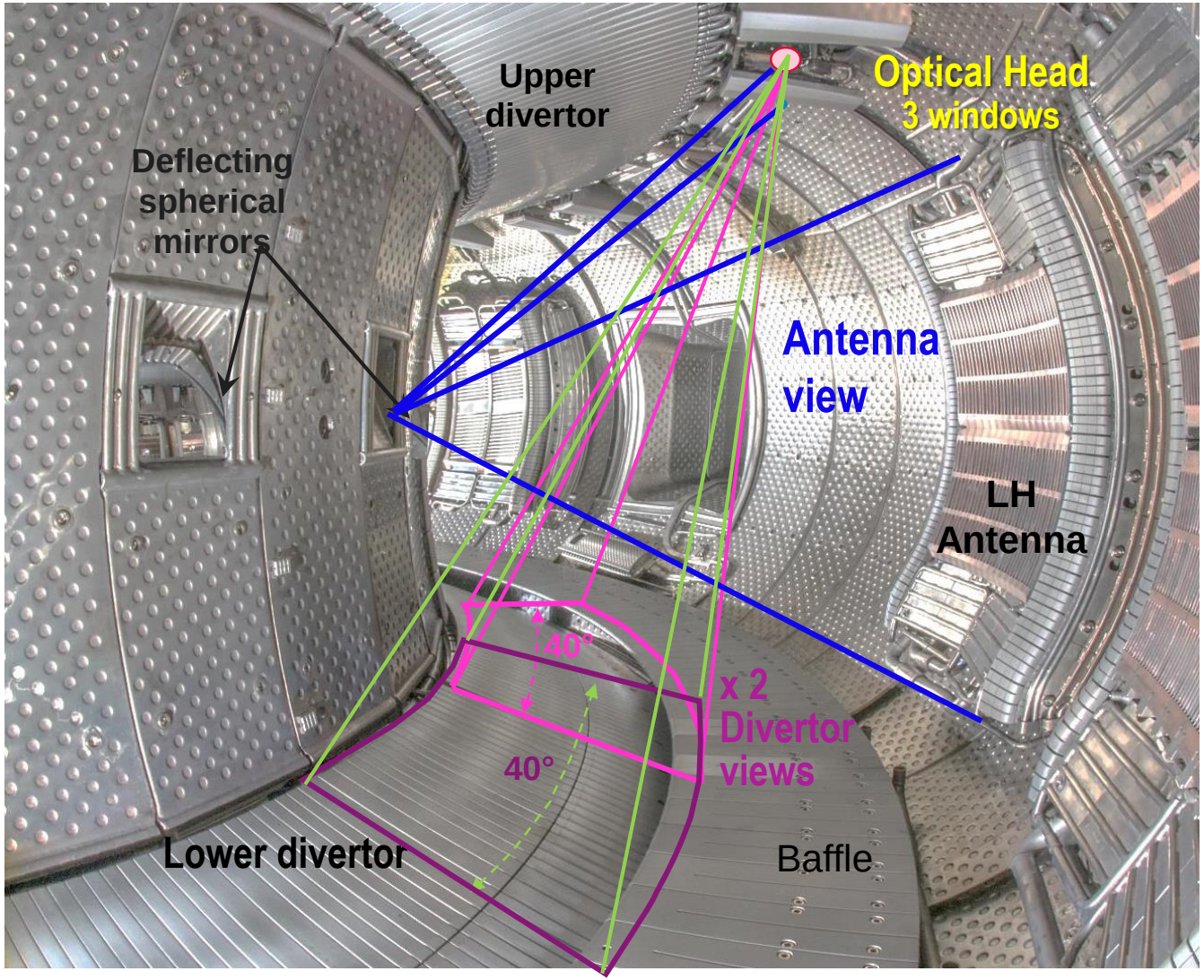


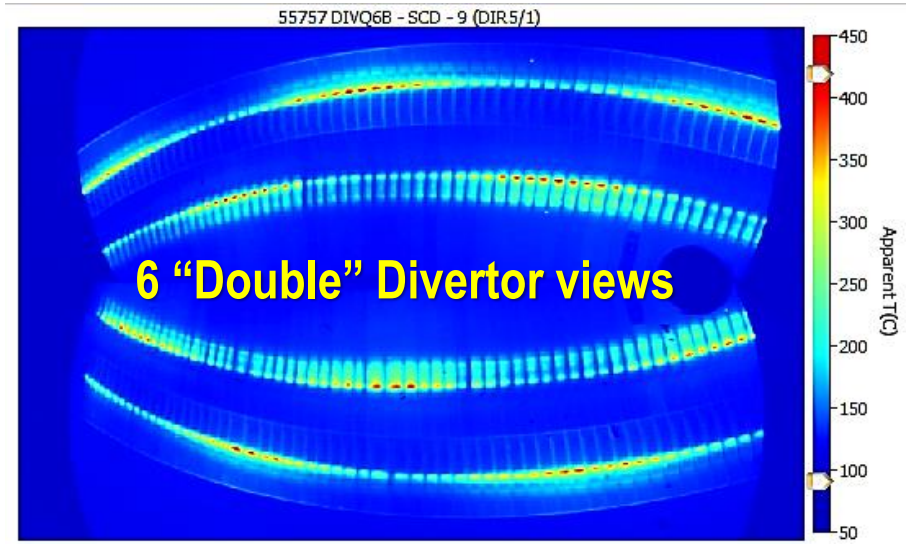
Fully actively cooled lower divertor

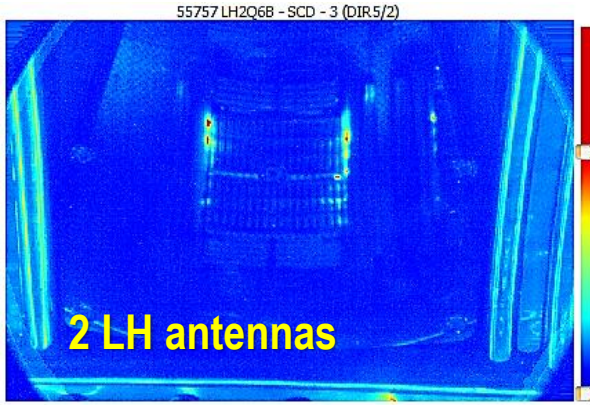
ITER like PFU

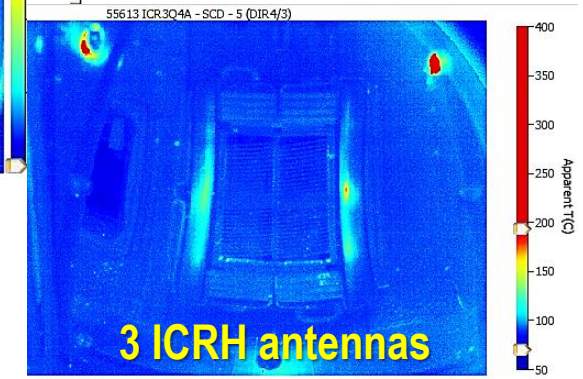
In WEST, all the plasma facing components are monitored by Infrared IR (1-5 μm) views

