



Platform Status

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



- ▶ Main achievements since last GB
- ▶ The ITER-grade lower divertor manufacturing, reception tests and assembly
- ▶ Heating and current drive systems
- ▶ Fueling and pumping systems
- ▶ Diagnostic systems

► **C4 performed as expected from July 2019 to Nov 2019**

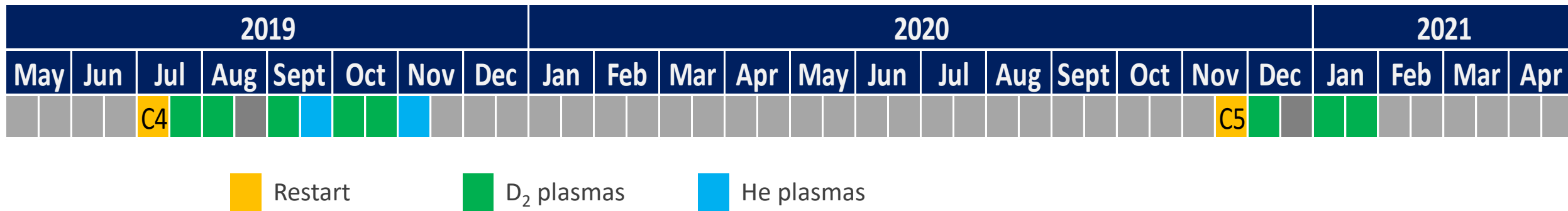
- 14 ITER-grade PFUs prototypes
- 4 weeks of He plasma

► **Installation of the full actively cooled divertor interrupted in 2020 by COVID-19 pandemic**

- Only 2 divertor sectors (2x38 PFUs) installed in 2020

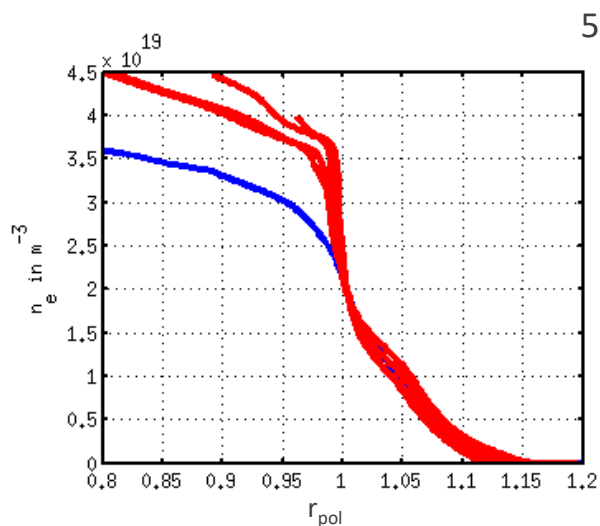
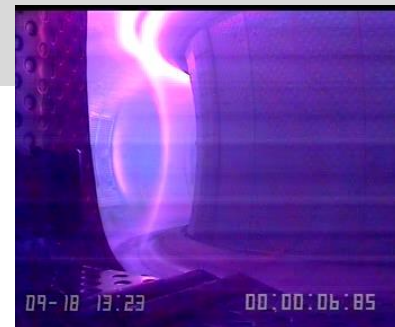
► **Short C5 campaign from Nov 2020 to January 2021**

- 2x38 ITER-grade PFUs (series + prototypes)
- Test of BN first wall limiter tiles and completion of EUROfusion experiments (melting experiment)

