



ITER Langmuir probes: Physics and technological issues under investigation in the WEST tokamak

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ITER Langmuir probes: Physics and technological issues under investigation in the WEST tokamak

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*see <http://west.cea.fr/WESTteam>

47th EPS Conference on Plasma Physics, June 21-25, 2021

WEST tokamak's main mission

-testing ITER-like divertor components and diagnostics in a tokamak environment

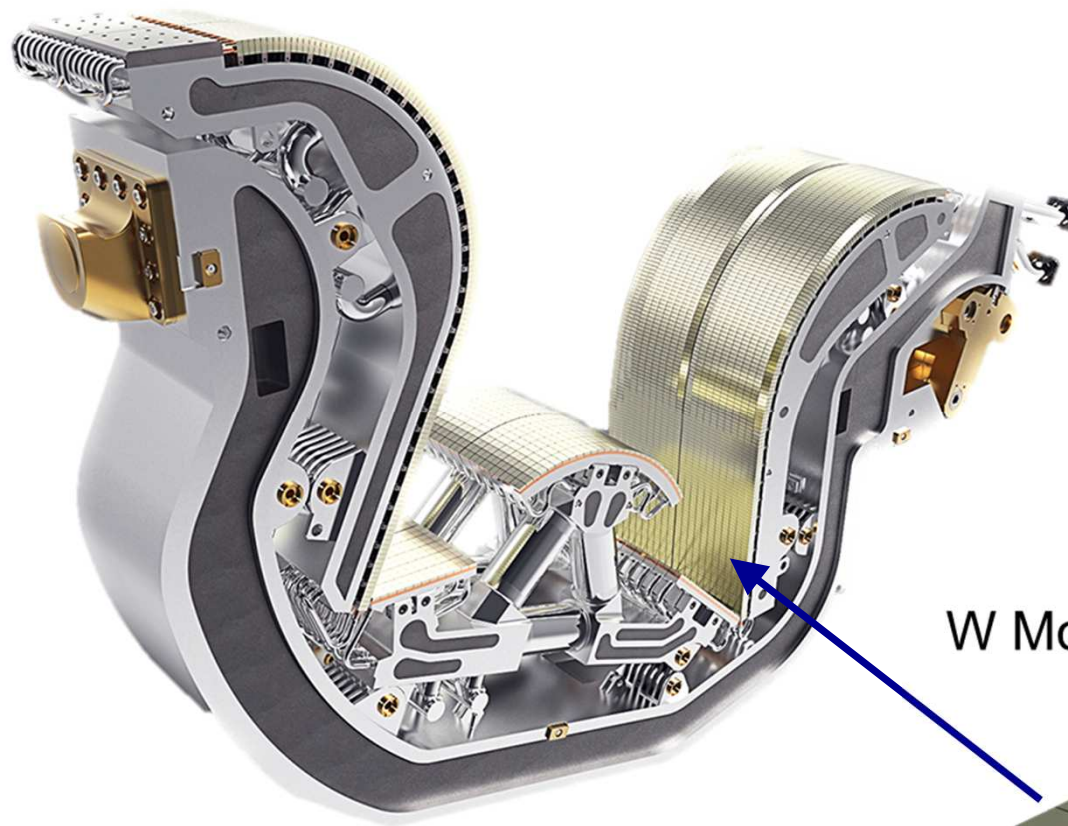
Missions of divertor Langmuir probes in WEST

-provide measurements of divertor plasma parameters for WEST scientific program

-investigate design issues impacting ITER probes (thermomechanical behaviour under intense, steady-state heat loads)

-evaluate accuracy of flush-mounted probe measurements by a physics-based approach

