

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

J. P. Gunn, J. -y Pascal, S. Antusch, R. Dejarnac, G. Dwivedi, A. Klein, J. Kotlan, J. Matějíček, M. Rieth, D. Šesták, et al.

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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

INTRODUCTION

WEST tokamak's main mission

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

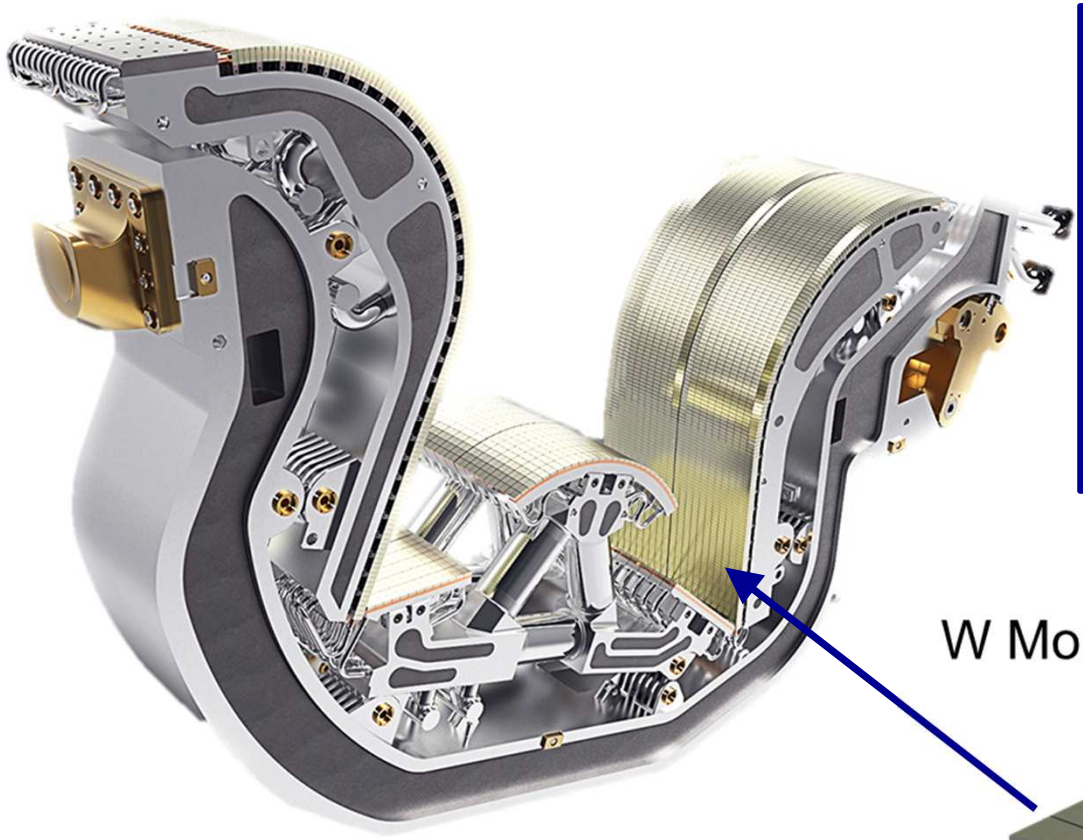
Missions of divertor Langmuir probes in WEST

-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

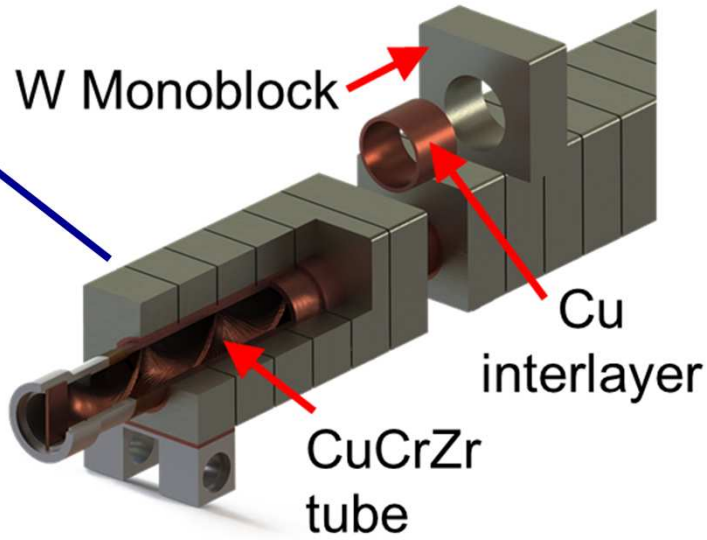
DIVERTOR HEAT FLUX IN ITER IS AT THE LIMIT OF WHAT MATERIALS CAN WITHSTAND



ITER divertor cassette

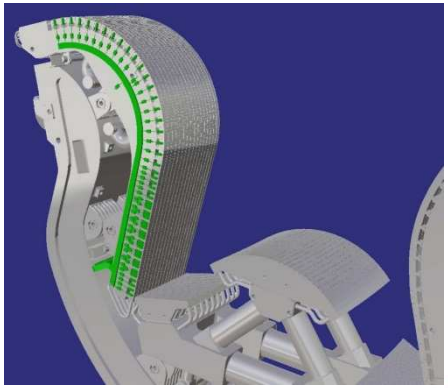
For heat flux of 10 MW/m^2, exposed leading edges must be avoided by careful component shaping.
Langmuir probes will suffer the same (or even worse) punishment as the divertor.