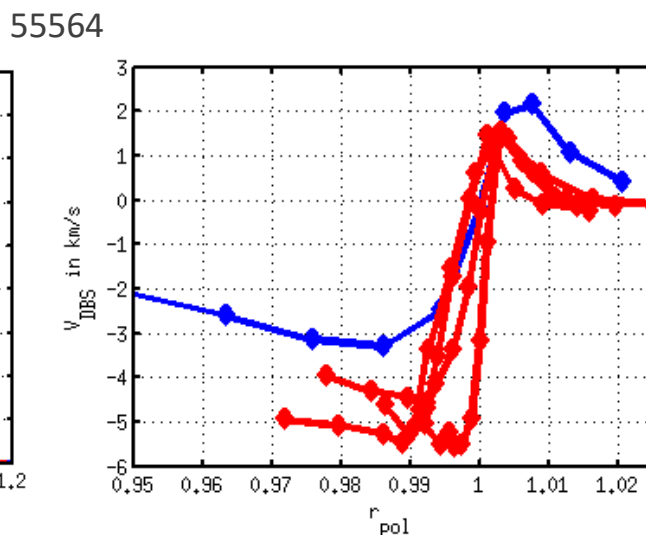


► **Shutdown ongoing since January 2021 for the installation of the full actively cooled ITER-grade divertor**

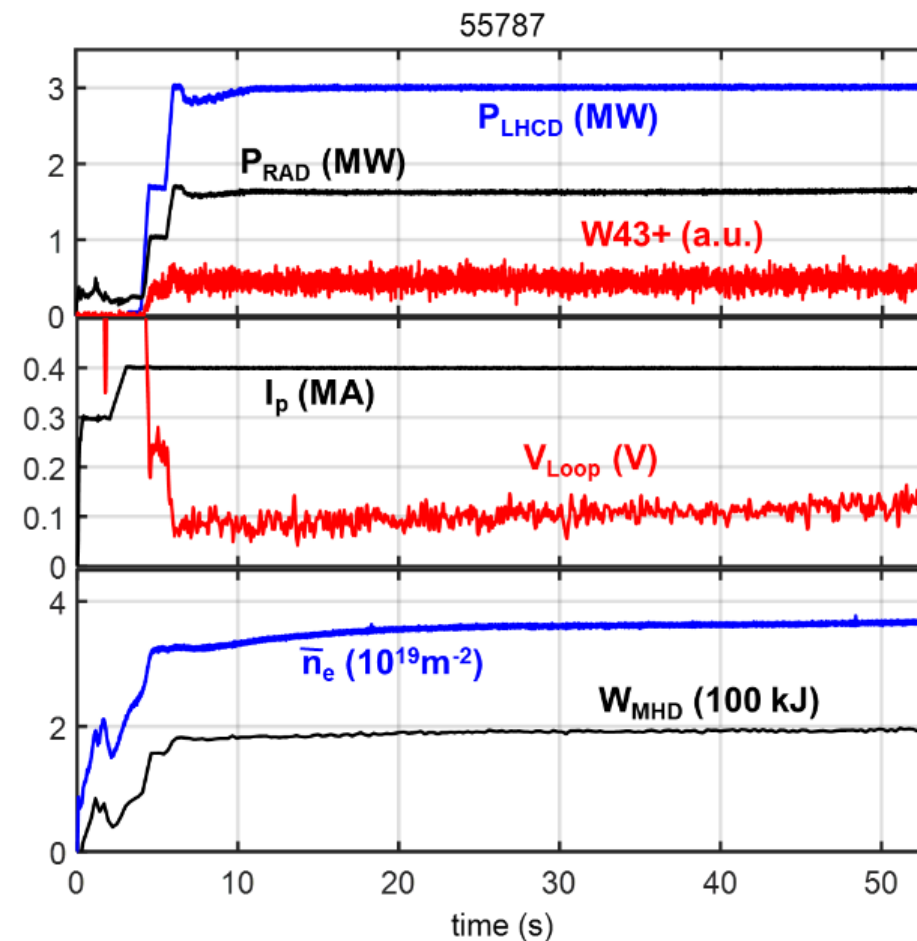
- ▶ **Up to 9 MW peak of combined RF power coupled**
 - LHCD alone: up to 5.4 MW
 - ICRH alone: up to 5.8 MW
- ▶ **First L-H transitions observed**
 - Transition threshold identified
- ▶ **Stable plasma discharges up to 55 s achieved**
 - Long pulse operation initiated for Plasma Wall Interaction experiments
- ▶ **5 MW/m² routinely achieved on divertor components**
 - Plasma Facing Unit misalignment and melting experiments performed



