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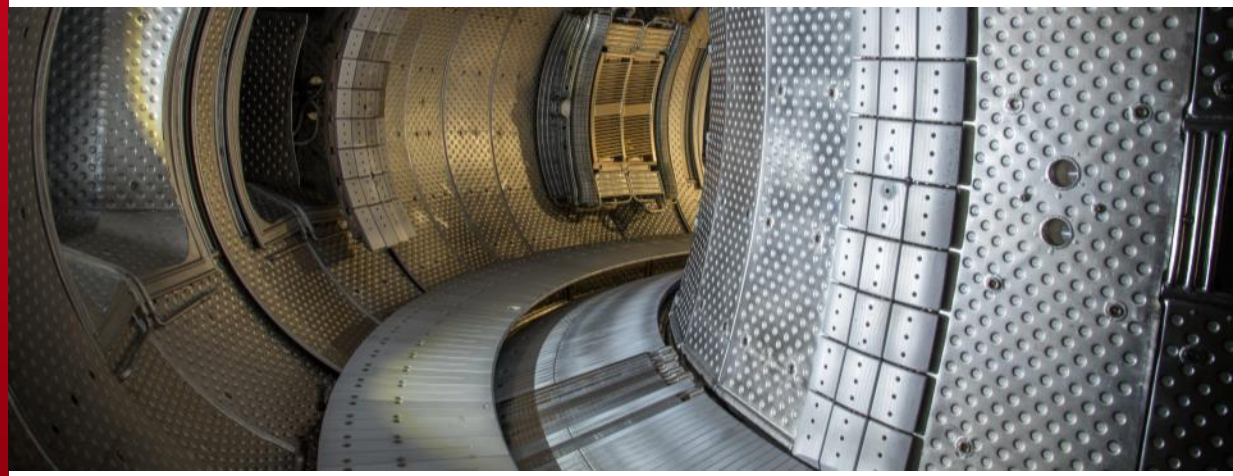
Task Force WEST-1 : Testing and Operating ITER Grade Plasma Facing Components

- Achievements of the C3 campaign
- Outlook for the C4 campaign



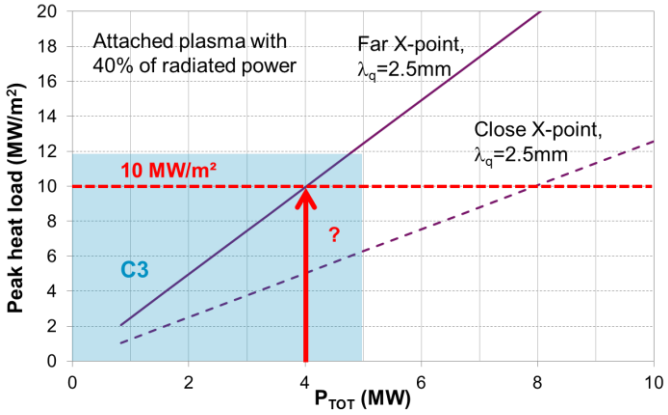
- Achievements of the C3 campaign :
  - Objectives / configuration
  - Scientific highlights (PFC / plasma)
- Outlook for the C4 campaign

- **Achievements of the C3 campaign :**
  - **Objectives / configuration**
  - **Scientific highlights (PFC / plasma)**
- **Outlook for the C4 campaign**

C3 campaign : first experiments on ITER like prototypes

Characterize WEST divertor operational domain (10 sessions)

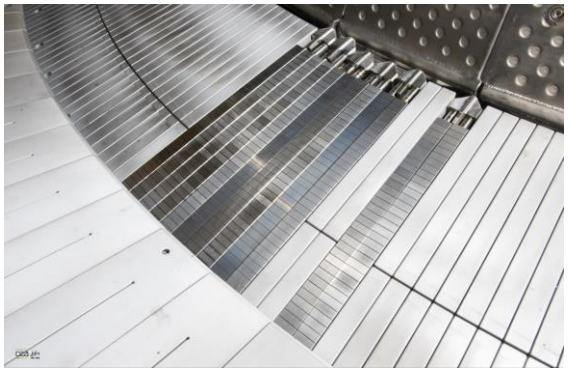
- Steady state heat load pattern : Qualification of PFC diags / SOL widths (5 sessions)
- Divertor regimes (1 session)
- W source : impurity & W sputtering (2 sessions), divertor vs main chamber source (1 session)
- Reference pulse (1 session)



KPI#2: Show that the input power required to get 10MW.m^{-2} on the divertor target is lower than 10MW

Assess power handling of ITER like PFU (19 sessions)

- "High Heat flux" scenario development (3 sessions)
- High power test of ITER PFC : shaping / tolerance to PFU misalignment (8 sessions)
- High power test of ITER PFC : pre-damaged (8 sessions)



KPI#5: Perform a 10 second diverted ELMy H-mode with at least 5MW.m^{-2} on the divertor target

Prepare for long pulse operation (1 session)

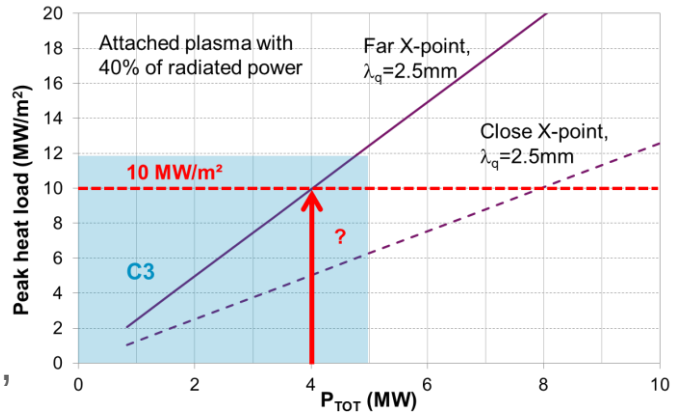
- Long pulse experiments using the upper div (1 session)

WEST GB5

C3 campaign : first experiments on ITER like prototypes

Characterize WEST divertor operational domain (6 sessions)

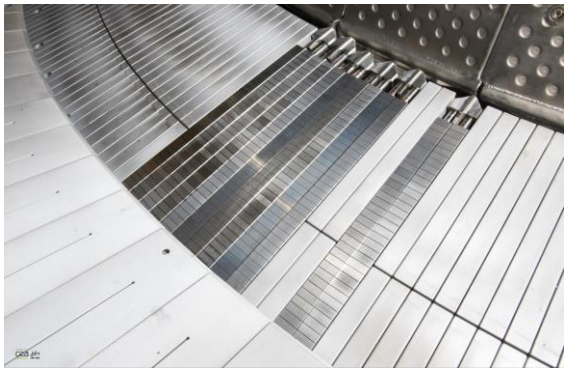
- Steady state heat load pattern : Qualification of PFC diags / SOL widths (4/5 sessions)
- Divertor regimes (1 session)
- W source : impurity & W sputtering (2/2 sessions), divertor vs main chamber source (1 session)
- Reference pulse (1 session)



KPI#2: Show that the input power required to get 10MW.m^{-2} on the divertor target is lower than 10MW

Assess power handling of ITER like PFU (13 sessions)

- "High Heat flux" scenario development (2 sessions)
- High power test of ITER PFC : shaping / tolerance to PFU misalignment (8/8 sessions)
- High power test of ITER PFC : pre-damaged (3/8 sessions)



KPI#5: Perform a 10 second diverted ELMy H-mode with at least 5MW.m^{-2} on the divertor target

Prepare for long pulse operation (4 sessions)

- Long pulse experiments using the upper div (4/5 session)

Significant international participation on site for C3

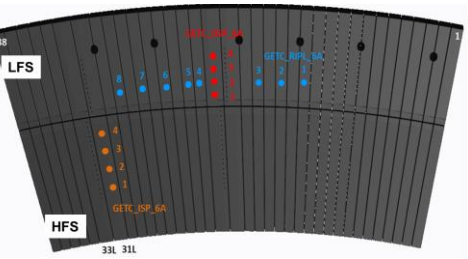
21 EUROfusion sessions executed

- 6 kept for C4 for higher power / H mode (SOL width, pre-damaged PFU)
- 1 shifted to C4 for technical reasons