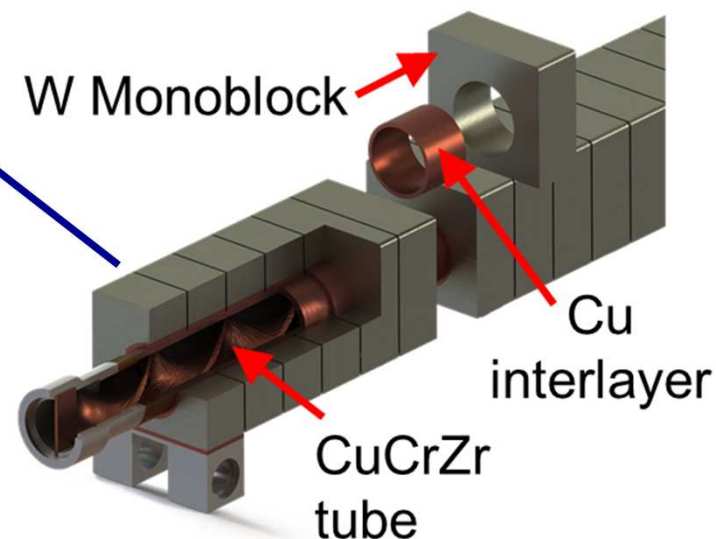
DIVERTOR HEAT FLUX IN ITER IS AT THE LIMIT OF WHAT MATERIALS CAN WITHSTAND



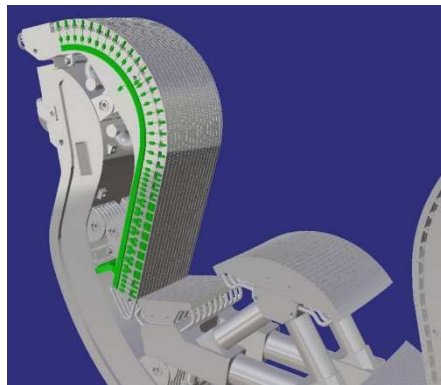
ITER divertor cassette

For heat flux of 10 MW/m^2 , exposed leading edges must be avoided by careful component shaping. Langmuir probes will suffer the same (or even worse) punishment as the divertor.

-Flush mounted probes are the only option.

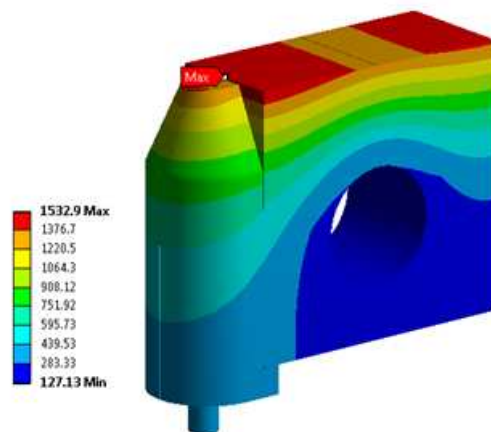


Probes must have good thermal contact with W monoblocks, and at the same time, be electrically insulated from them

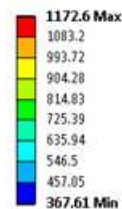


Preliminary design:

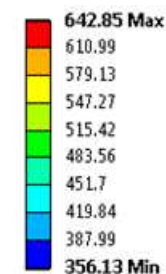
- tapered W heat shield bonded to monoblock (heat spreading)
- flush-mounted probe insulated from heat shield by alumina sheath (all brazed together)