-Flush mounted probes are the only option.



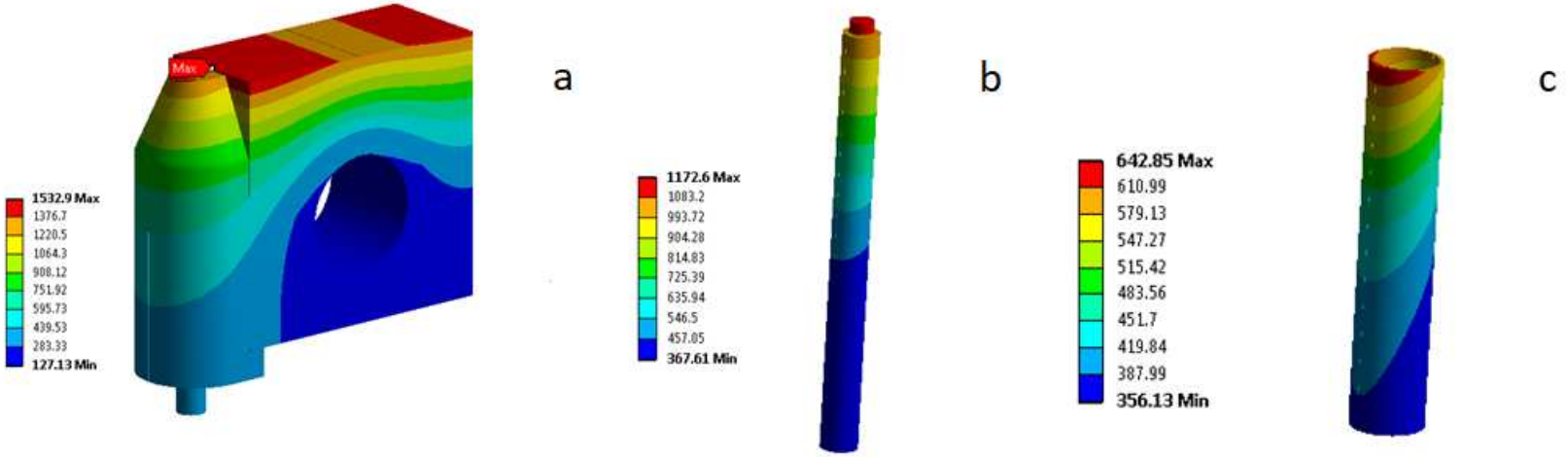
DESIGN OF ITER LANGMUIR PROBES

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)