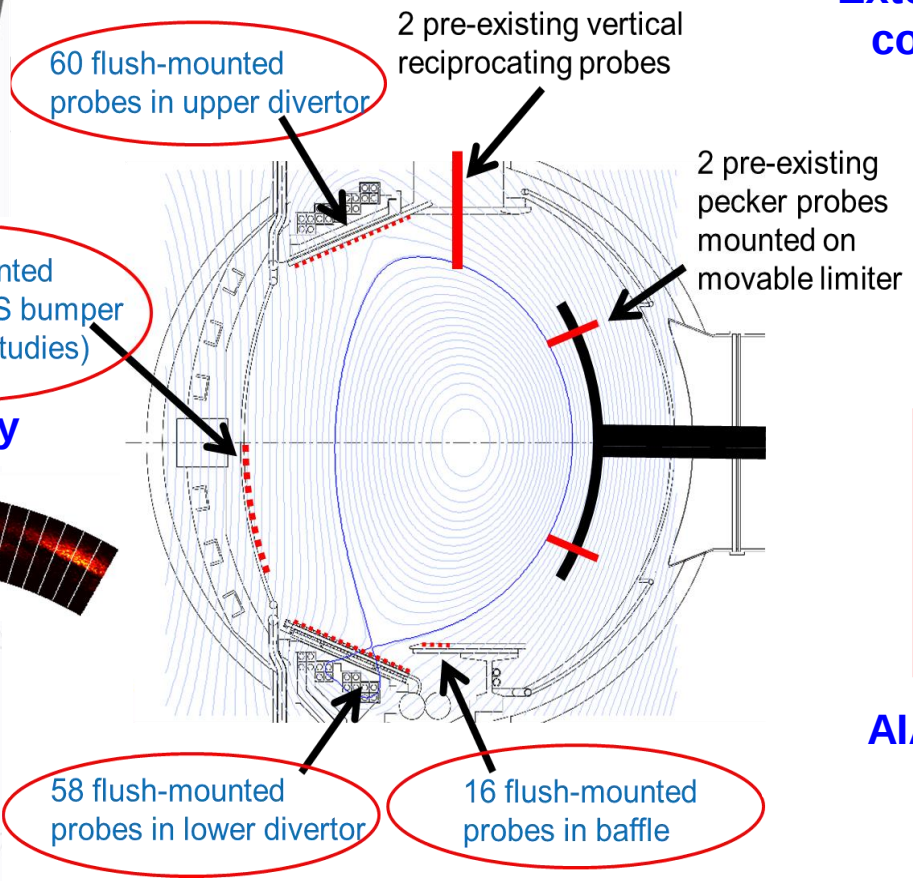
~20 visiting scientists on site (~10 from EU + CN, JA, USA)

Full set of plasma edge / PFC diagnostics operational

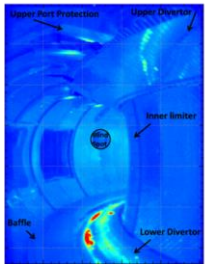
Thermocouples / FBG

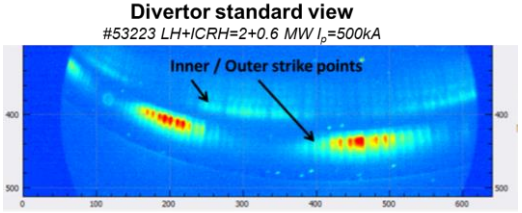


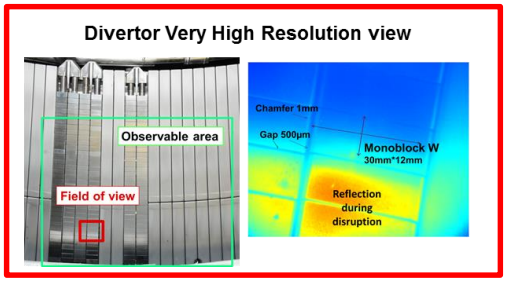
Wide array of Langmuir probes



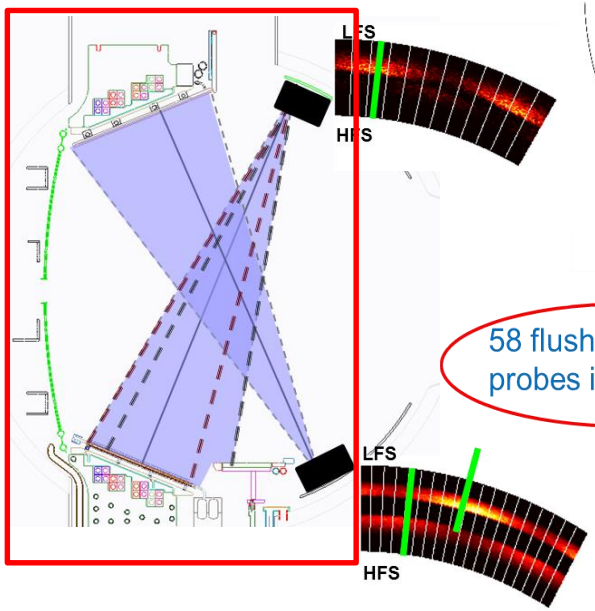
Extensive IR coverage







Visible spectroscopy

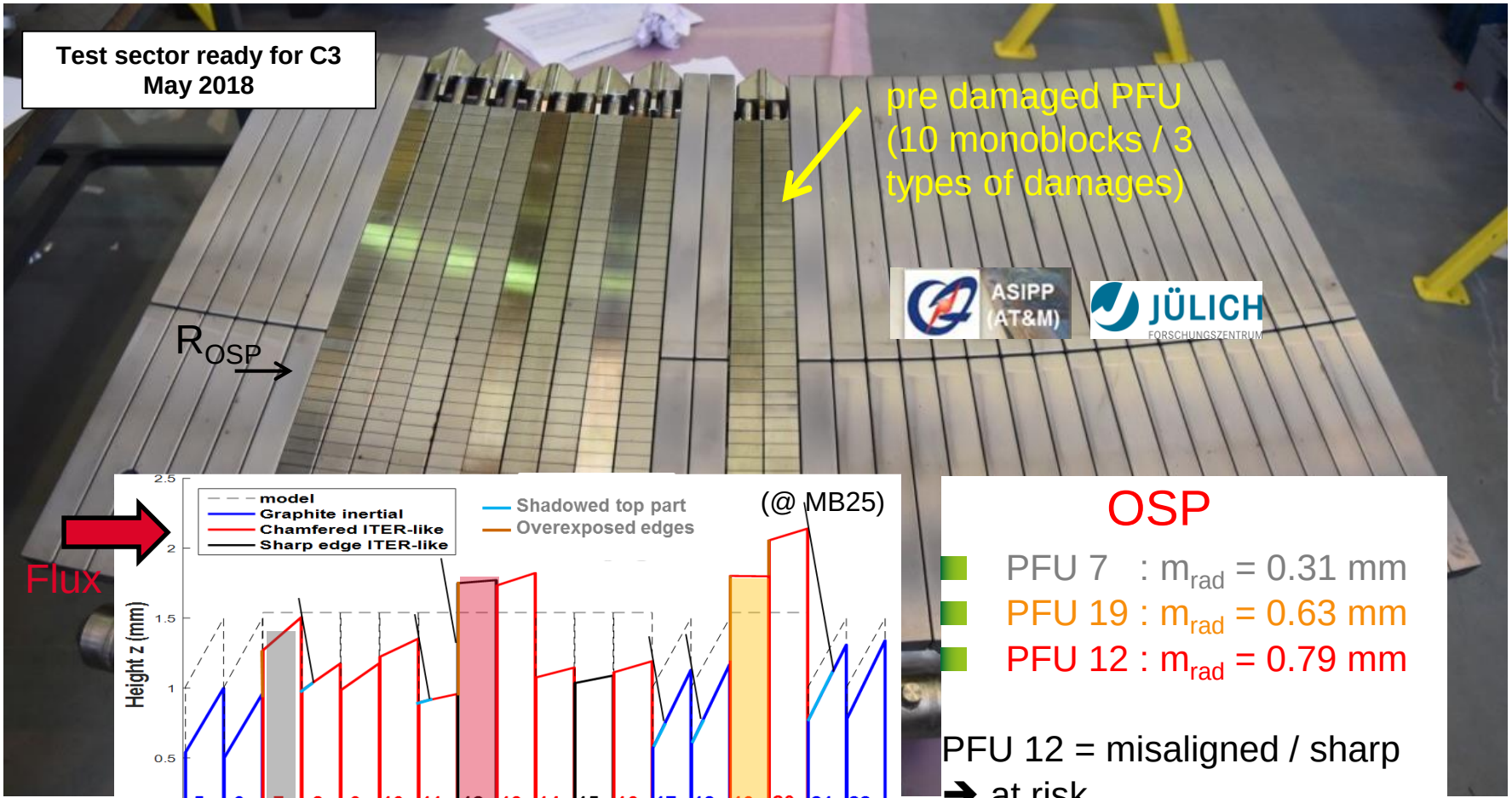


AIA

+ PFC calorimetry, bolometry, barometry, RGA, vis camera …

PFU with significant misalignment exposed in C3

- 12 ITER like PFU for C3 : different W grades/manufacturers (6 F4E, 3 JADA, 3 ASIPP), sharp vs chamfered PFU + pre-damaged PFU