a



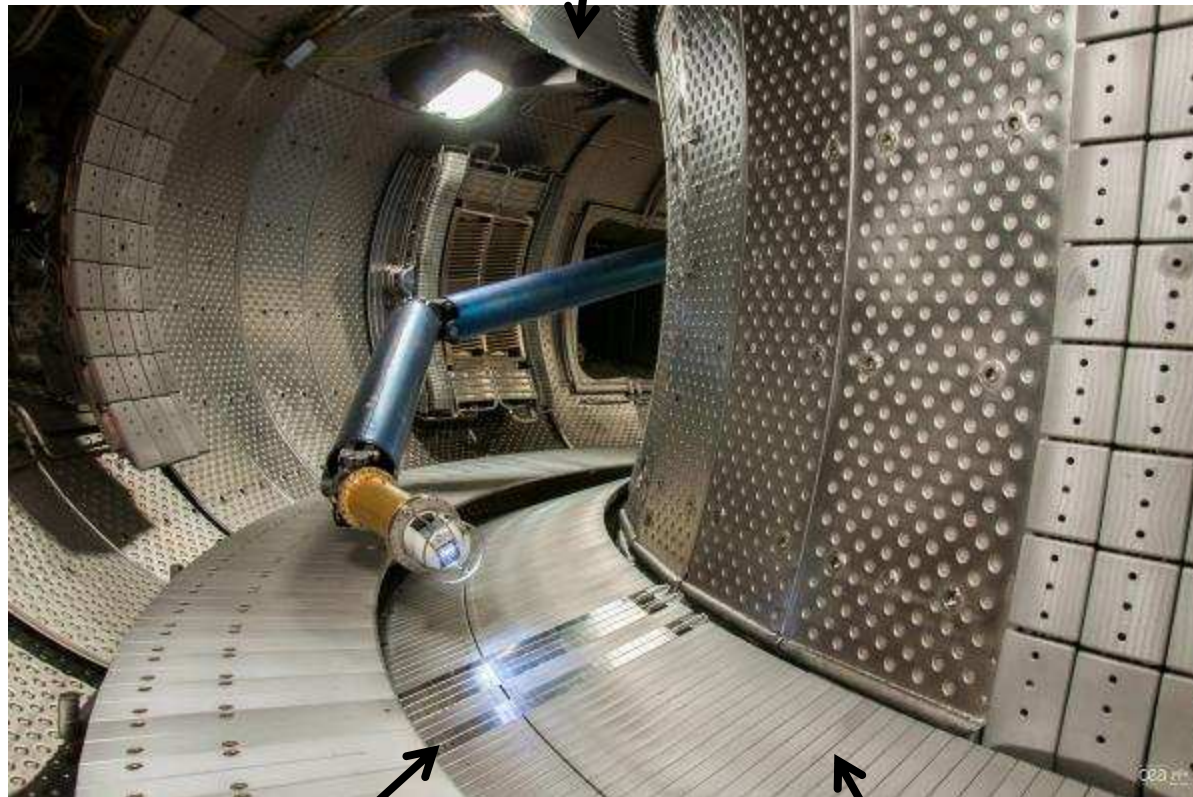
b



c

a) temperature field of DLP and monoblock; b) temperature field of probe; c) temperature field of ceramic

W-coated CuCrZr upper divertor targets (actively cooled)

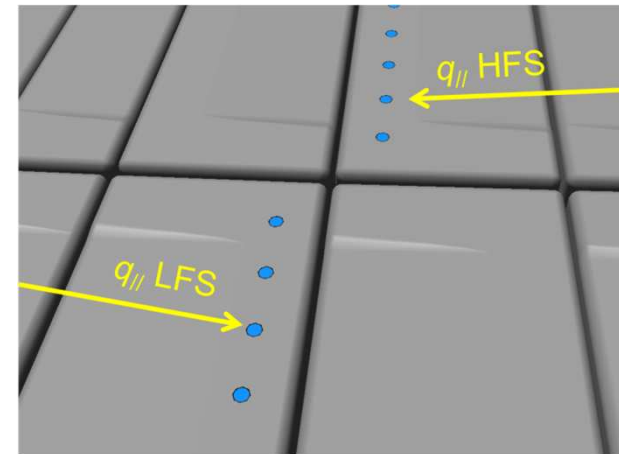
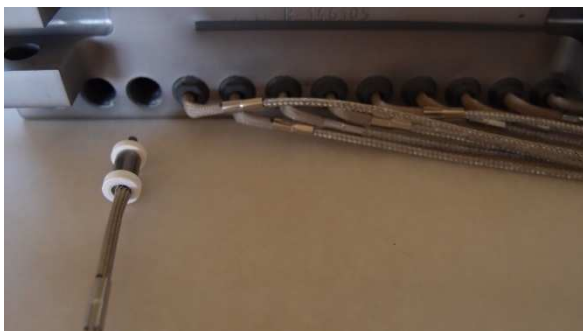
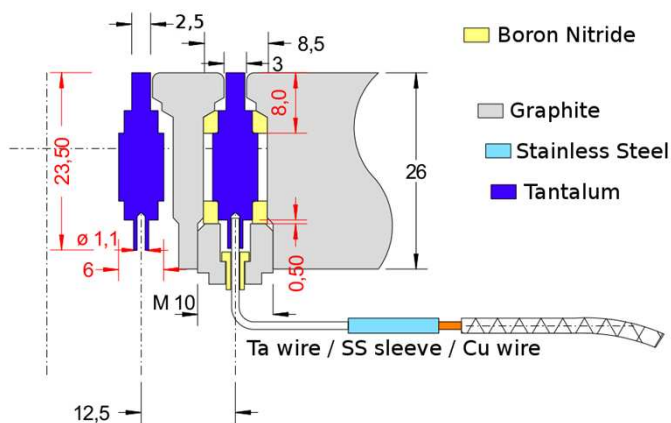


ITER like full W divertor targets
(actively cooled)

W-coated graphite lower divertor
targets (uncooled)

Probes provided in-kind by IPP-Prague

2 arrays of 29 probes (tantalum metal)
-high melting temperature ($\sim 3000^\circ\text{C}$) and ductile at room temperature (allows crimping wires onto bottom of probe)
Radial resolution 12.5 mm