Endoscopes & Fields of VIEW



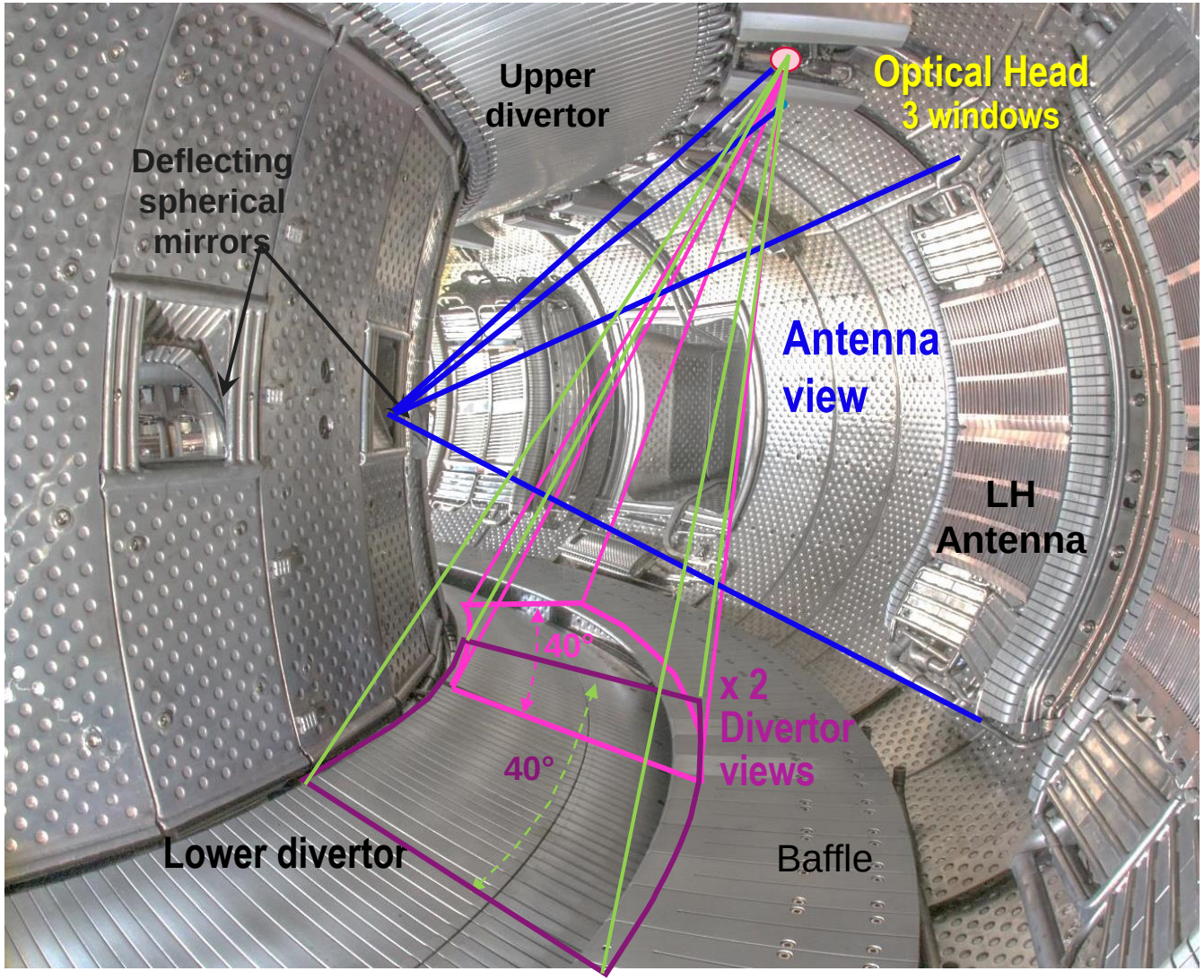






X Courtois et al., FED 2019

Endoscopes & Fields of VIEW



X Courtois et al., FED 2019

MWIR band (3.9µm) (T_{min}~150°C – S/N~3)

14 LoS on :

Antennas fully covered (3 ICRH + 2 LHCD)
Divertor (6 sectors / coverage 100%)
Wide Angle view (4.3µm)
Very high resolution (3.9µm) & Fast IR (From C7)

Spatial Resolution

Antenna : 4 mm/px
Divertor : 2.5 mm/px
Very High resolution for divertor: 0.1mm/px

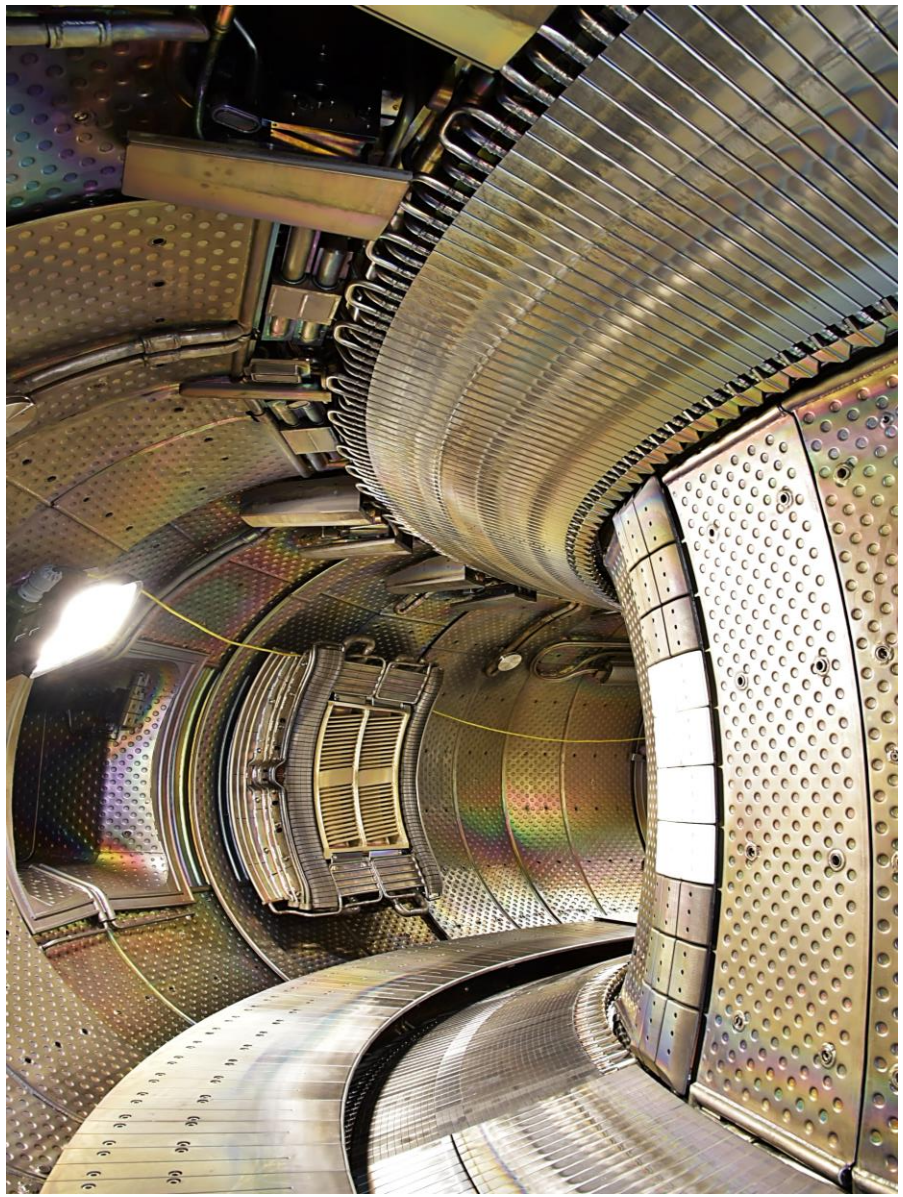
IR WEST Cameras (14) :