Density profile evolution



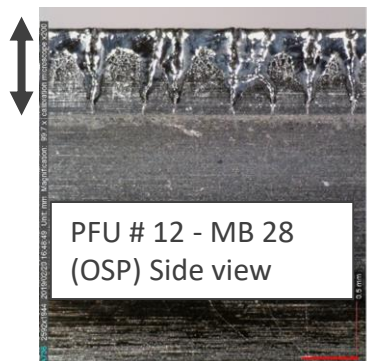
ExB velocity profile



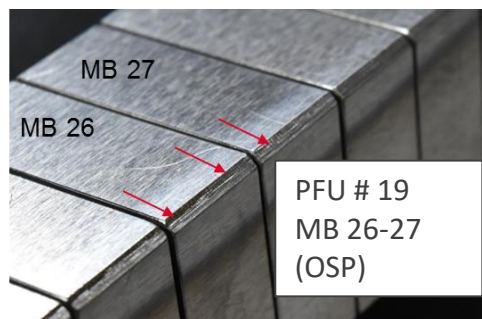
No failure but first evidence of damages on ITER-grade PFUs

- Cracks and local melting observed on misaligned PFUs side (both for sharp and chamfered), even outside peak heat flux area

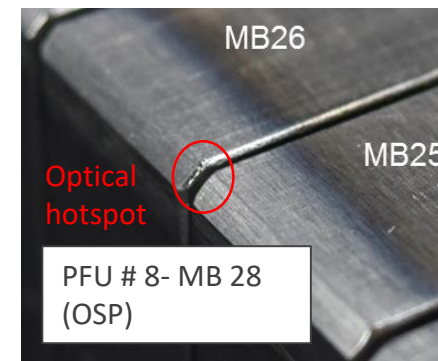
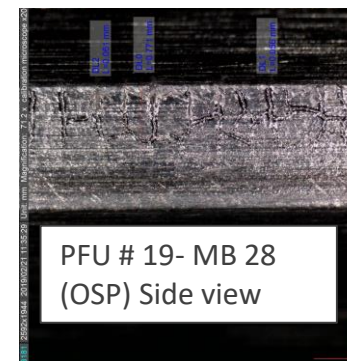
Misalignment
~ 0.8 mm



Misaligned / sharp

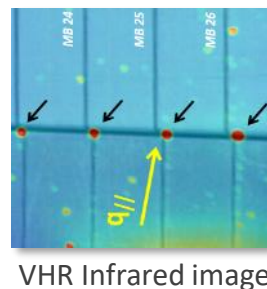
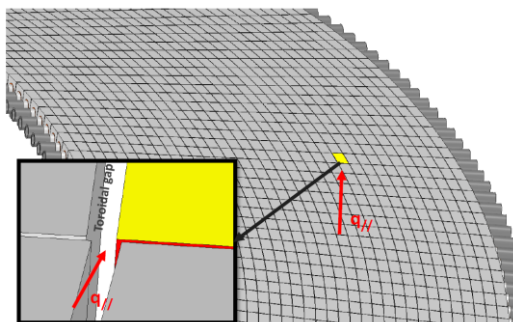


Misaligned / chamfered

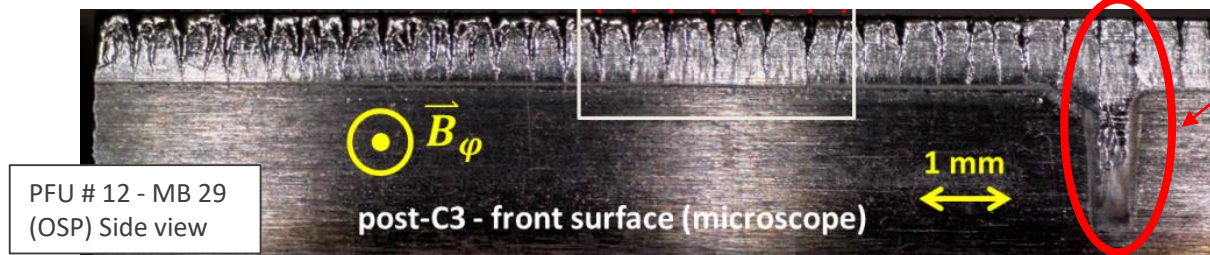


Aligned / chamfered

- Optical hot spots evidenced even for PFUs aligned within specs (local melting / cracks)