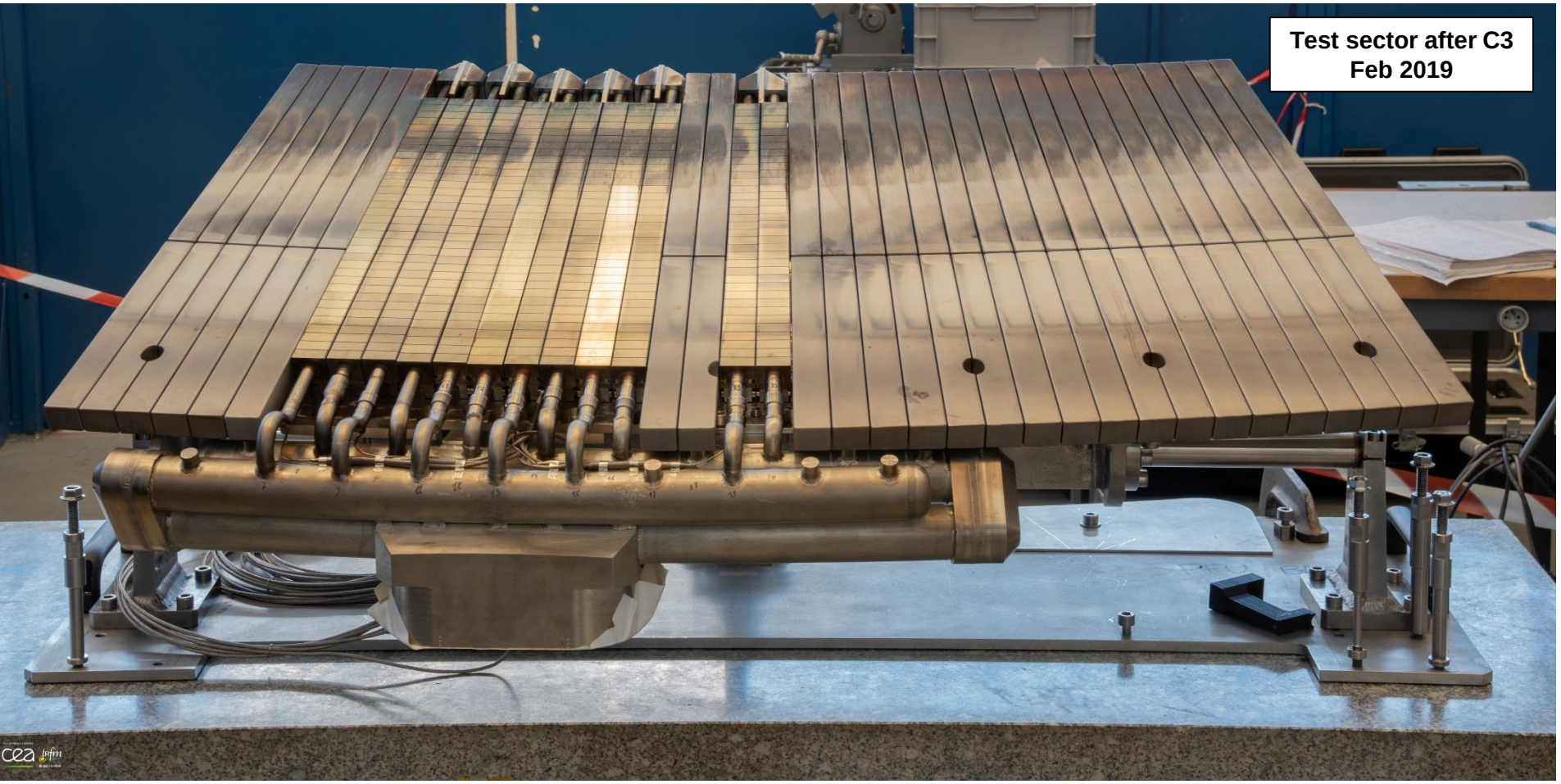
OSP

- PFU 7 : m_{rad} = 0.31 mm
- PFU 19 : m_{rad} = 0.63 mm
- PFU 12 : m_{rad} = 0.79 mm

PFU 12 = misaligned / sharp
➔ at risk

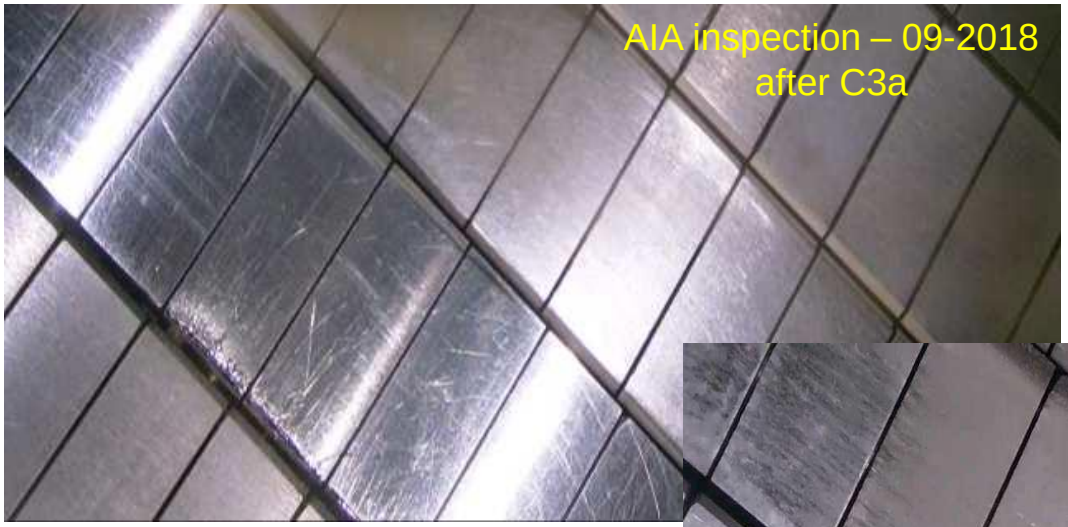
- Achievements of the C3 campaign :
  - Objectives / configuration
  - Scientific highlights (PFC / plasma)
- Outlook for the C4 campaign