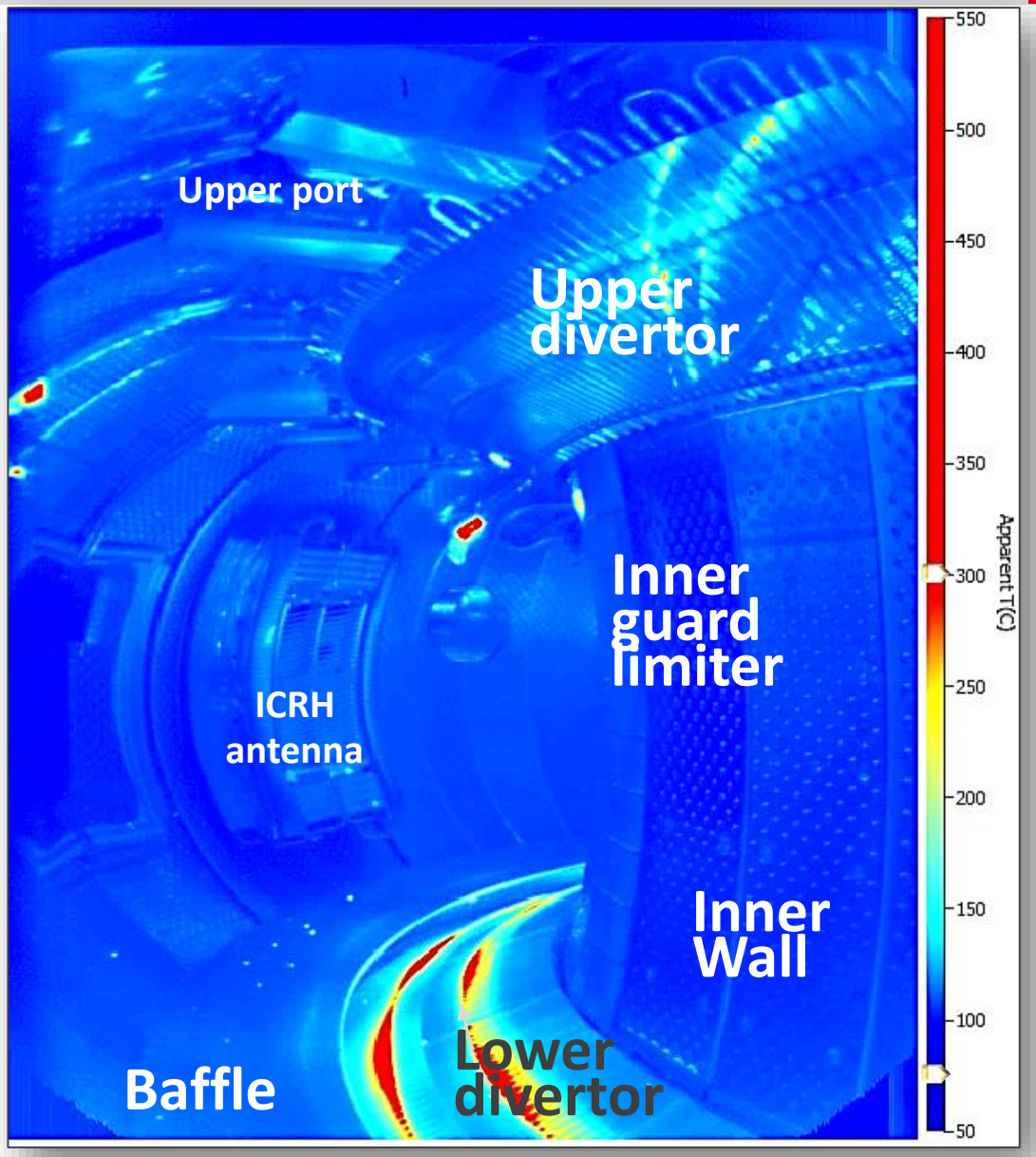
512*640px multi integration time f = 50Hz

Real time data processing for LHCD and ICRH power feedback control since C5

→ Real time protection of heating devices

IR Wide Angle tangential view





Control room organisation

Session Leader (SL)

Engineer in Charge (EiC)

Scientific coordinator (SC)

Diagnostic coordinator (DC)