FLUSH PROBE TIPS HAVE TO BE EXTREMELY WELL ALIGNED WITH THE DIVERTOR SURFACE

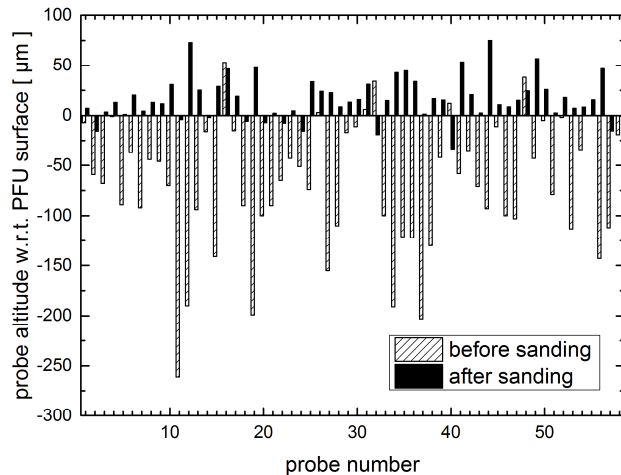
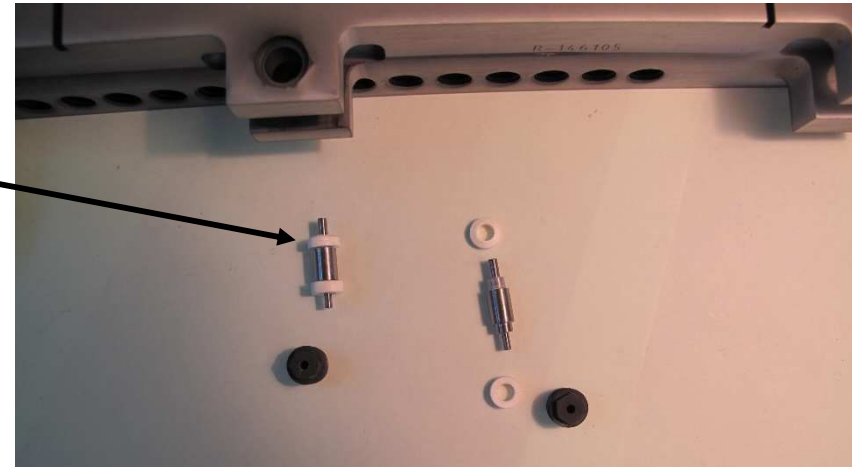
Probes were manufactured to be recessed 0.1 mm below surface

Boron nitride spacers were sanded manually on emery cloth until the probes "felt" flush by rubbing the surface with our finger

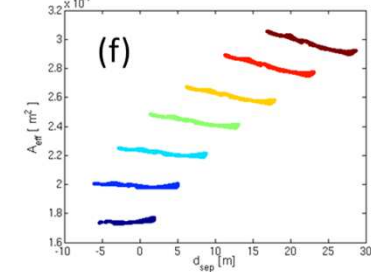
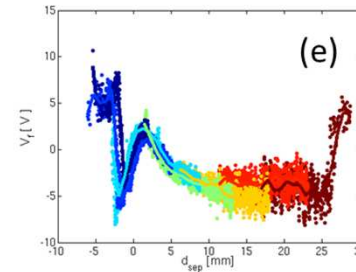
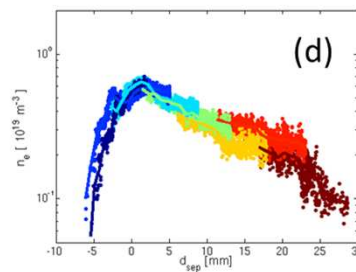
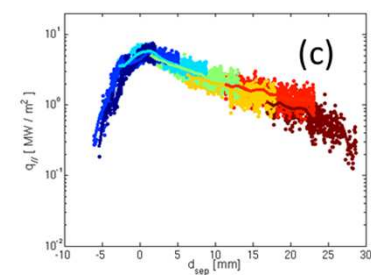
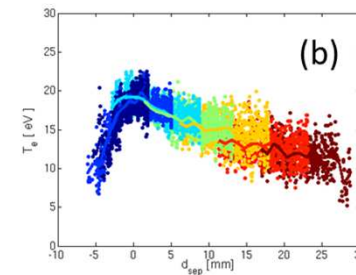
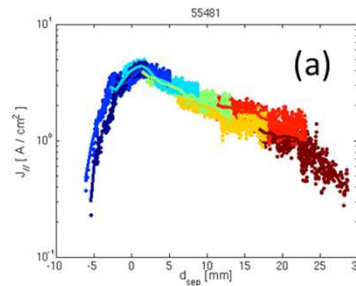
Mean alignment measured by confocal microscopy before and after sanding