Test divertor sector after C3 : Every monoblock has a story to tell

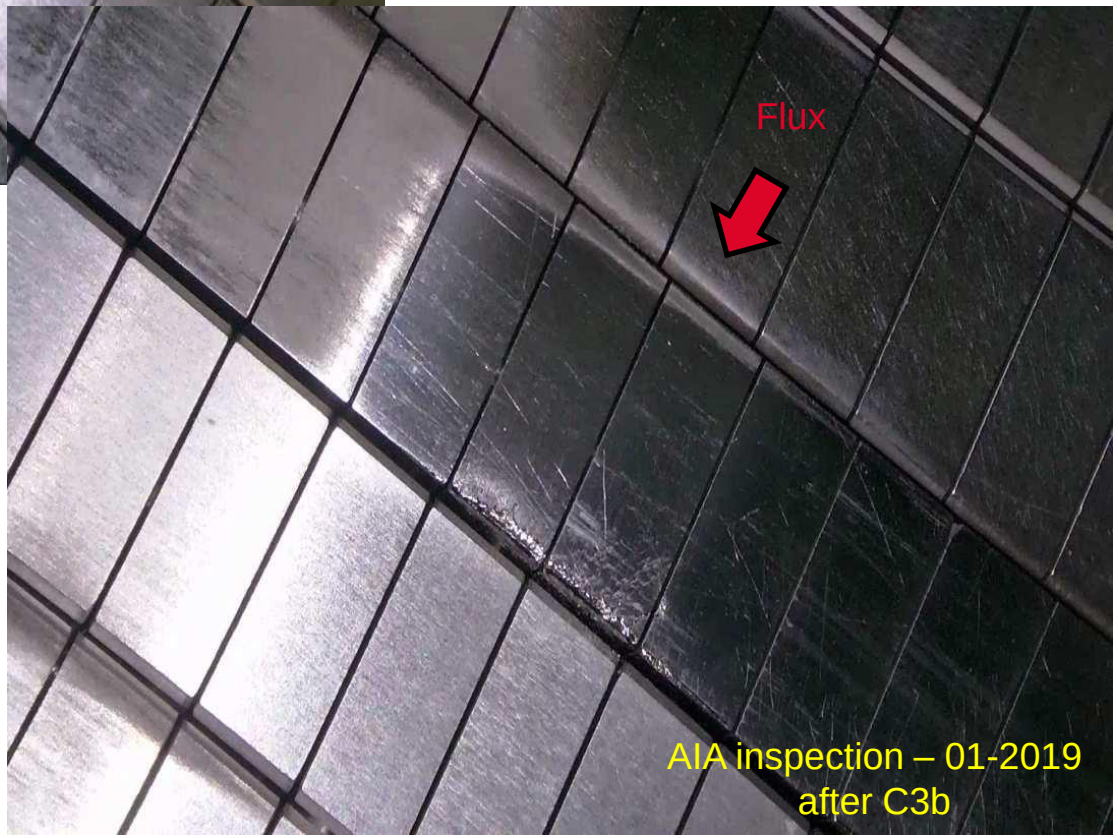


- Top surface : plasma footprint clearly visible (erosion/redeposition ?)
- Leading edges : impact of plasma operation

Melting on PFU#12 identified during AIA inspection after C3a



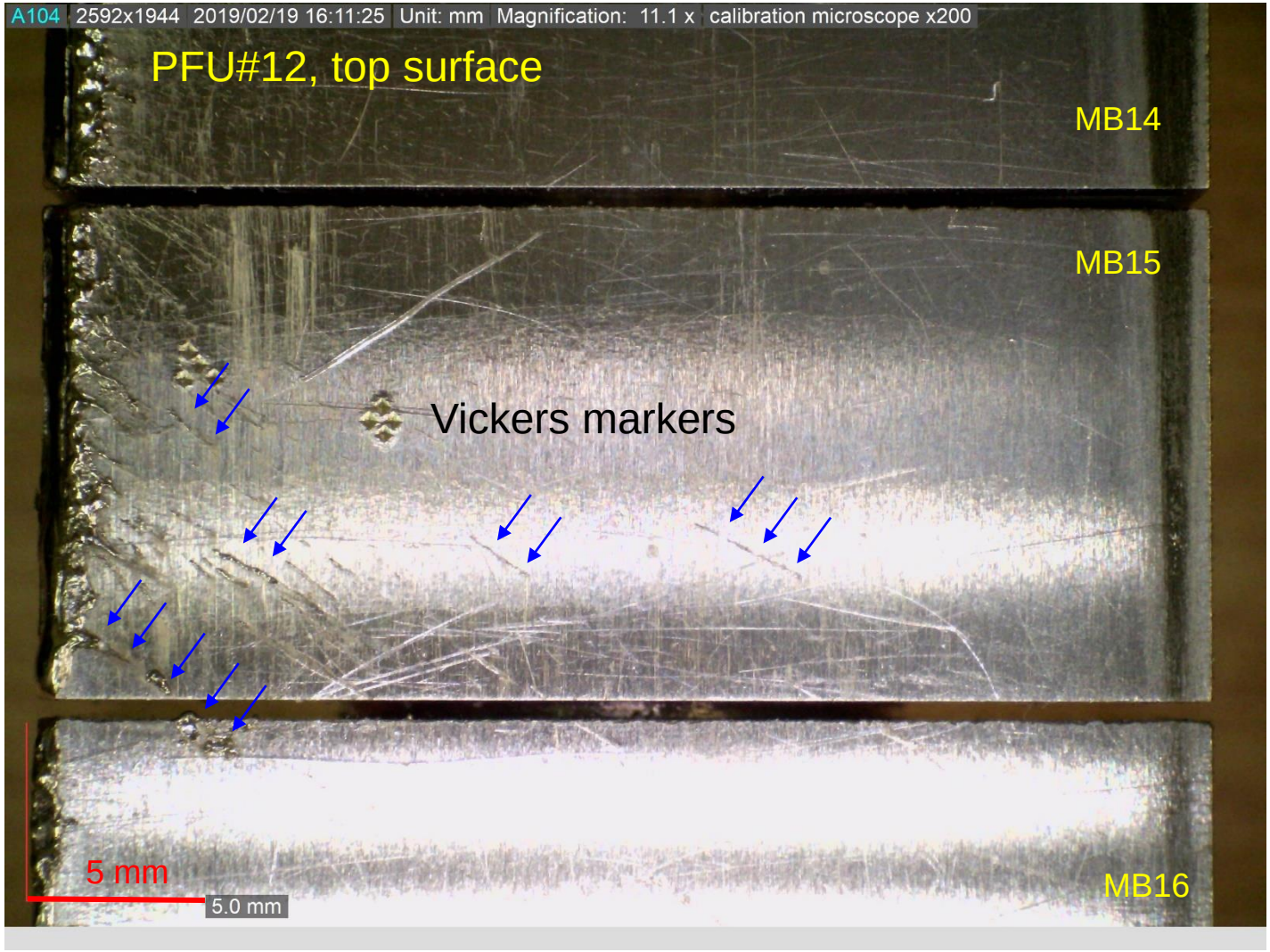
- Melting on PFU#12 (sharp + misaligned) identified after C3a with AIA



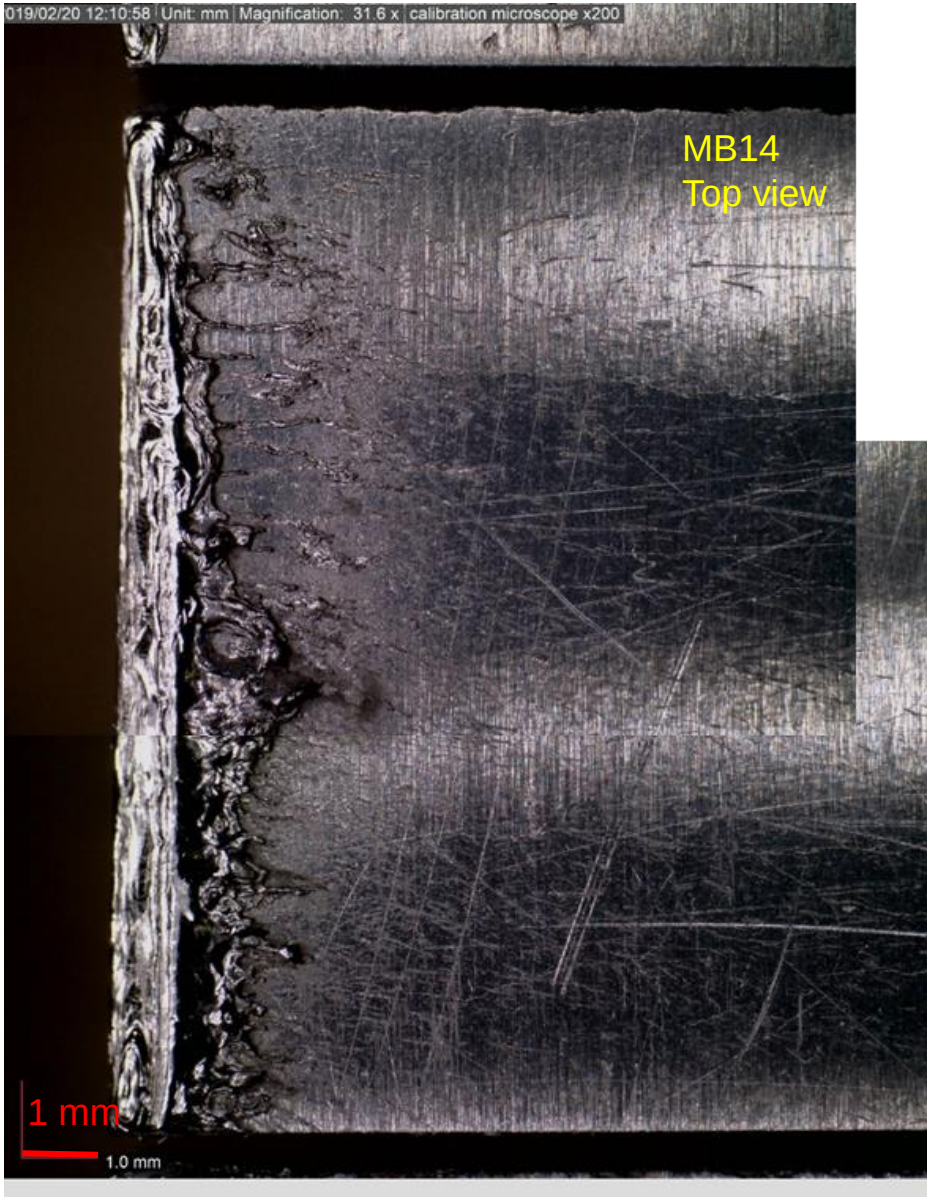
- Did not evolve after C3b
- Located on trailing edge of PFU12

➔ probably due to a (a few) single event(s) (shift of plasma towards HFS + disruption ?)