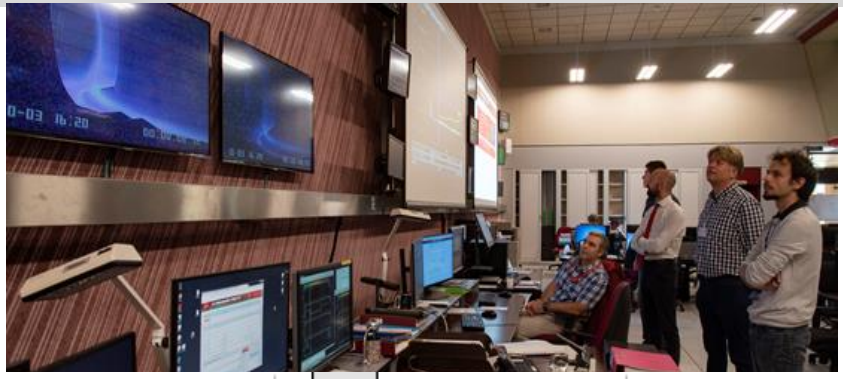
LHCD & ICRH Operators

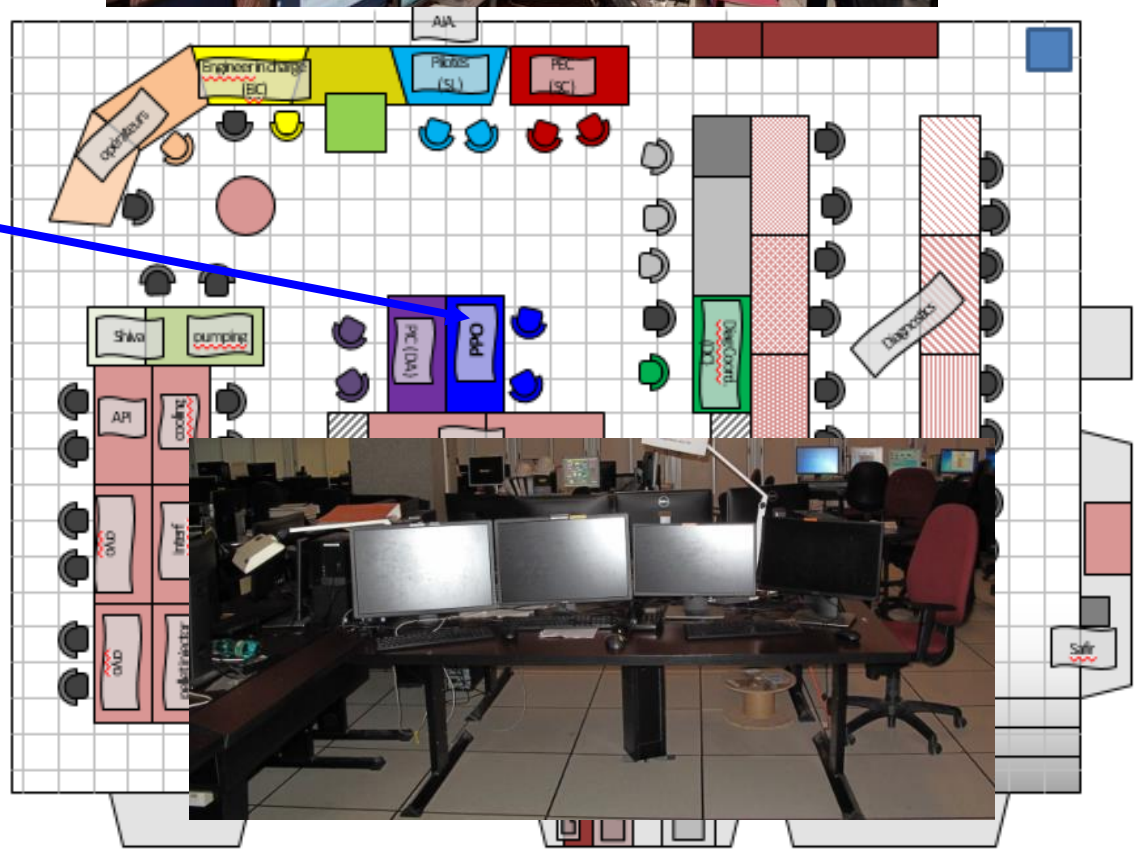
Diagnosticians, Operators

PFC Protection Officer (PPO)

- “Central” position in the control room
- Analysis between pulses (SL, SC, EiC)
- Heat load pattern as expected ?
- Unexpected event ?