Before : $-69 \pm 65 \mu\text{m}$ \sim ion Larmor radius

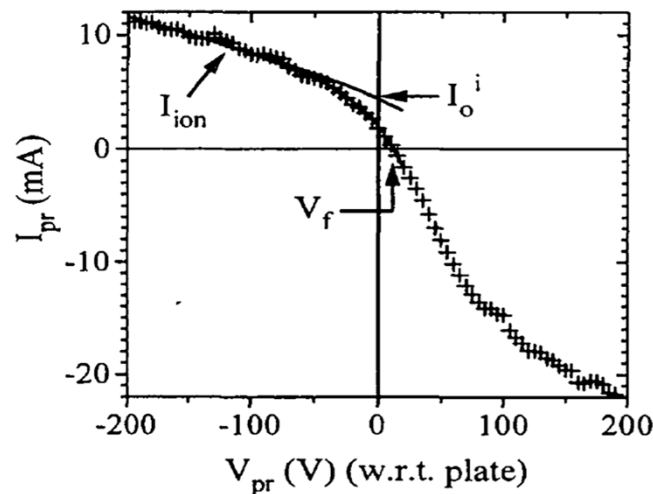
After : $+16 \pm 22 \mu\text{m}$ $<$ ion Larmor radius



R. Dejarnac, et al., Flush-mounted
Langmuir probes in the WEST tokamak
divertor Fusion Engineering and Design
163 (2021) 112120



Target profiles during OSP sweep are continuous⁷



flush-mounted probe I-V characteristic

short-circuit
ion current
 $\sim \sin \alpha$

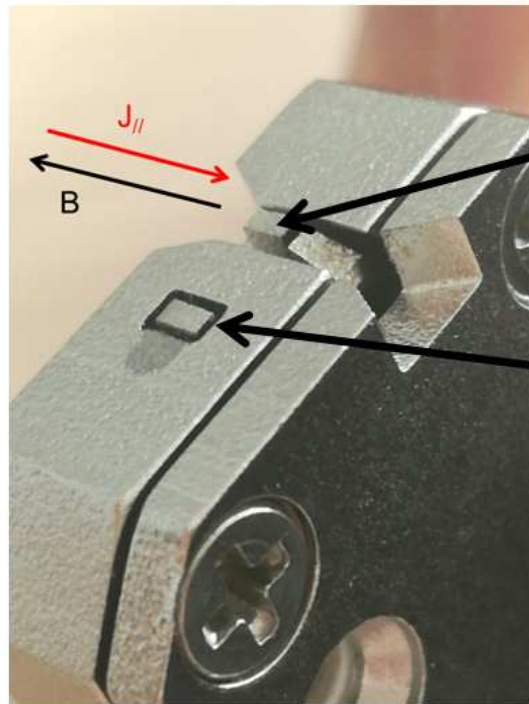
sheath expansion
current
 $\sim \sin^{-1/2} \alpha$

$$I_{ion} = I_{o,i} + I_{sh}$$

$$= J_{//,i} [A_{pr} \sin \alpha + 2r_{pr} (d(V_{pr}) - d_0)]$$

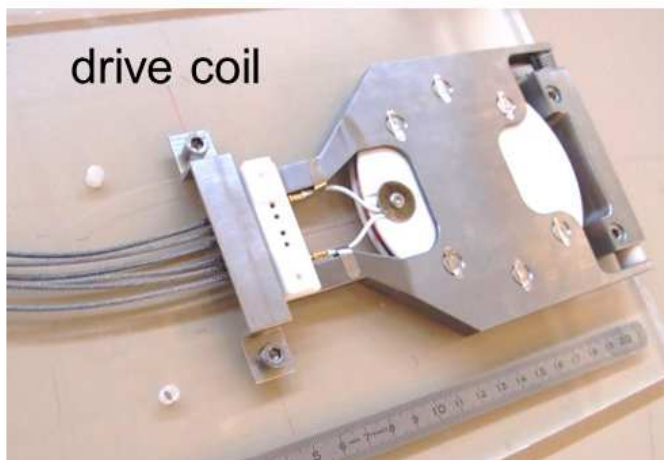
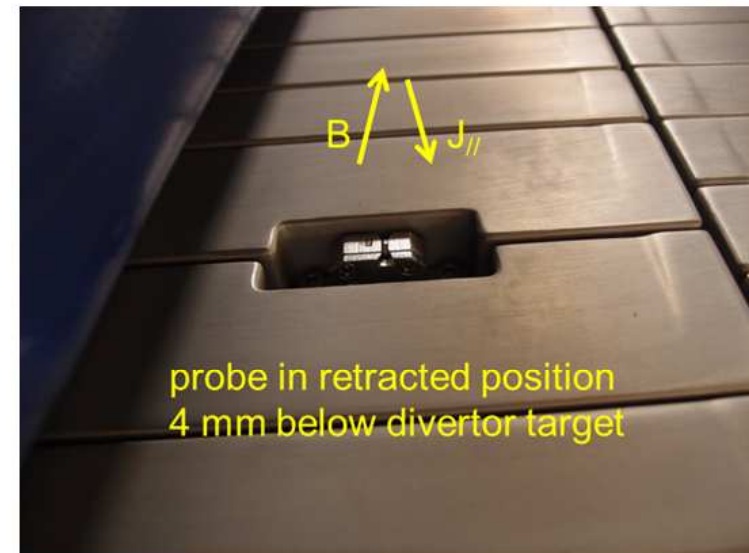
In collaboration with SWIP (Chengdu) and ITER, a dedicated probe was designed in order to measure simultaneously with a flush probe and a classical proud probe having a well-defined collecting area.