Top surface : melt material across monoblocks (PFU#12)

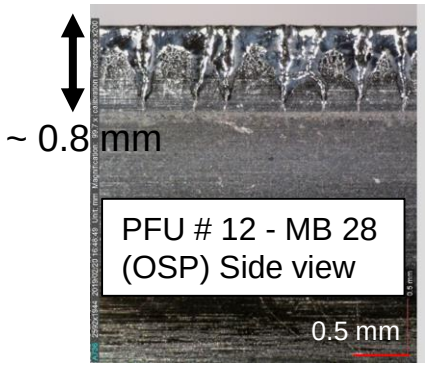


Melt material on top and side surface in damaged area (PFU#12)

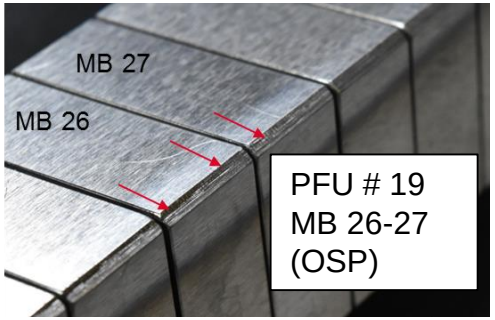


First evidence of damage observed on misaligned ITER like PFU

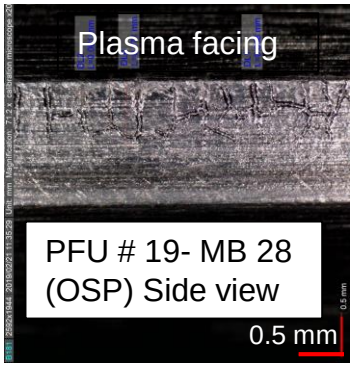
- **Cracks and local melting** observed on misaligned PFU side (both for sharp and chamfered), even outside peak heat flux area : impact of transients on “cold” monoblocks (cycling across DBTT) ?

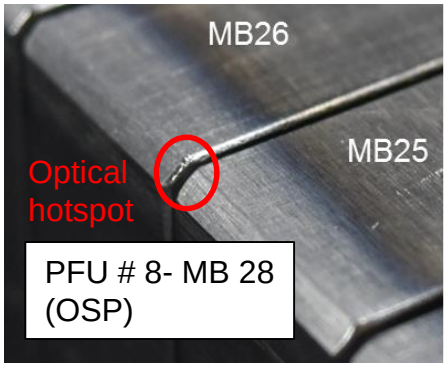


Misaligned / sharp



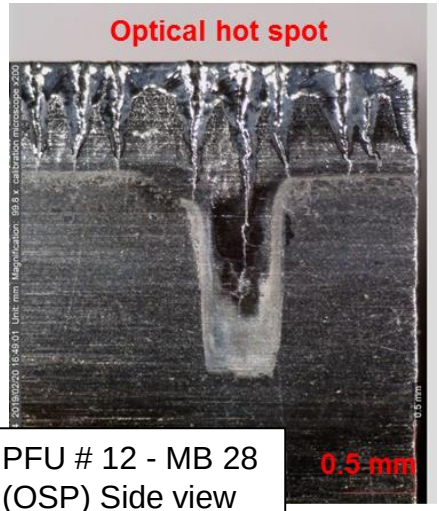
Misaligned / chamfered

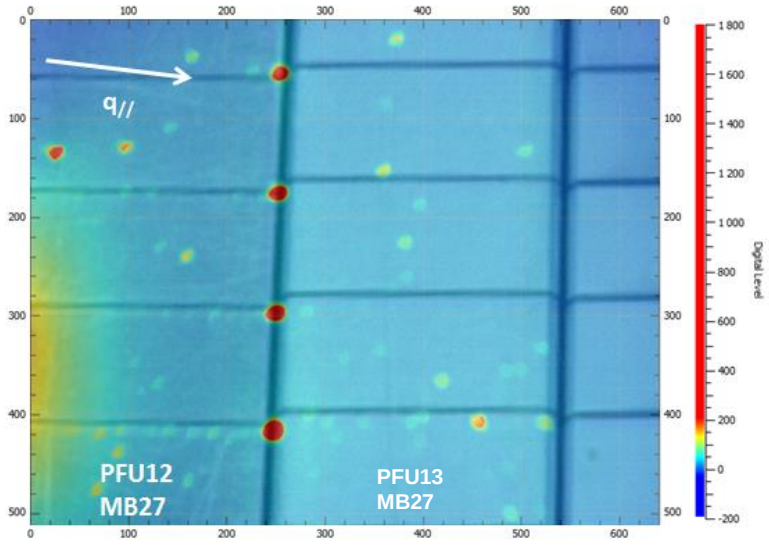




Aligned / chamfered

- **Optical hot spots** evidenced even for PFU aligned within specs (local melting / cracks)
- **Impact on operation to be assessed** (12 ITER like PFU, no ELMs)
- **Damage propagation to be monitored** after the C4 campaign





VHR IR during a disruption (visible view superimposed)

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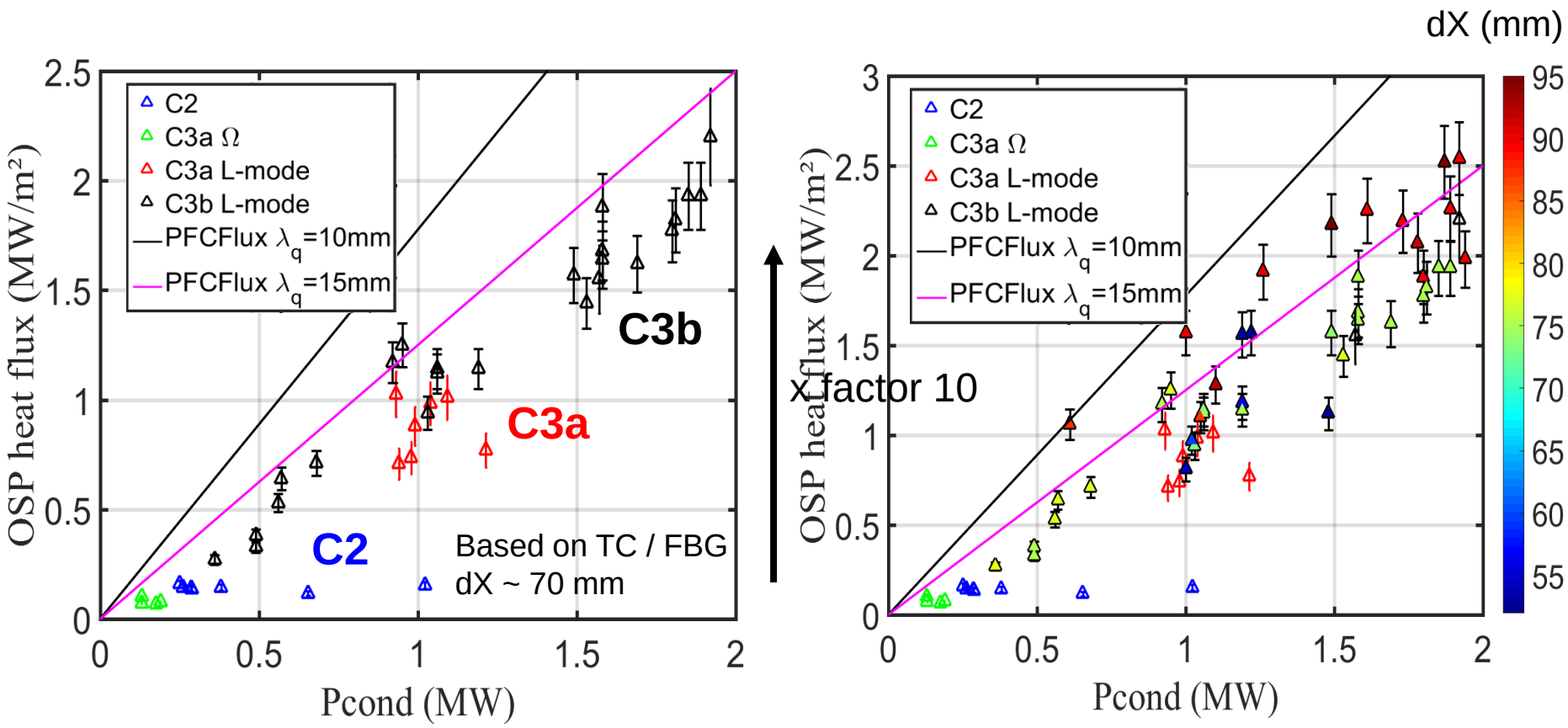
Divertor peak heat flux : steady progress in C3