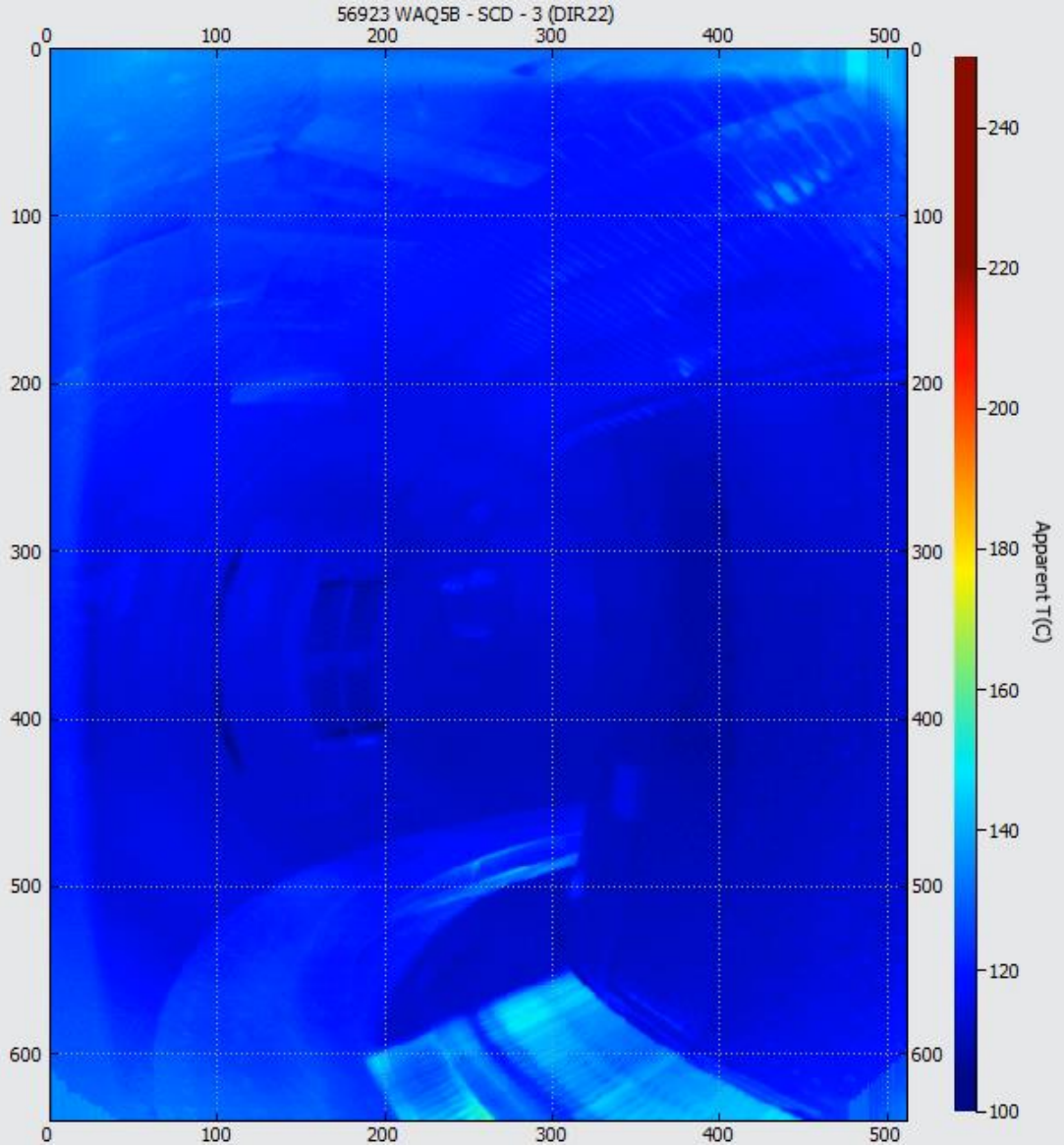
Scientific team





“*Steady state*” in metallic device

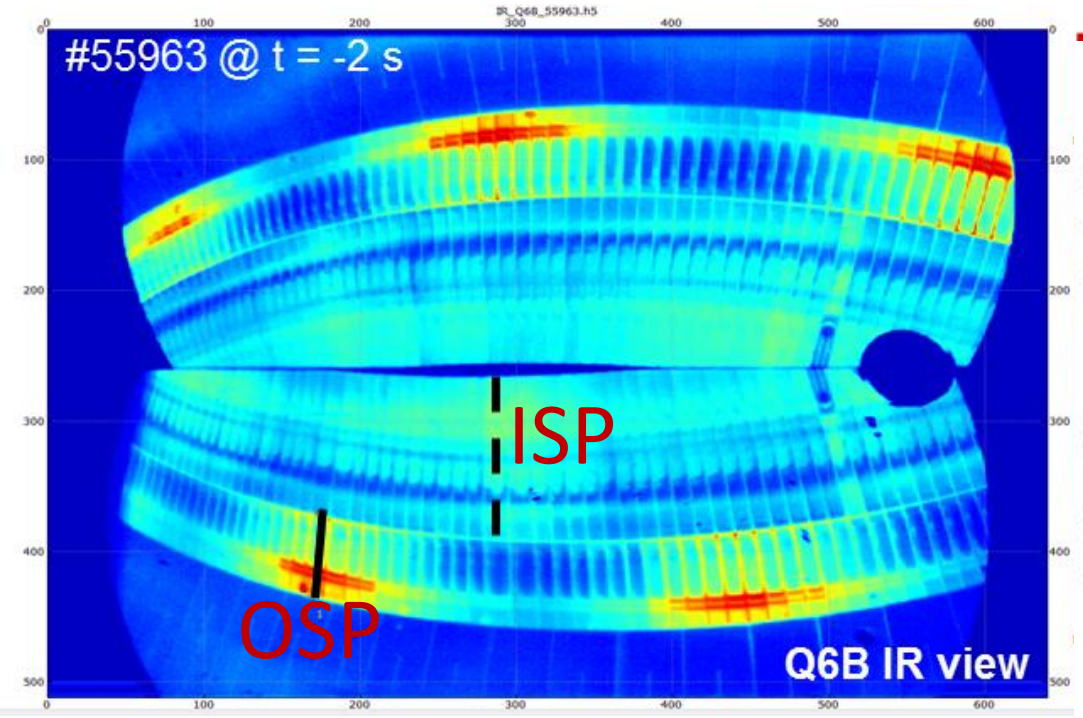
 # 56923 - Long pulse
Impurity (BN) Powder Dropper (7 to 23 s)

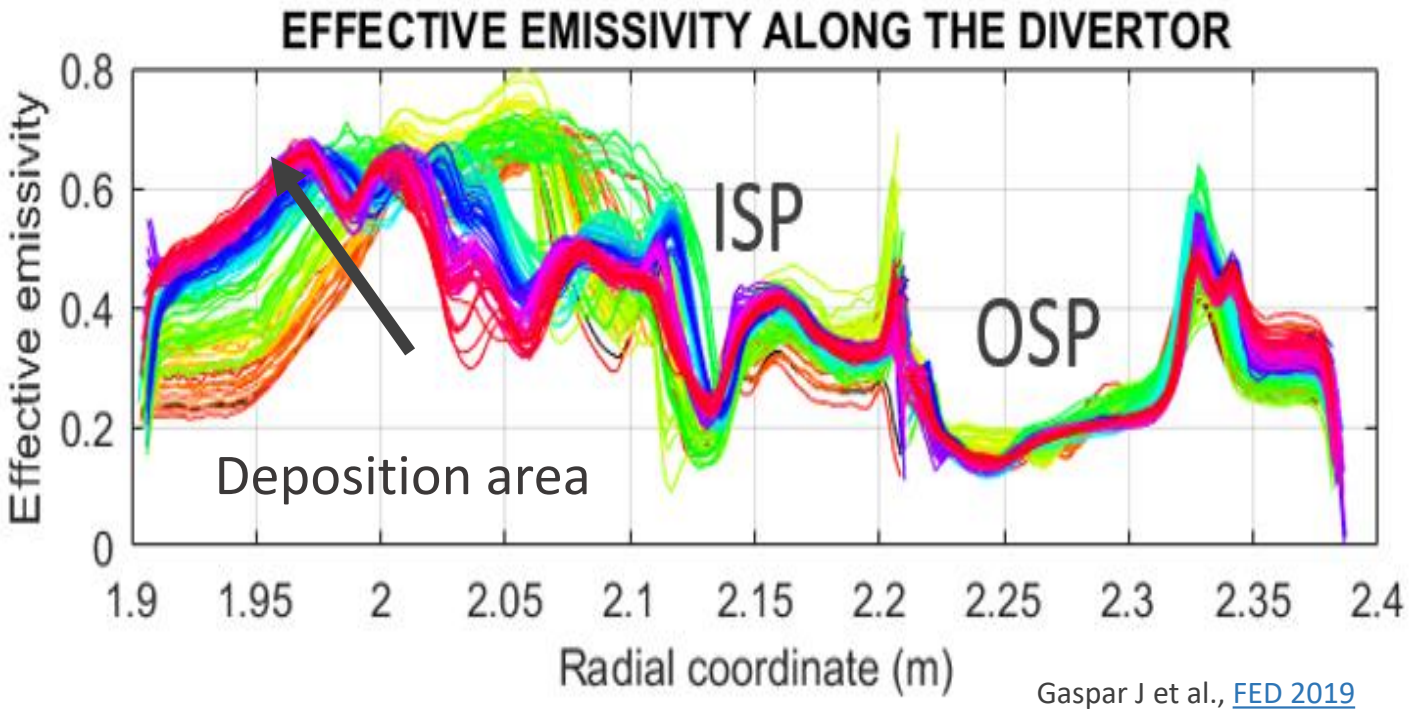


Clear Illustration of

- Inertial PFCs
- Actively cooled PFCs
- Transient (Powder…)
- Reciprocating probe
- Reflected flux
- …