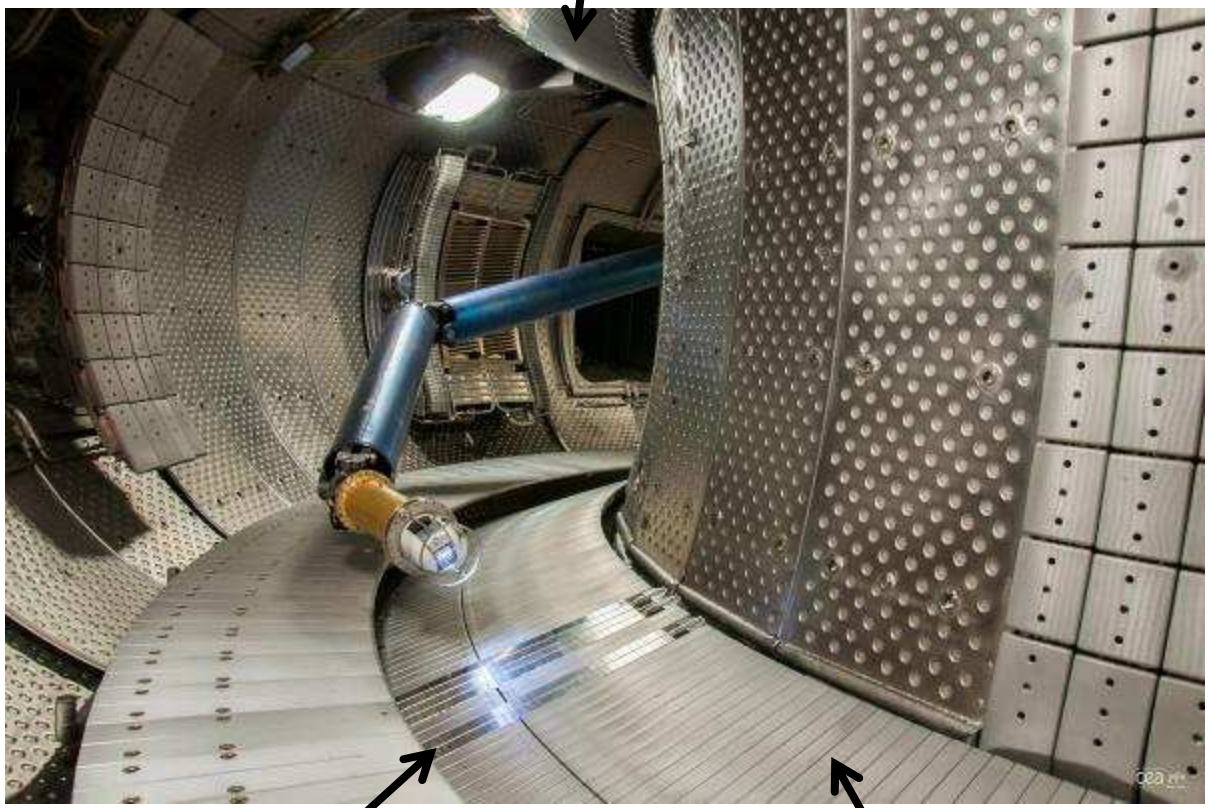


a) temperature field of DLP and monoblock; b) temperature field of probe; c) temperature field of ceramic

Wei Zhao, Yali Wang, Yuzhong Jin, Li Zhao, Hongxia Zhou, Lin Nie, Guangwu Zhong, Chunjia Liu, Christopher Watts, James Paul Gunn, "**Preliminary Design of ITER Divertor Langmuir Probe System**", Fusion Science and Technology, **76**, 79 (2020).

WEST TOKAMAK (CADARACHE, FRANCE)
PHASE 1 OPERATION (2016-2021)

W-coated CuCrZr upper divertor targets (actively cooled)



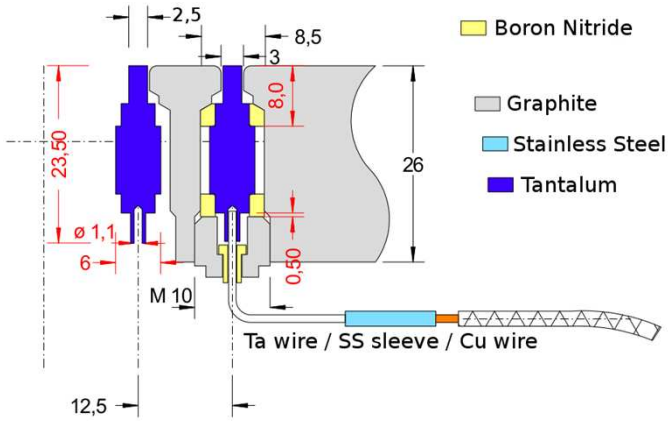
ITER like full W divertor targets (actively cooled)

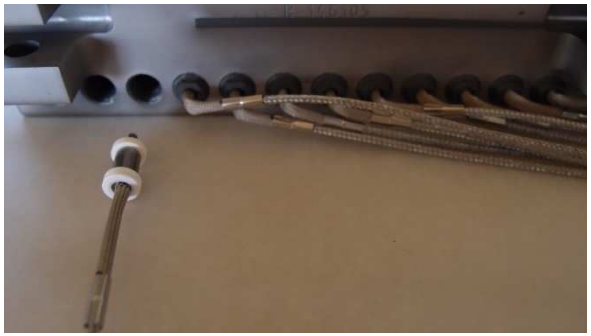
W-coated graphite lower divertor targets (uncooled)

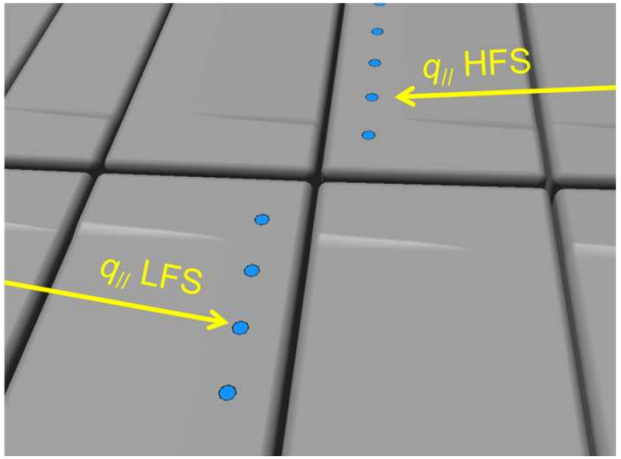
LOWER DIVERTOR
FLUSH-MOUNTED PROBES IN INERTIAL GRAPHITE

Probes provided in-kind by IPP-Prague

2 arrays of 29 probes (tantalum metal)
-high melting temperature (~3000℃) and ductile at ro om 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