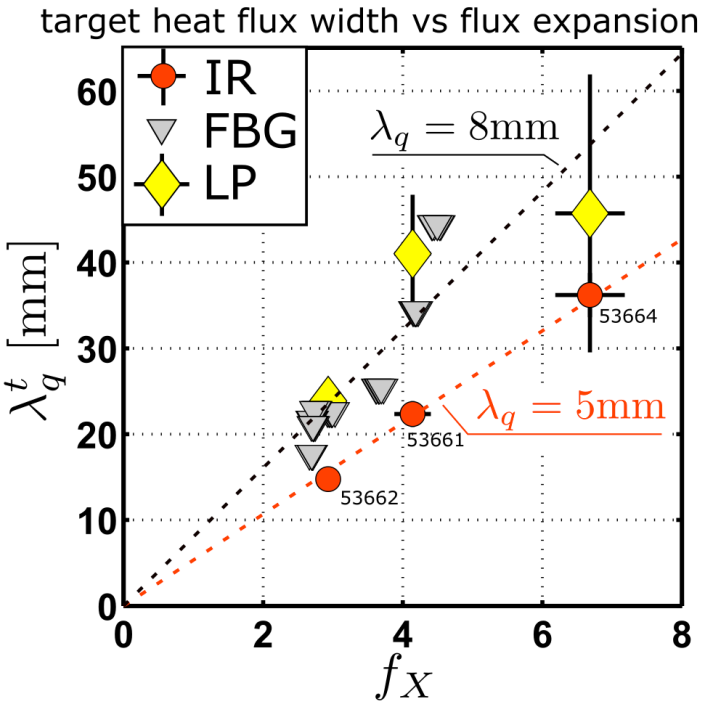


Divertor peak heat flux ~ 2.5 MW/m²

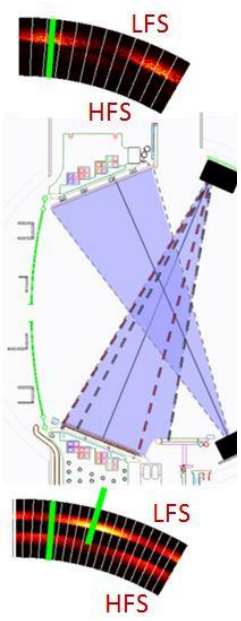
Characterizing WEST divertor

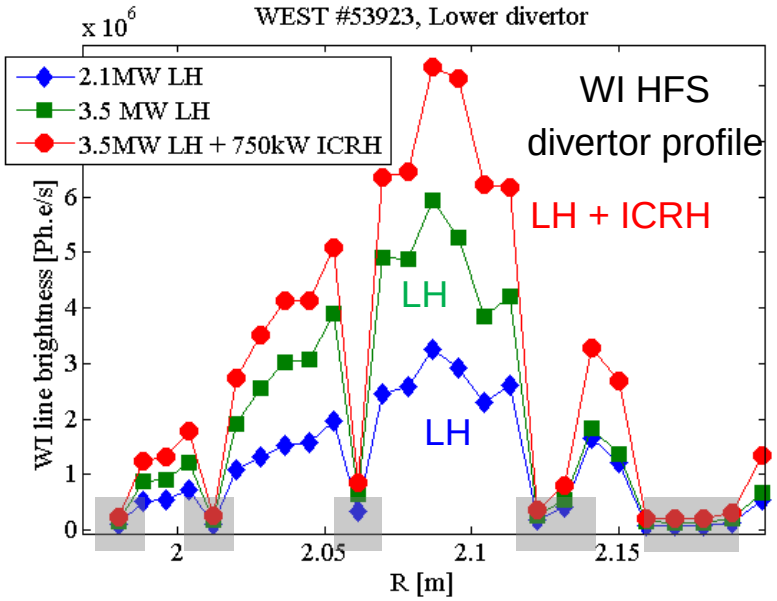
L mode divertor heat load pattern

- Scan in dX (30 to 90 mm) and Ip (λ_q)
- Cross comparison of diagnostics ongoing : probes (sheath transmission ?) , IR (emissivity ?), TC/FBG (inversion ?)
- λ_q^m in the range 5-8 mm (L mode scaling ~ 4 mm)



Tungsten source(s) under analysis





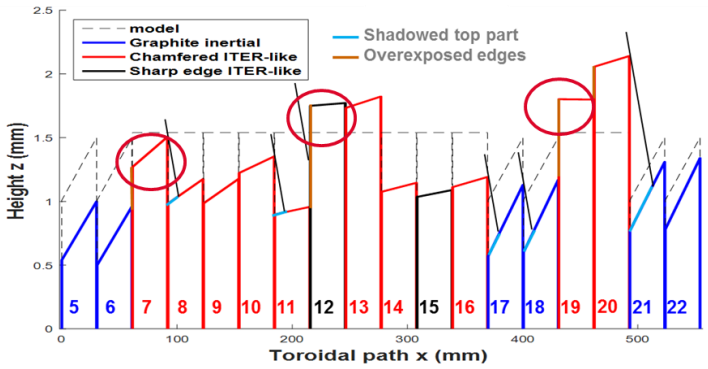
- Lower divertor LoS on ITER like PFU at max ISP/OSP (spatial resolution 10 mm ~1 monoblock)

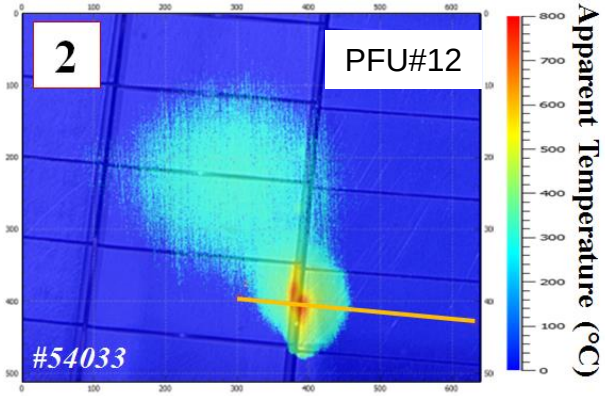
NB : broken / low transmission optical fibers

First experiments on ITER like PFU

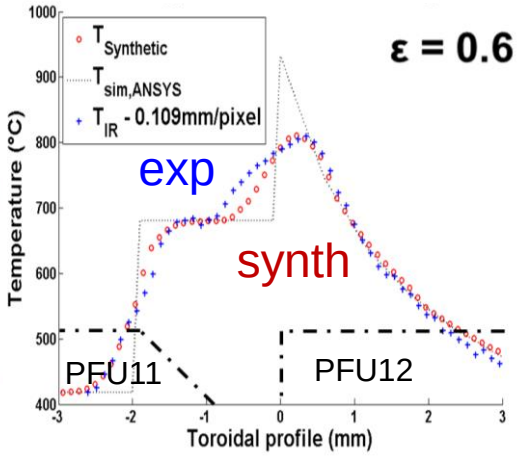
PFU misalignment : leading edge loads evidenced