Monitoring of W emissivity required during exp. campaigns

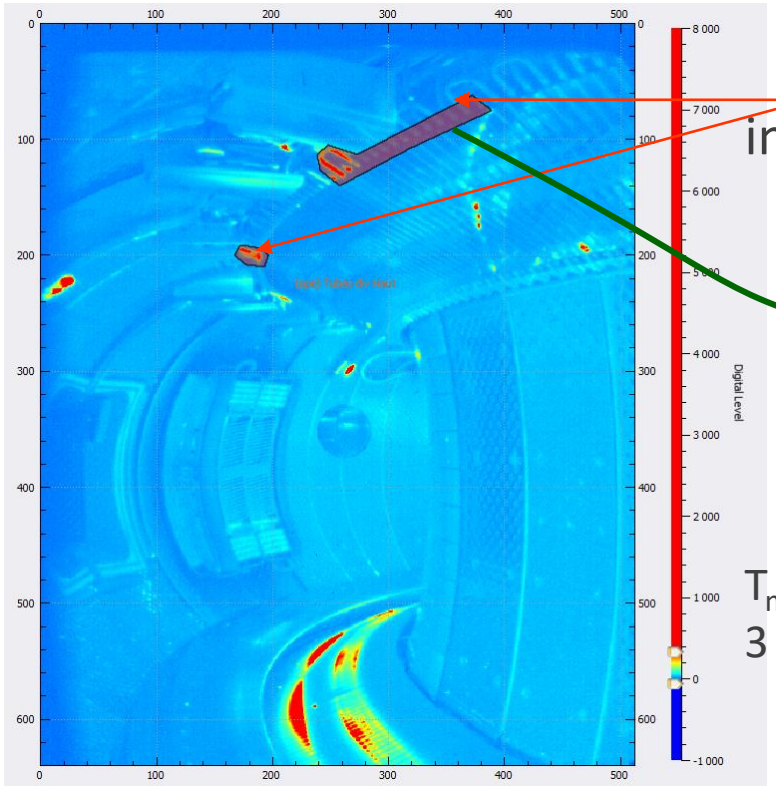




Gaspar J et al., FED 2019
Aumeunier MH et al., NME 2021

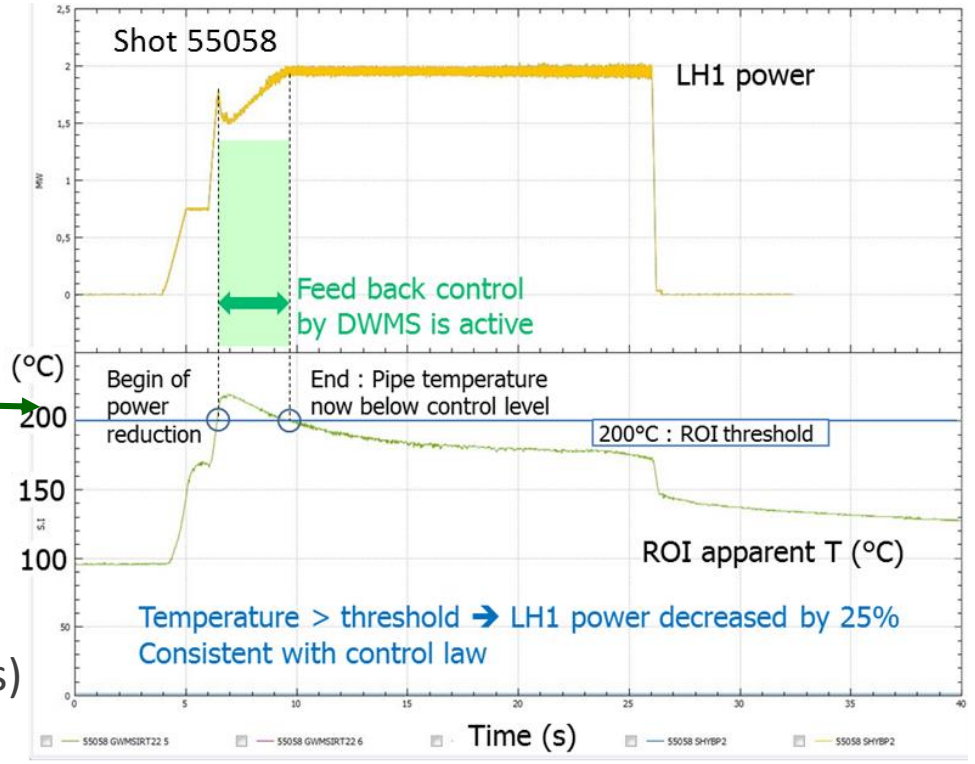
- Dedicated method for emissivity monitoring of inertial PFCs over experimental campaign
- Complex spatial distribution of emissivity on the divertor – correlated with erosion/redeposition pattern (plasma scenario)
- Emissivity ~0.12 and ~cst ISP and OSP regions (consistent with pristine PFU)
- Low emissivity → IR camera collects "low emitted flux" and potentially "high reflected flux"

Wall Monitoring System routinely used for machine protection



Regions of interest (ROI)

T_{max} for each ROI
3 consecutive frames (150ms)

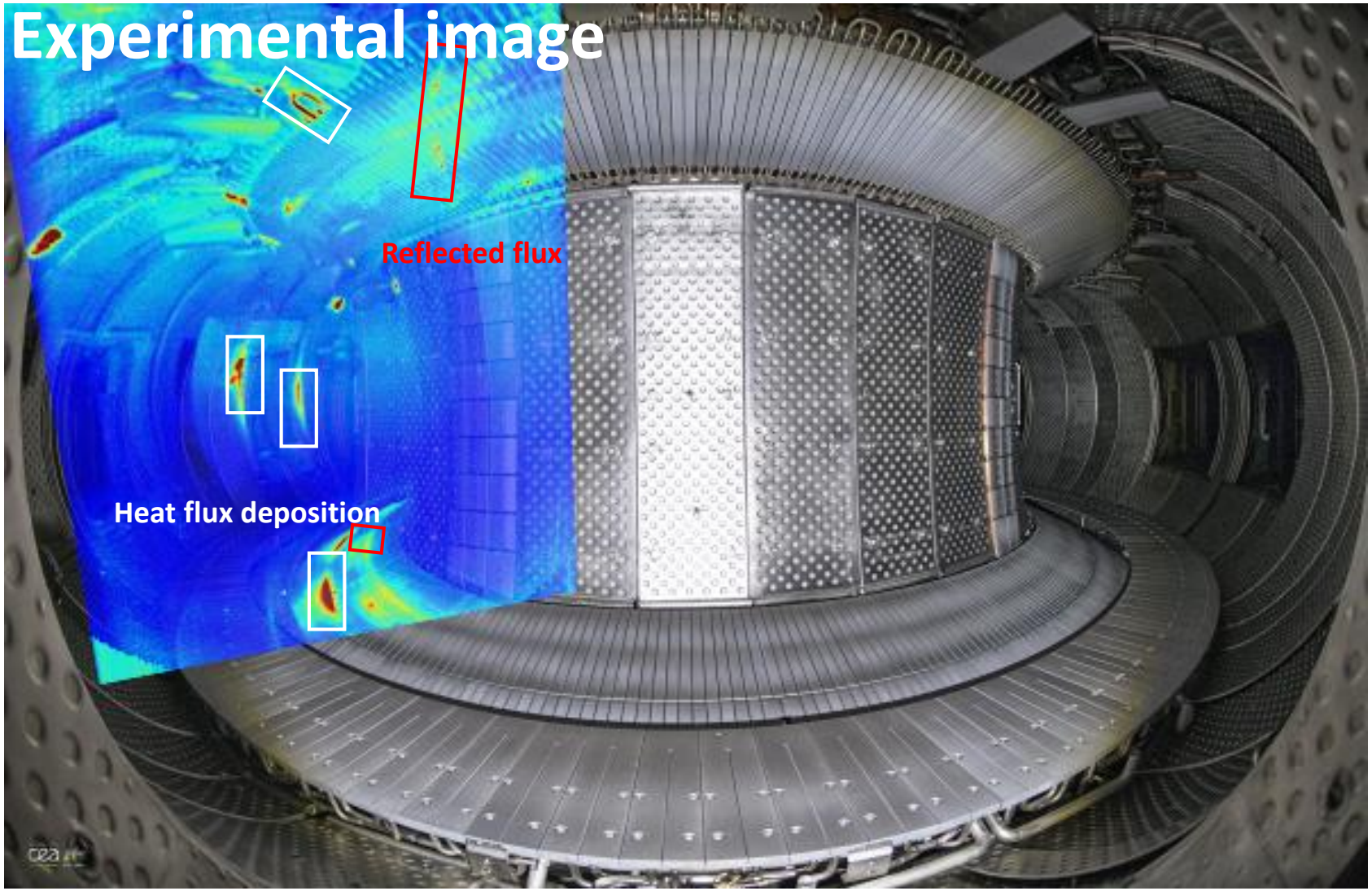


IR data transferred to the "Wall Monitoring System" (WMS) → Plasma Control System (PCS) in real time.