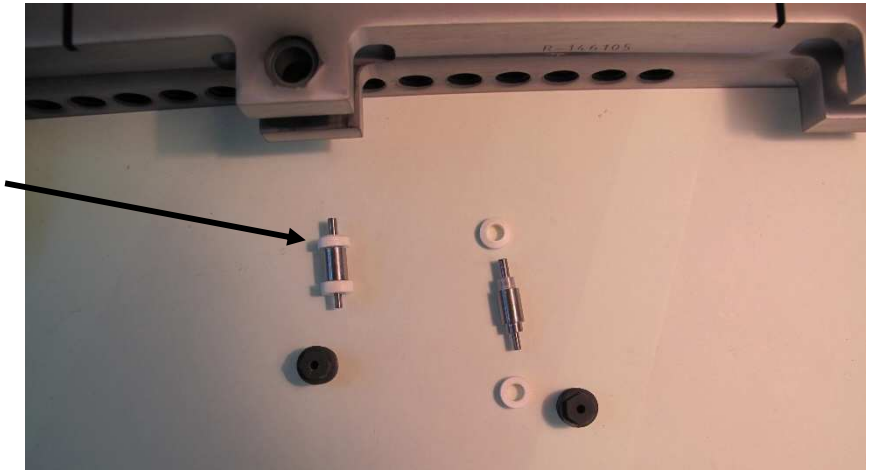
Probes were manufactured to be recessed 0.1 mm below surface

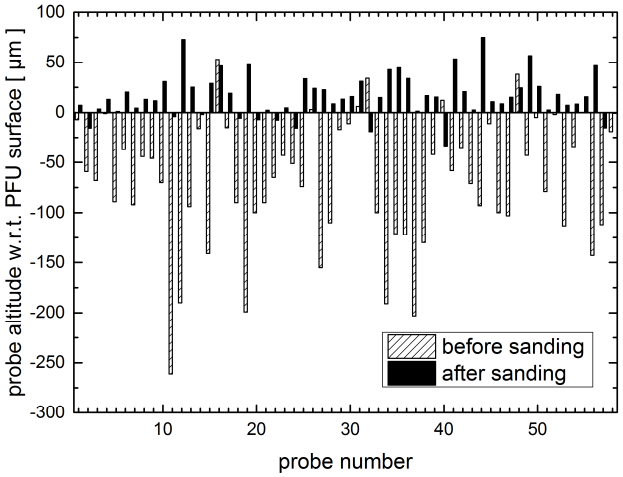
Boron nitride spacers were sanded manually on emery cloth until the probes "felt" flush by rubbing the surface with our finger