The principal aim was to learn whether flush-mounted probes measure density and temperature correctly, despite their complex collection physics.

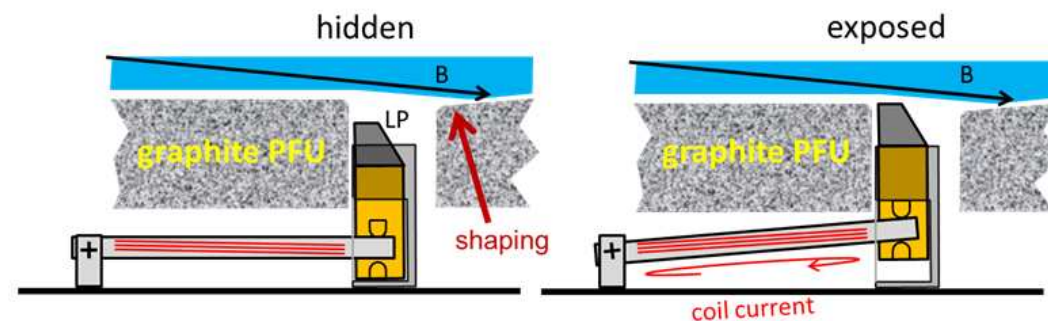


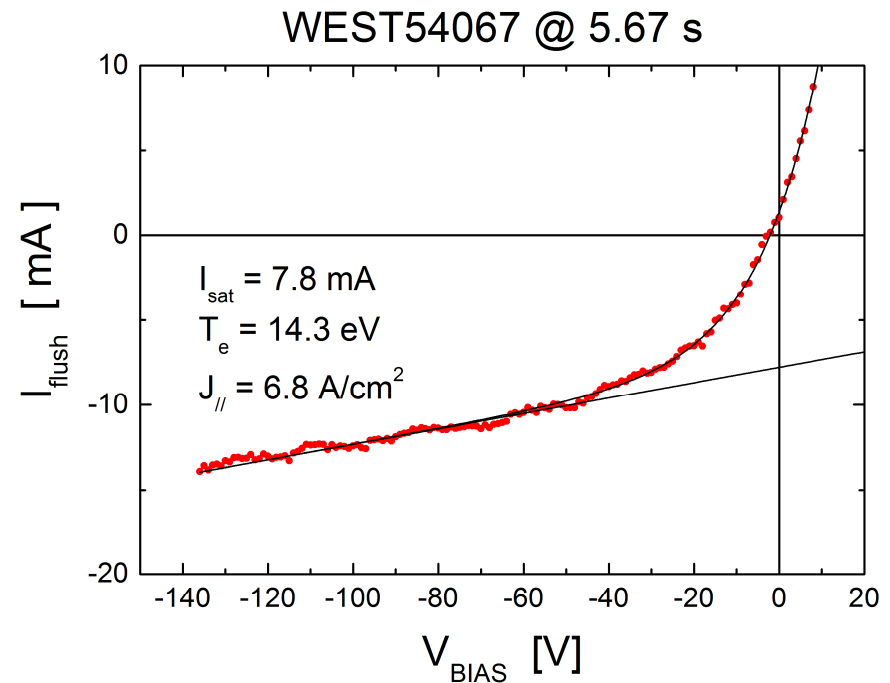
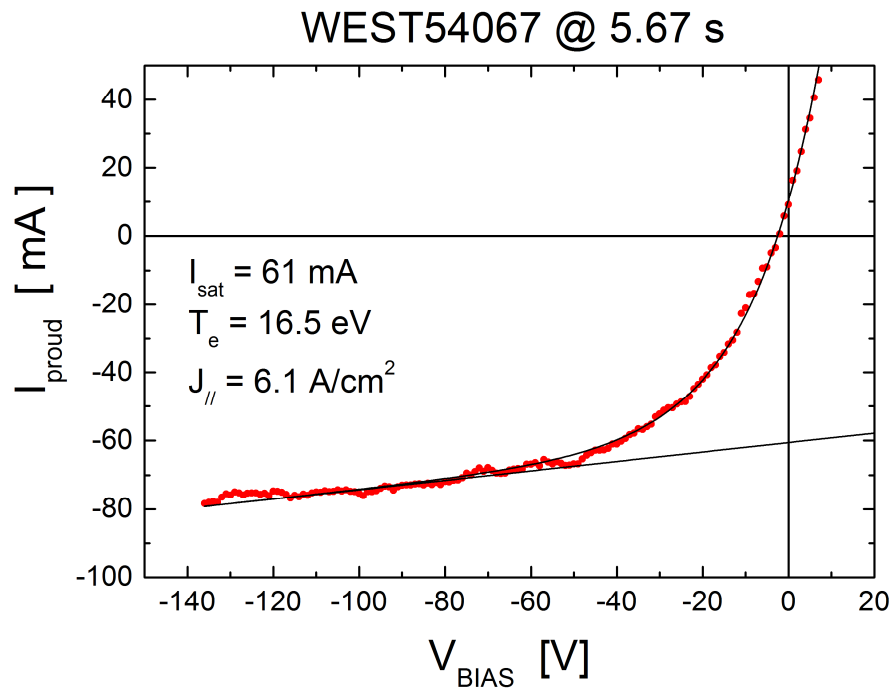
proud probe protrudes
1 mm above target