- Repeated high power discharges to explore PFU misalignment with VHR IR (Ip = 500 kA, PLH = 4.5MW/4s)
- Consistent $q_{//}$ estimate @ $\varepsilon = 0.6$ for the 3 PFU observed



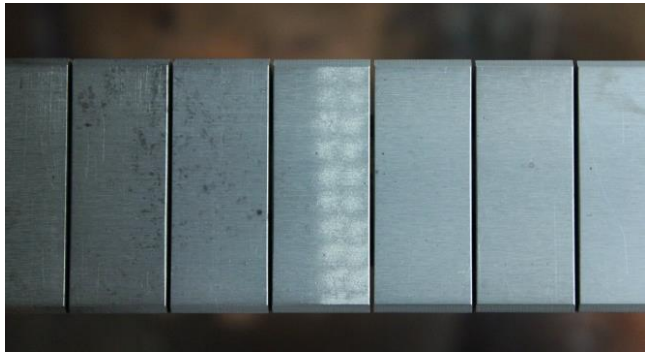


PFU 12 #54033



Plasma scenario developed for pre damaged PFU exposure

- New scenario (Ip = 500 kA, PLH = 4 MW/4s) developed @ dx=100mm for ISP on damaged MB11
- Damage no longer visible on MB11 after C3
- SEM/EDX, laser profilometer indicate erosion and surface contamination



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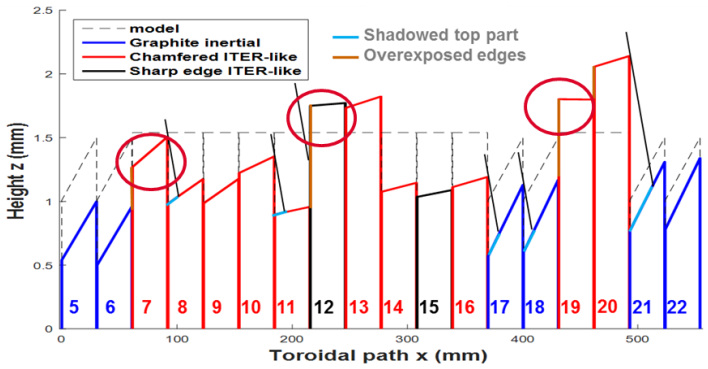
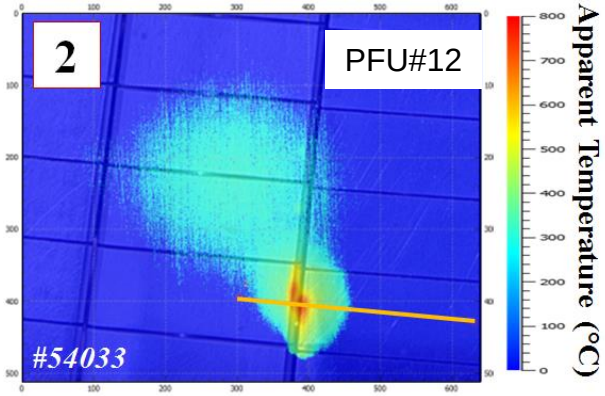
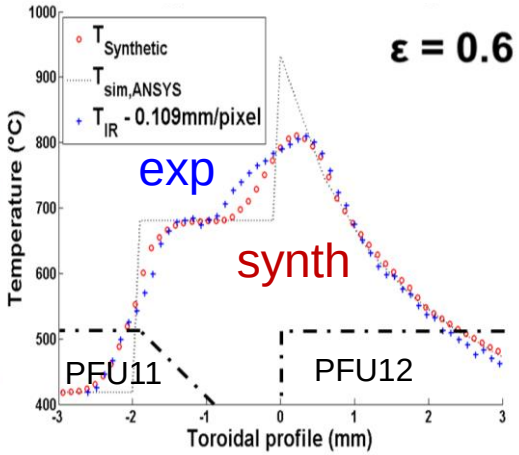




PFU 12 #54033



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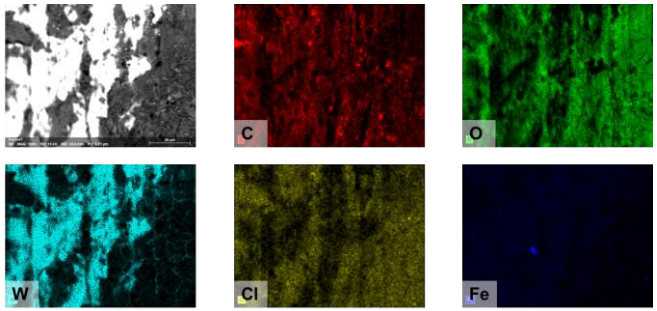
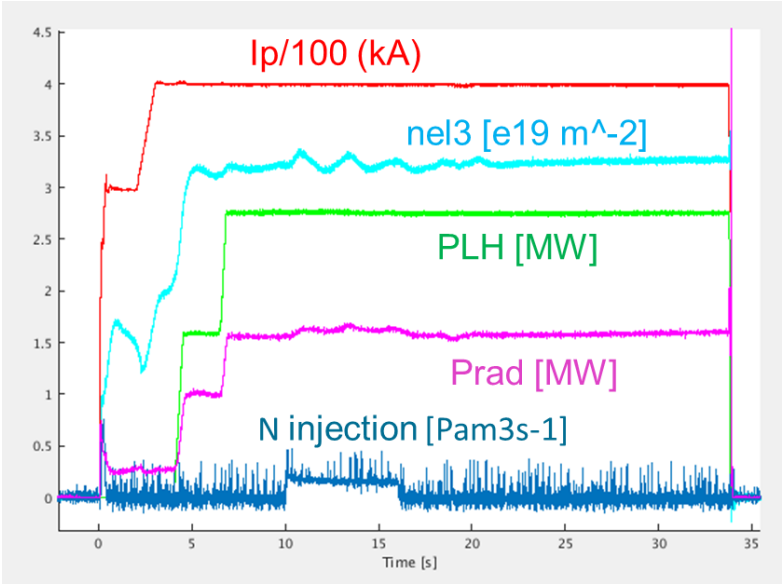
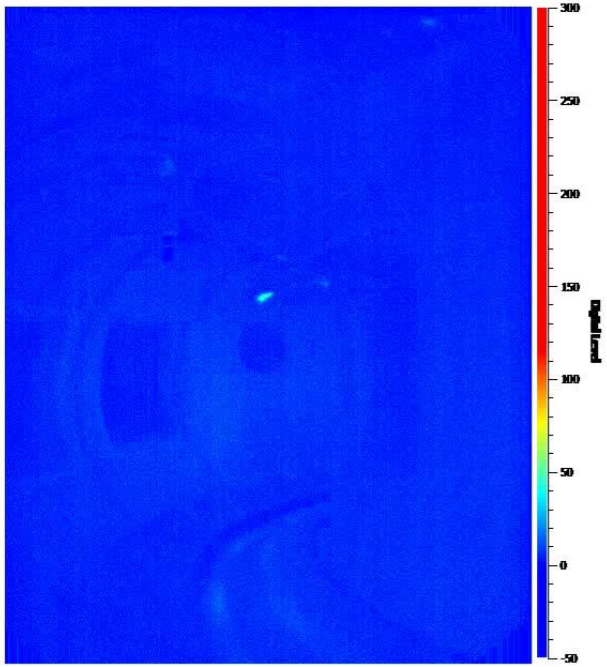


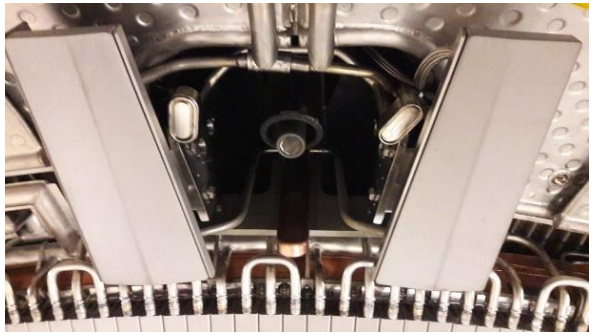
Exploring material migration in long pulse