Mean alignment measured by confocal microscopy before and after sanding

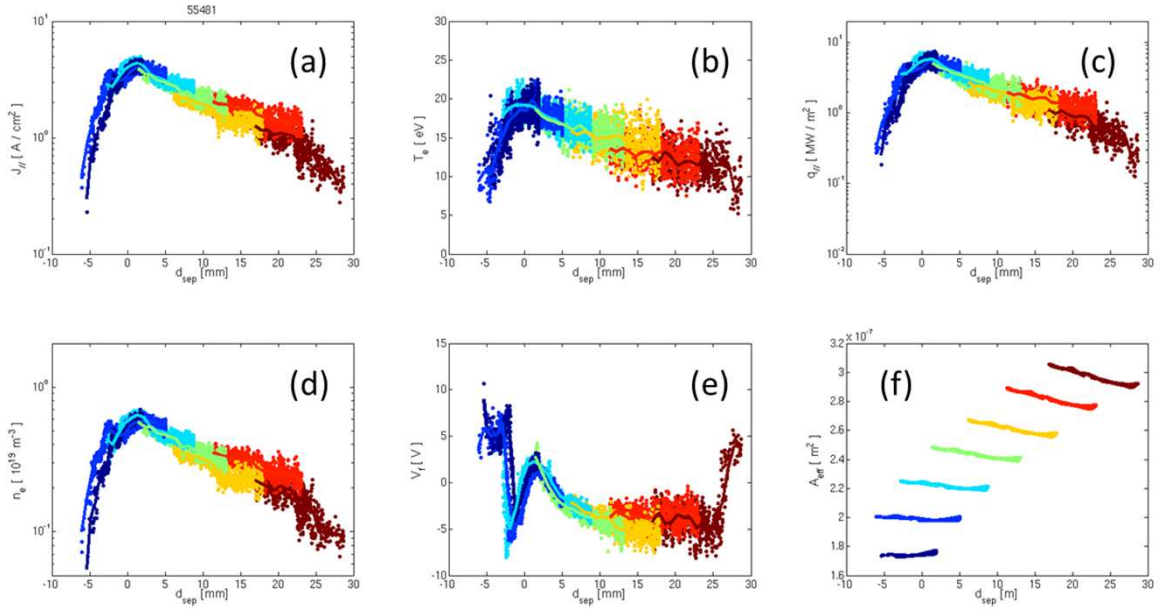
Before : -69±65 µm ~ion Larmor radius

After : +16±22 µm <ion Larmor radius



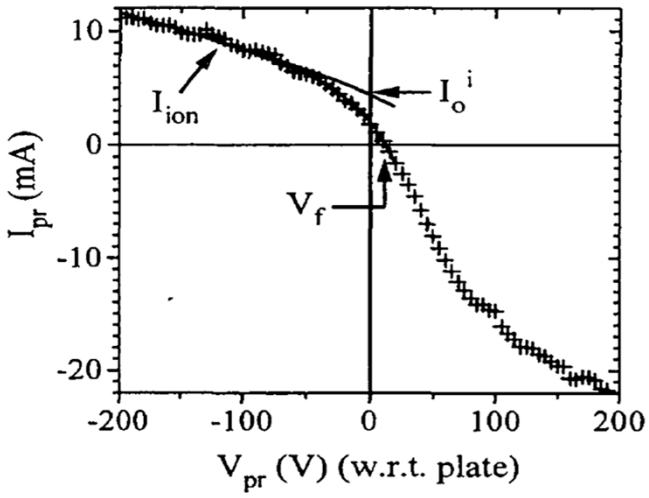


R. Dejarnac, et al., Flush-mounted Langmuir probes in the WEST tokamak divertor Fusion Engineering and Design **163** (2021) 112120



Target profiles during OSP sweep are continuous

ALIGNMENT BETWEEN PROBES IS CRITICAL, BUT CAN THEY MEASURE CORRECTLY TO BEGIN WITH?



flush-mounted probe I-V characteristic

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

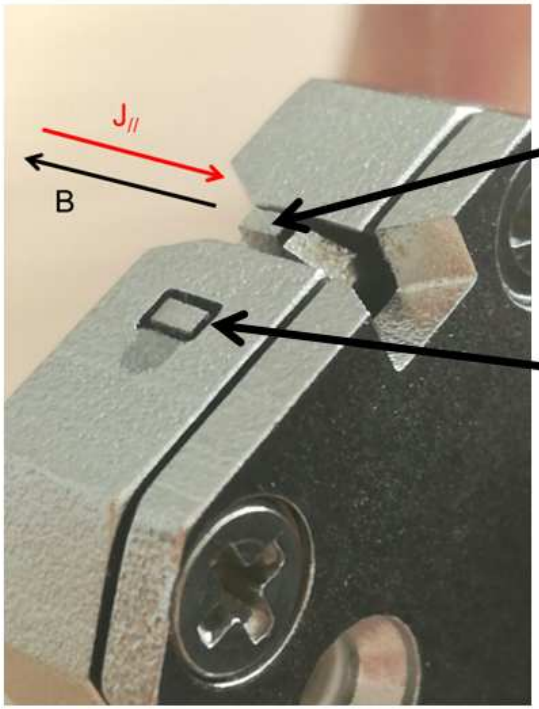
sheath expansion current $\sim sin^{-1/2}\alpha$

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

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.

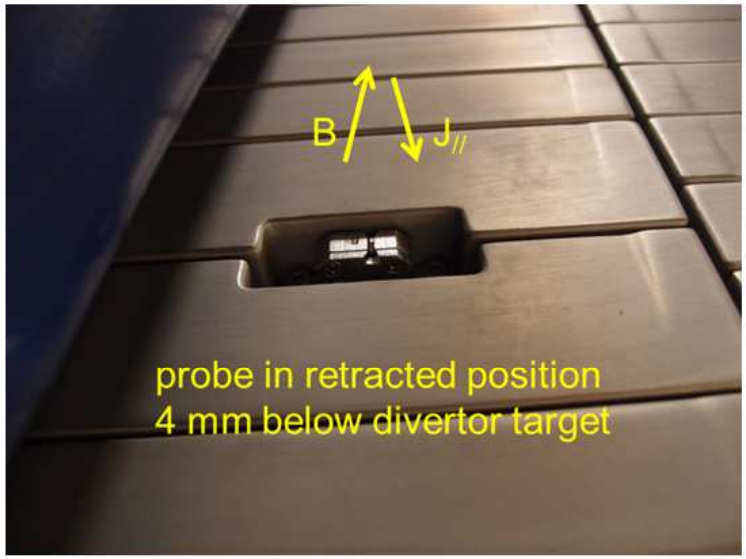
The principal aim was to learn whether flush-mounted probes measure density and temperature correctly, despite their complex collection physics.