flush probe



drive coil

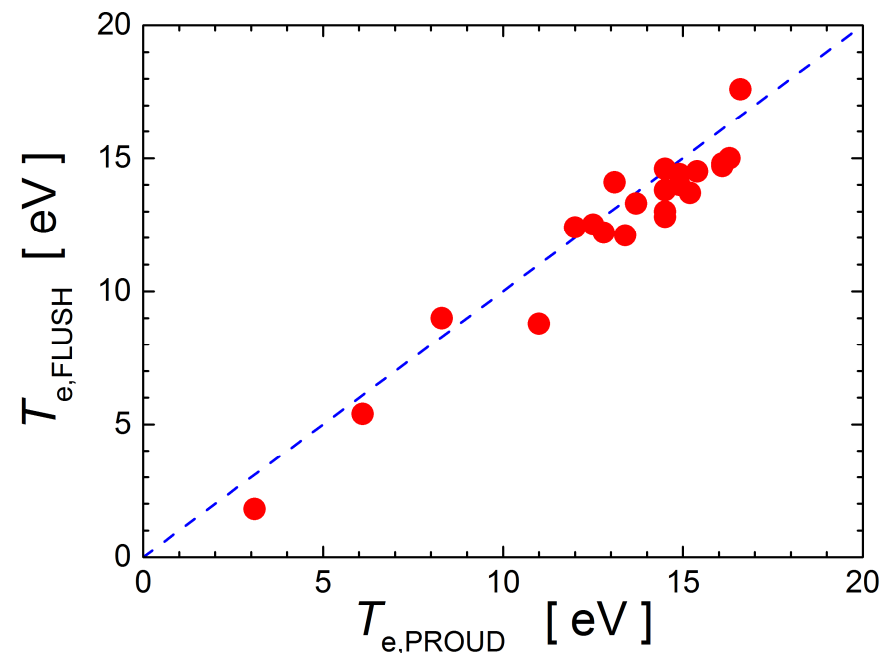
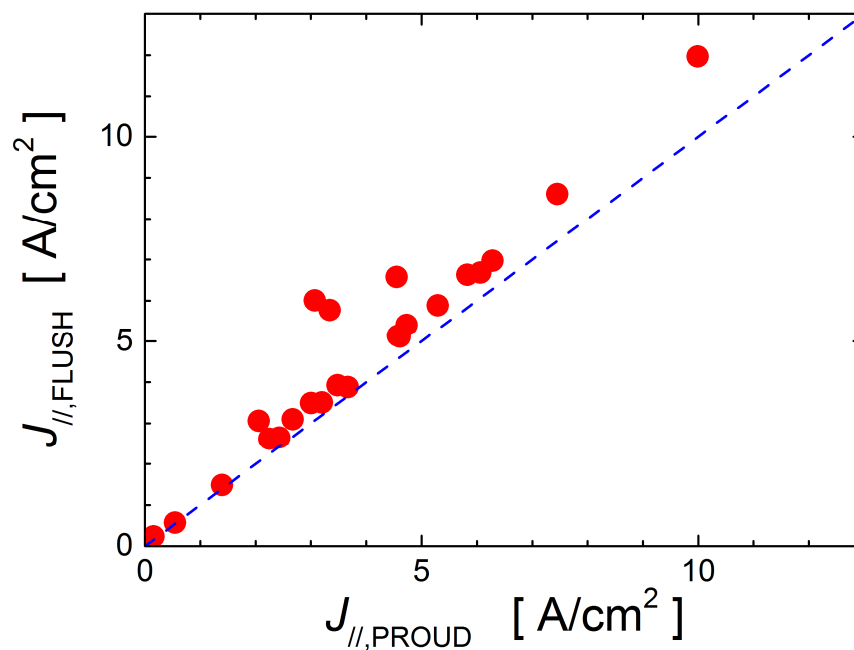




ion current extrapolated to machine ground
 electron current
 ion current variation due to sheath expansion