Input power reduction and/or plasma scenario modification to stay below the threshold

Allow for accessing to high performance plasma scenario

Essential step for the protection: The simulation



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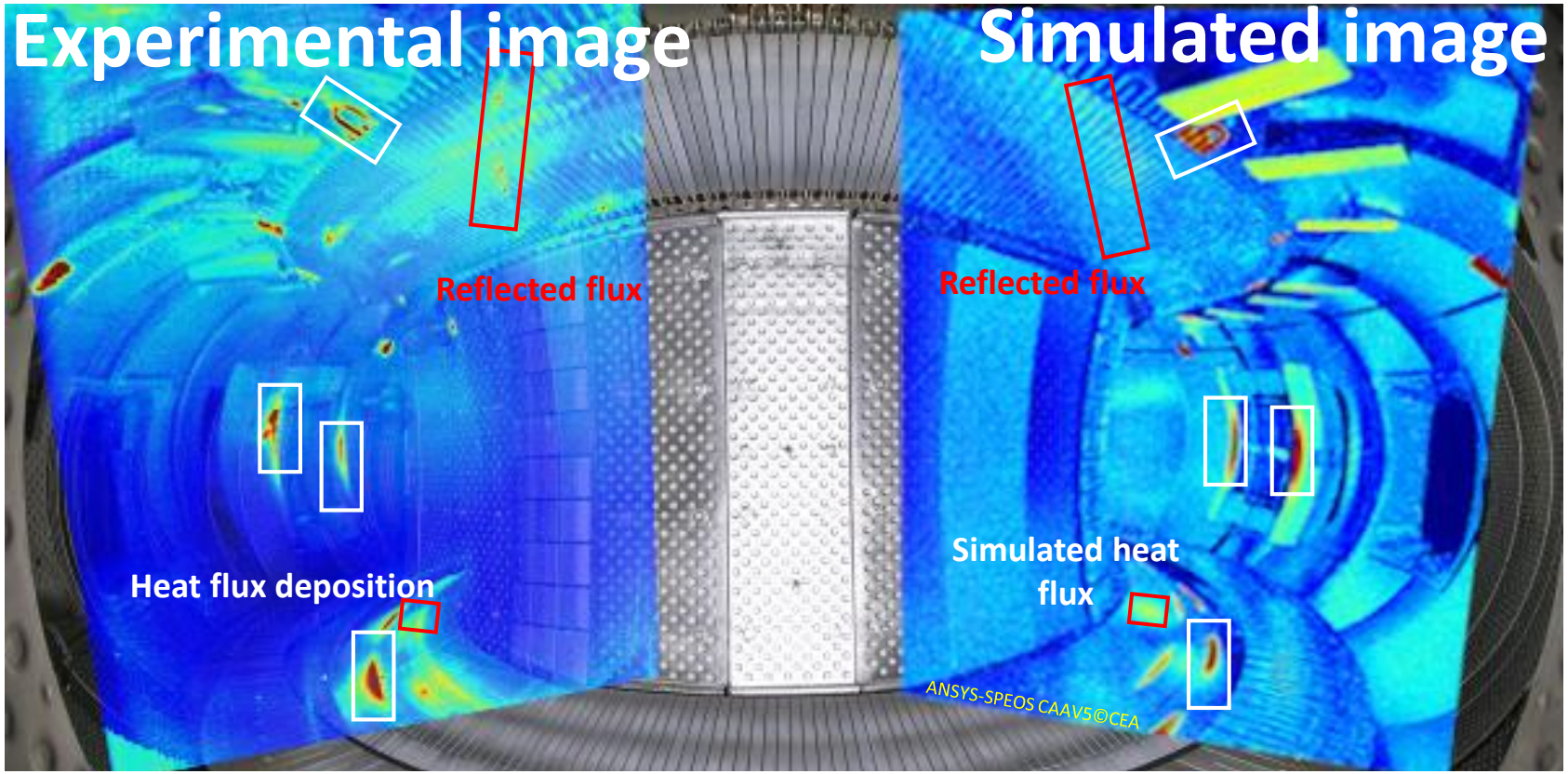


- Heat flux deposition (PFCFLUX) for dedicated scenario associated to a magnetic equilibrium
- Validation of the heat flux deposition pattern, the reflected fluxes, the steady state and transient
  - → Closed loop from pulse preparation, real time processing, post pulse analysis
  - → Machine learning and Artificial Intelligence (See next talk by MH Aumeunier)

Preliminary summary of the WEST IR machine protection

Wall Monitoring System availability:

- Routinely operating since July 2019
- 98% for the overall C4 & C5 campaign (>2000 pulses)
- 100% for the high power scenario development