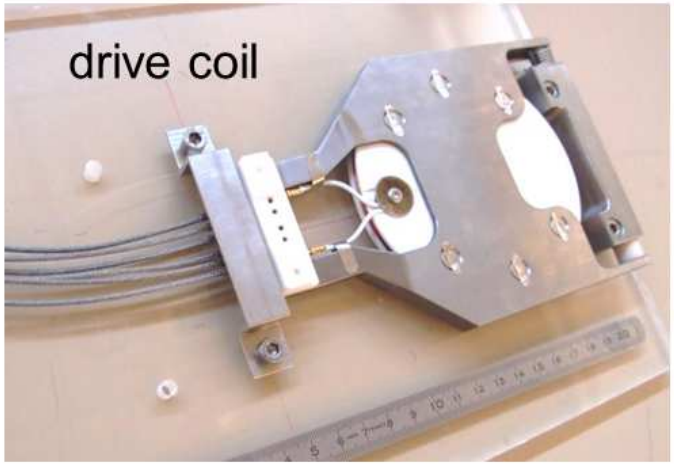
MOUSETRAP PROBE - A MINI LABORATORY FOR STUDYING FLUSH-MOUNTED PROBE PHYSICS

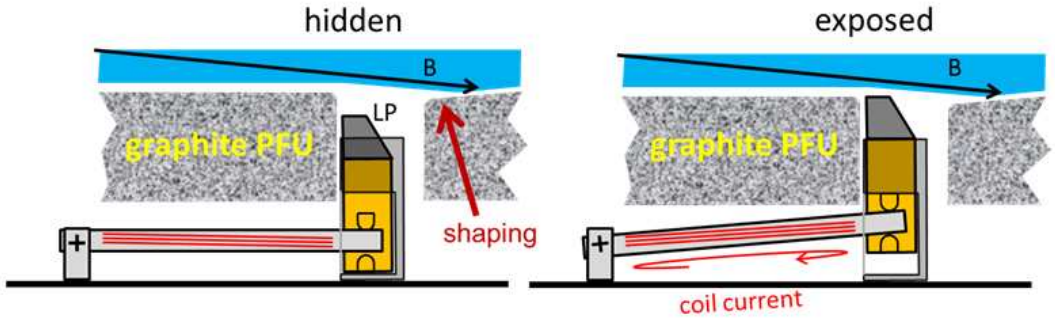


proud probe protrudes
1 mm above target

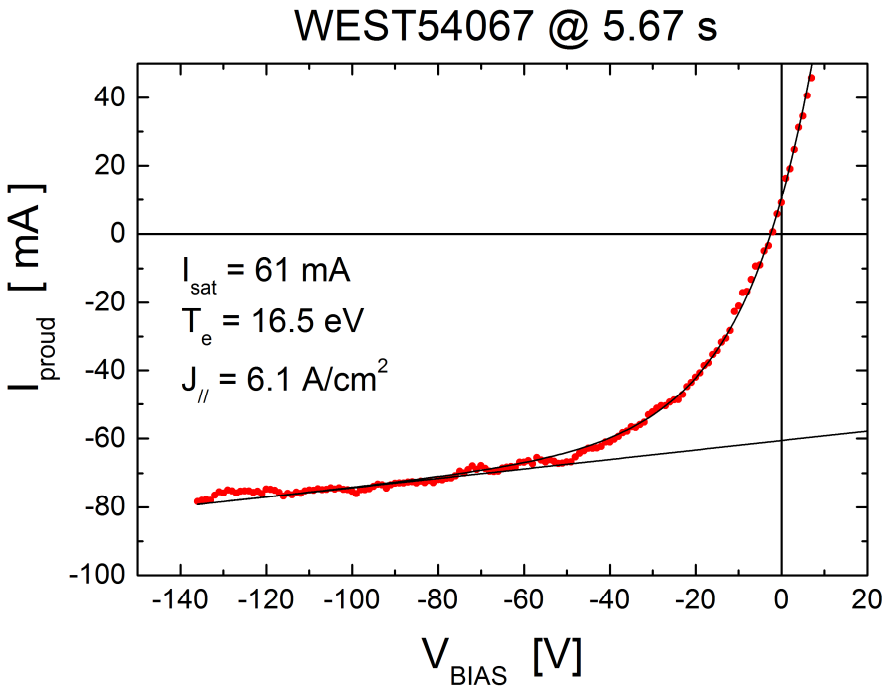
flush probe

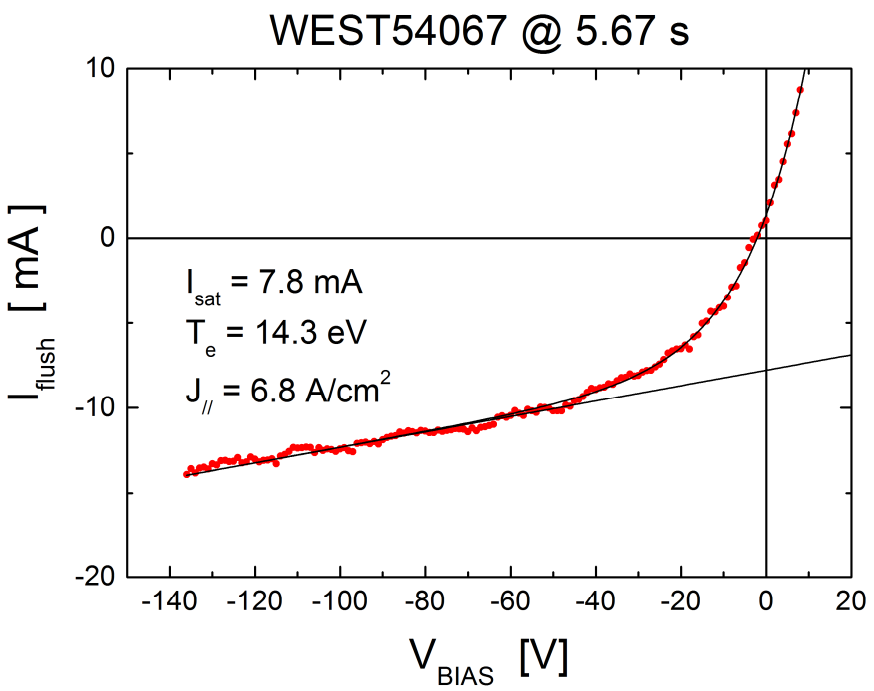