- **Routine long pulse operation performed on upper divertor**
  - Long pulse scenario on upper div developed (Ip = 400 kA, PLH = 2.3 MW / 30 s)
  - ~20 mn of plasma in 2 operation days
  - N injection scan (rate / duration, divertor and outer bumper injection)
  - No N legacy effect evidenced





- **ORNL collector probe successfully exposed**



  - ~10 s in far SOL (Te< 10 eV to avoid re-erosion)
  - Samples post mortem analysis ongoing
  - Large US delegation in January 2019 (modelling)

Significant WEST contribution @ PFMC 2019

10 WEST papers at PFMC

- First plasma operation in WEST with tungsten as plasma facing material, J. Bucalossi et al (invited)
- Thermal behavior of misaligned leading edges on ITER-like Plasma Facing Units in WEST, A. Grosjean et al.
- Properties of heat load profiles on the lower divertor of WEST in L-mode experiments, N. Fedorczak et al
- Tungsten divertor sources in WEST related to impurity inventory and local plasma conditions, G. van Rooij (DIFFER) et al
- Modeling of tungsten migration in WEST with SolEdge2D-EIRENE and ERO2.0, A. Gallo (AMU) et al
- Long pulse and nitrogen seeded discharges on the actively cooled tungsten upper divertor in WEST, T. Dittmar (FZJ) et al (oral)
- Long pulse experiment on actively cooled upper divertor, T. Loarer et al.
- Initial Experiments on Tungsten Erosion and Migration Using a Combination of In-situ Spectroscopy and Collector Probes in the WEST Tokamak, Z. Unterberg (ORNL) et al.
- Observation of plasma facing components in WEST tokamak after the C1, C2 and C3 campaigns, M. Diez et al.
- L-mode WEST tungsten divertor operation: Edge plasma transport simulations with SOLEDGE2D-EIRENE and comparison with experiments, R. Mao et al.

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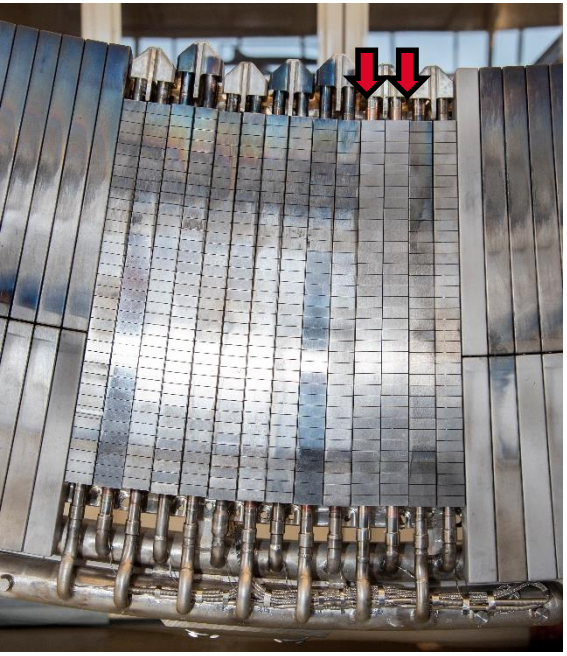
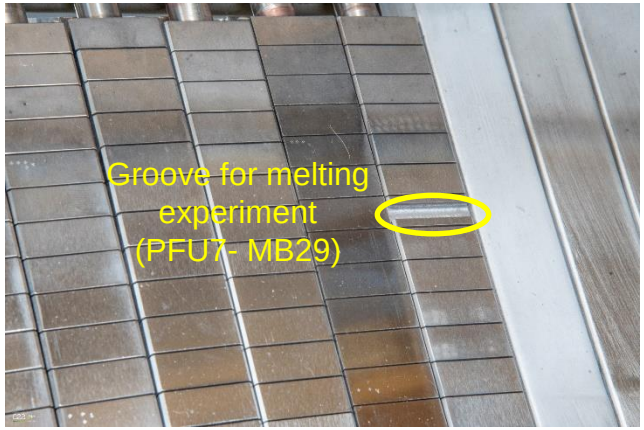
Divertor test sector fully equipped for C4



- 14 ITER like PFU (2 additional F4E PFU)



- PFU re-aligned within specs (4 PFU misaligned @ 0.3 mm)
- Pre-damaged PFU at max OSP
- Vickers marking for VHR IR
- Groove machined for a melting experiment

C4 campaign discussed at the WEST workshop

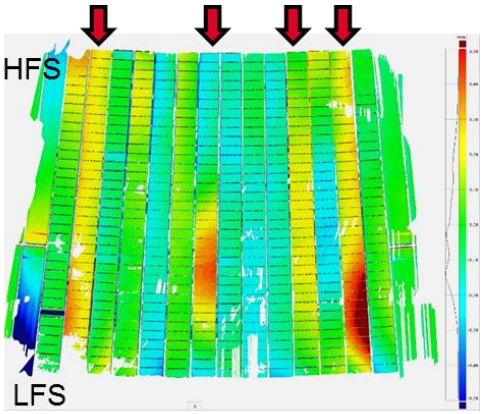
WEST workshop, March 2018

Main objectives :

- Increase injected power **towards 10 MW** → *H-mode*
- Perform a **He campaign** (He-W PWI) → *EUROfusion / US*

D phase : complete exploration of divertor / PFU exposure (cf C3)

- **WEST divertor operational domain (3 sessions)**
  - SOL widths (1 session)
  - W source : divertor vs main chamber (1 session), Divertor regimes (1 session) + regular reference pulse
- **Long pulse operation (1 session)**
  - Long pulse experiments using the upper div (1 session)
- **Power handling of ITER like PFU (12 sessions)**
  - "High Heat flux" scenario development (2 sessions)
  - Shaping / tolerance to PFU misalignment (3 sessions)
  - Pre-damaged PFU exposure (5 sessions)
  - PFU melting experiment (2 sessions)



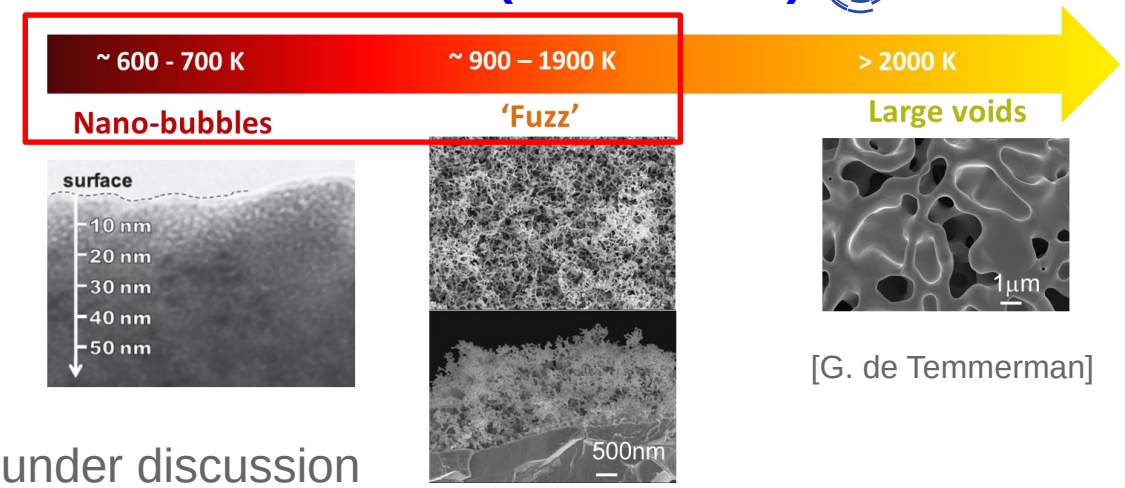
Extensive He campaign performed at the end of C4

He vs D comparison (11 sessions)

- He to D changeover (3 sessions)
- Steady state heat load pattern : He vs D (3 sessions)
- W source : He vs D (4 sessions)
- Divertor regimes : detachment He vs D (1 session)

Interactions of W inertial / ITER like PFU with He (5 sessions)

- Nanostructure formation (He nanobubbles, W fuzz …) ➔ material properties ?
- ~1 week of repetitive long pulses (~1 mn) : ~ 10^{25} He/m^2
- ORNL collector probe exposure
- Tracer experiment (eg He^3, N^{15}) under discussion
- Followed by post mortem analysis (lower divertor dismantled for WEST phase 2)



[G. de Temmerman]

see talk of S. Brezinsek

~ 40 EU visitors + US team expected for C4 : you are welcome to join !

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