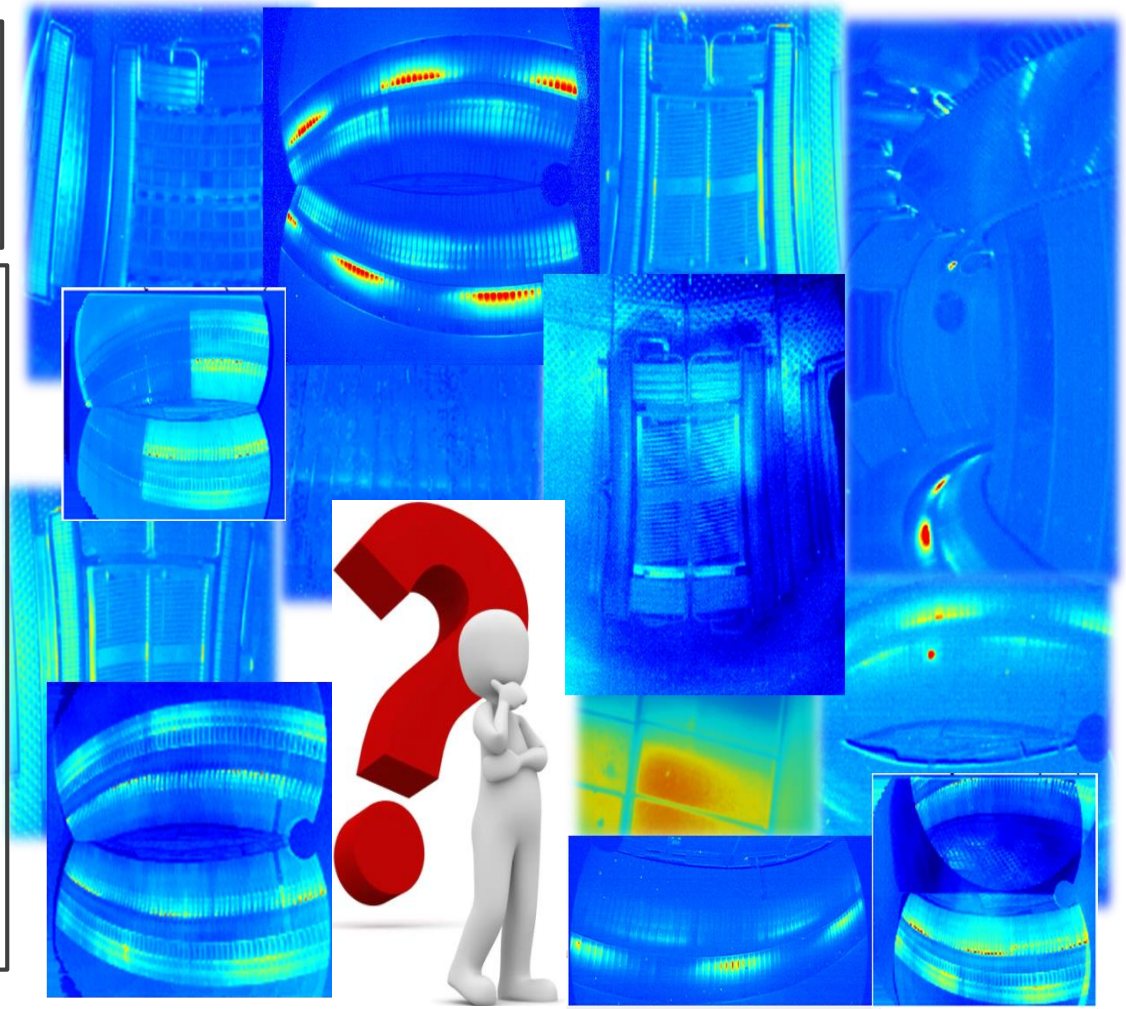
- Over the **C4 campaign: 1442 pulses** cumulating 3:30 of plasma including 50 min of He plasmas.

→ **63 cases (4.4%)** of feedback control through an input power drop of the LH launchers. Mainly during **scenario development**, without triggering a soft landing.

→ **17 pulses (1.5%)** immediately stopped (transition to soft landing)

- 12 with a fast T_{surf} increase (Not managed by actuator)
- 2 events due to ROI misalignment on the target (Human error).
- 2 events due to dusts (Strong and fast T_{surf} increase).
- 1 unidentified technical failure

14 views inWEST



Next Steps

So far in WEST:

- Input power (9/15 MW)
- L-mode and steady state
- Huge emissivity variations (0.12 to 0.8!)
- Emitted and reflected fluxes identified…

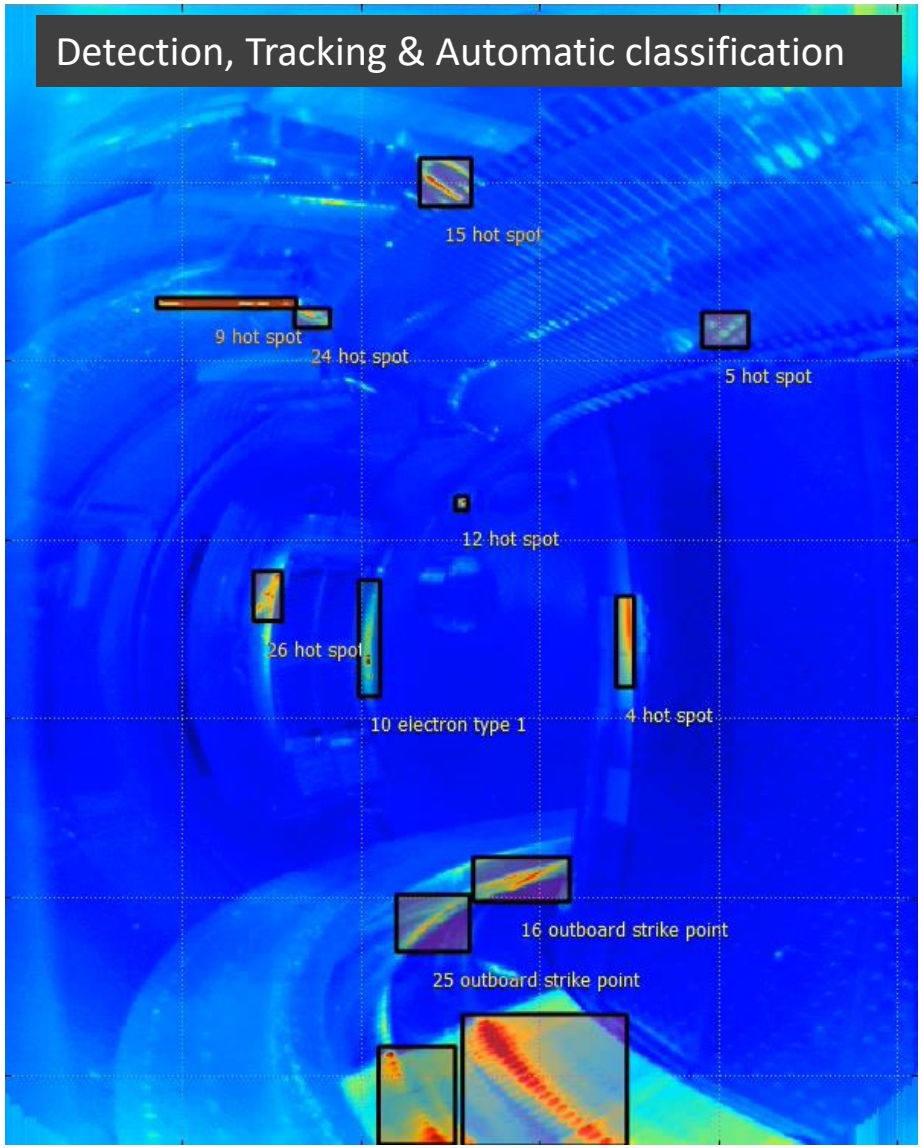
Next step for WEST & Common to all fusion devices (not only metallic)

- Increase input power/energy >10MW & ~GJ
- Access to H-mode → Transient phenomenon to be integrated in the Wall monitoring System (e.g. Dusts ≠ ELMs…)
- Emissivity monitoring/evaluation over the campaigns
- Integrated 3D modelling including reflected fluxes (Hot spot detection)
- Integrated IR synthetic diagnostic & inverse method → See next talk by MH Aumeunier et al., ("*IR Interpretation in metallic environment*")

Significant upgrade through data bases & Artificial Intelligence:
Detection, tracking, automatic classification…

→ "Protect" the machine but allow for performances

→ Implementation and validation of "*Machine Protection 2.0*" on WEST



Thank you for your attention