DESPITE VERY DIFFERENT COLLECTING GEOMETRIES BOTH PROBES GIVE THE SAME RESULTS





ion current extrapolated to machine ground

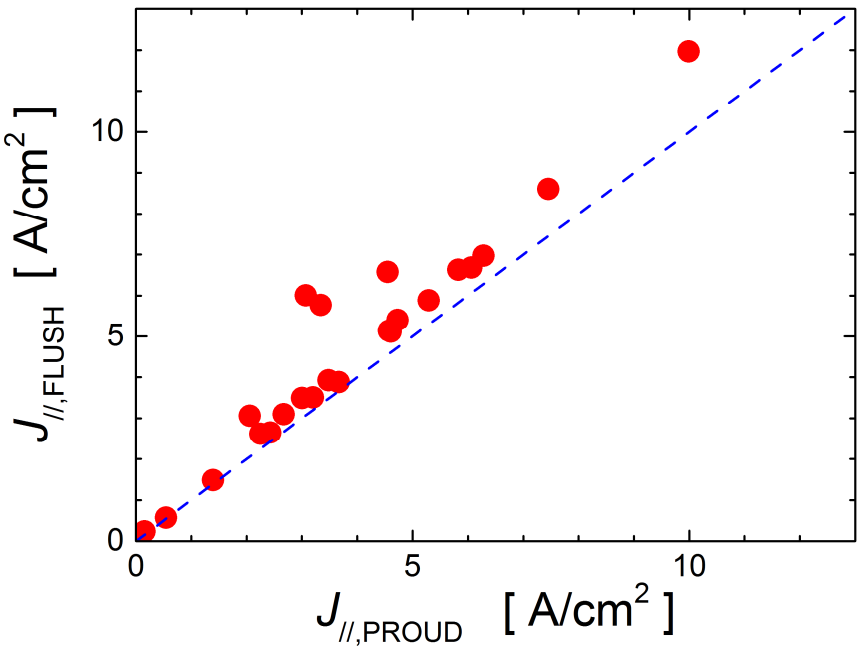
electron current

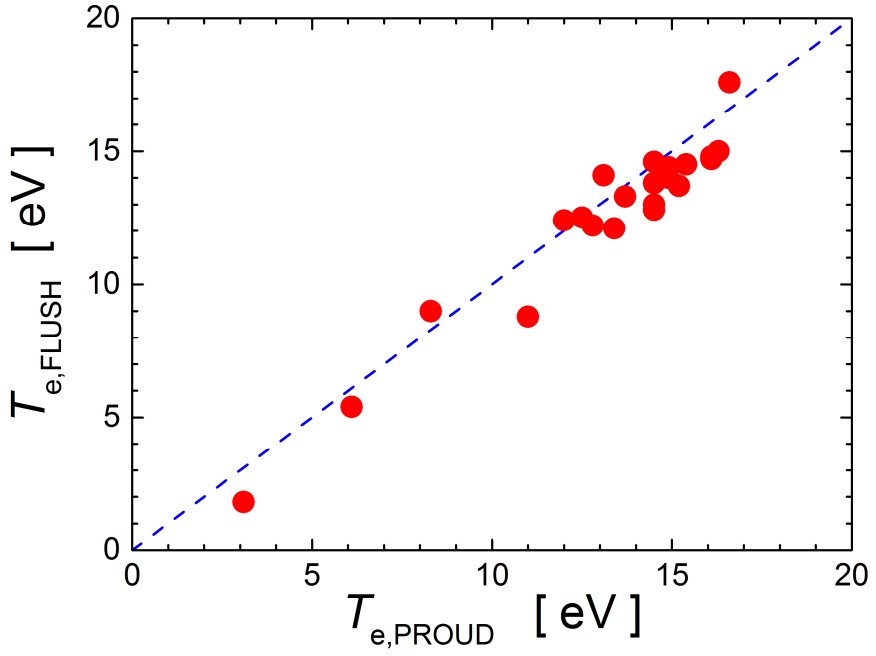
ion current variation due to sheath expansion