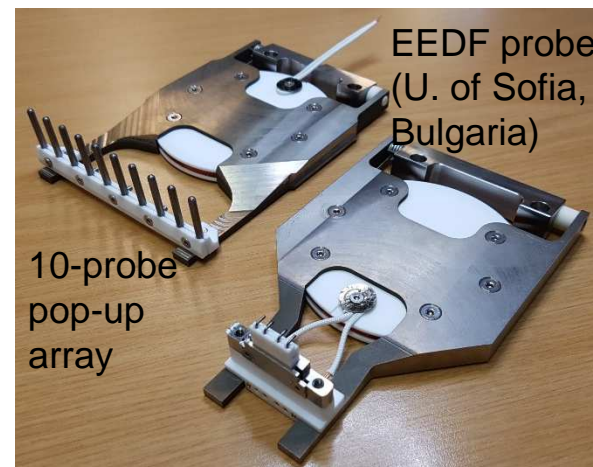
$$I(V) = I_{\text{sat}} \left[1 - \exp\left(\frac{V - V_f}{T_e}\right) \right] + \frac{\Delta I}{\Delta V} V$$

All data from experiment of December 14, 2018



The mousetrap operated successfully throughout WEST Phase 1 operation, making a total of 2587 reciprocations on 1587 discharges, in all plasma scenarios.

Six new mousetrap drive mechanisms have been installed in the WEST Phase 2 full ITER-like tungsten divertor, which will begin operation in 2022.



Courtesy of B. Guillermin

In-kind contribution by

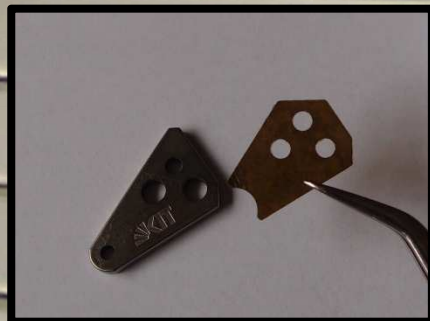


S. Antusch, et al., "Processing of complex near-net-shaped tungsten parts by PIM", Nuclear Materials and Energy 16, 71 (2018).



2 arrays of 30 probes
-spatial resolution 12.5 mm
-manufactured by tungsten powder injection moulding
-flared geometry to spread heat
- $T_{\text{tip}} \sim 800^{\circ}\text{C} / 12 \text{ MW/m}^2$

Two types of electrical insulation being tested



0.1 mm phlogopite mica sheets
 $T_{\text{max}} \sim 1000^{\circ}\text{C}$



HVOF plasma-sprayed alumina
(Stony Brook University + IPP Prague) $T_{\text{max}} > 1900^{\circ}\text{C}$

59/60 probes still working
Survived discharges up to 1 minute long
Total exposure 52 minutes
Heat flux $\sim \text{MW/m}^2$

In-kind contribution by



Slots were cut between PFUs to house probes, and threaded screwholes were cut to fix probes to the monoblock sides (both by electroerosion, CISRI International Trading Co.,LTD, China - great work!). Insulation by mica sheets.

In addition to providing data for the WEST scientific program, Langmuir probes provide input to the ITER probe design.

Three principal issues were investigated:

1) lower divertor flush-mounted probes highlighted the importance of individual probe alignment with divertor surface to yield coherent measurements between different probes (strike point sweep in WEST provides nice continuous profiles)

2) The mousetrap probe in WEST has shown that flush-mounted probe data can be analyzed with confidence. Good news for ITER Langmuir probes.

The brilliant performance of the magnetic drive system has encouraged us to install six more such devices in WEST Phase 2 (we believe that it could be a viable option for ITER probes, and in fact the concept has already been adopted for the ITER fast ion loss detector).

3) upper divertor wafer probes - good results concerning thin electrically insulating layers (both phlogopite mica and HVOF sprayed alumina). Good performance of PIM tungsten in a tokamak environment.

-The same solution has been adopted for WEST Phase 2 full-W ITER-like PFUs.