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

MOUSETRAP : FLUSH-MOUNTED AND PROUD PROBES YIELD SAME RESULTS

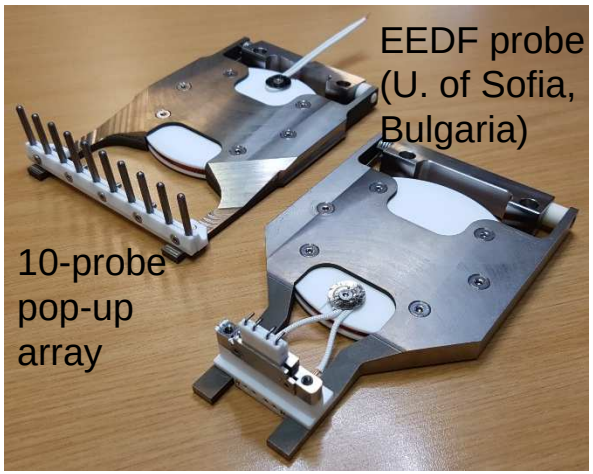
All data from experiment of December 14, 2018





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

UPPER DIVERTOR: W WAFER PROBES BOLTED TO ACTIVELY COOLED, W-COATED, COPPER PFUs

In-kind contribution by KIT Karlsruhe Institute of Technology

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_{tip} ~ 800℃ / 12 MW/m ^{2}

Two types of electrical insulation being tested



0.1 mm phlogopite mica sheets
T_{max} ~ 1000℃



HVOF plasma-sprayed alumina (Stony Brook University + IPP Prague) T_{max} > 1900℃

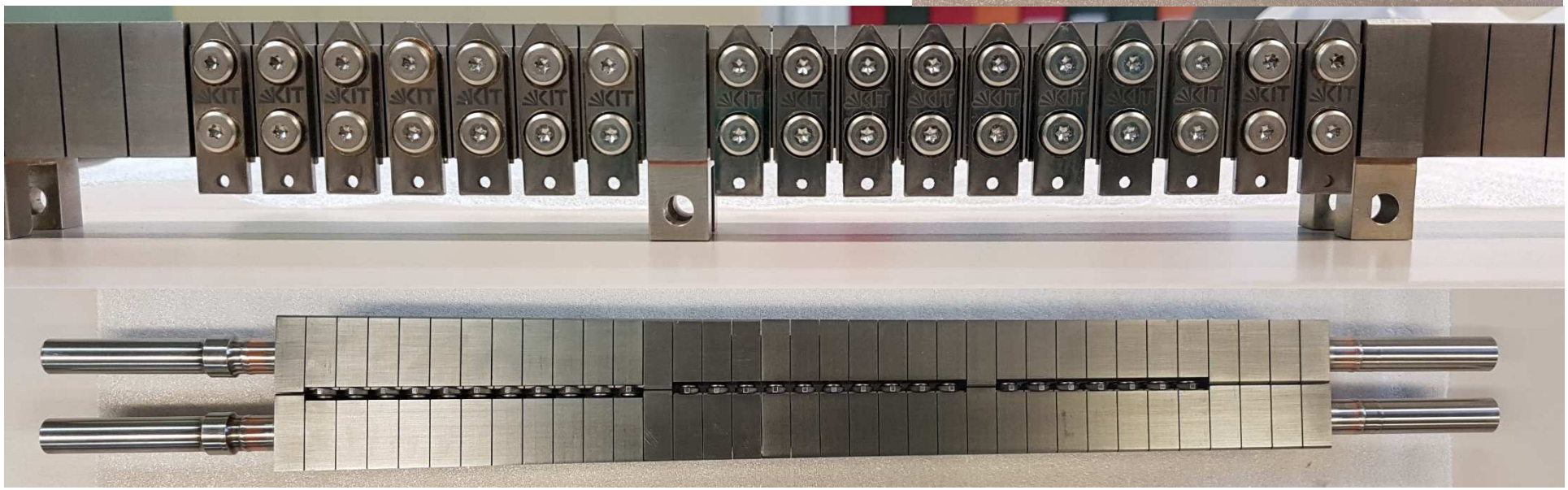
59/60 probes still working
Survived discharges up to 1 minute long
Total exposure 52 minutes
Heat flux ~ MW/m^2

WAFER PROBE DESIGN WILL BE TESTED ON ITER-LIKE FULL W PFUs IN WEST PHASE 2 (>2022)

In-kind contribution by

Karlsruhe Institute of Technology





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.

SUMMARY

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.