VHR Infrared image



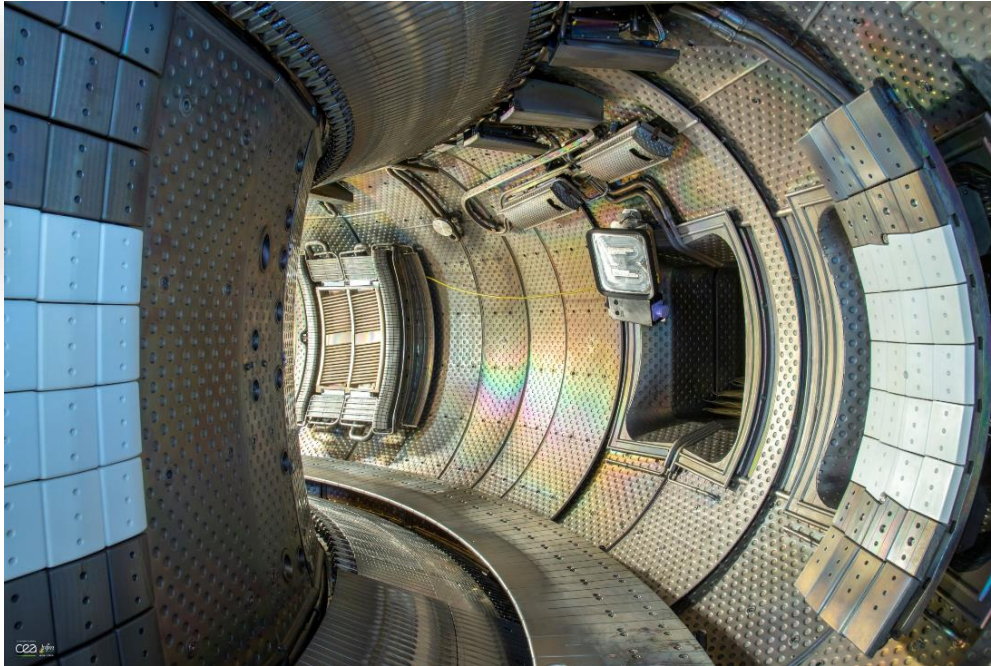
Optical hot spot

► **13 boronizations performed during C4**

- Necessary to get H-mode conditions at the present additional power level
- Transient effect on W radiation

► **Operation with midplane BN tiles during C5**

- Initial arcing problems solved by the first boronization
- Robust ramp-up phase before X-point formation



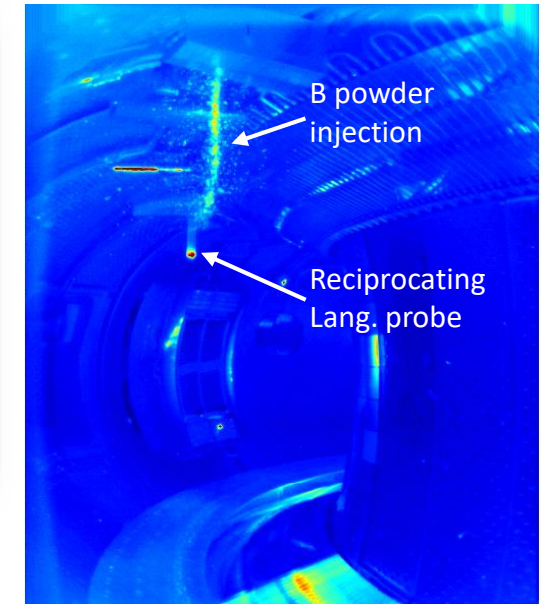
New GDC electrodes (C5)

► **Installation and commissioning of the PPPL powder dropper during C5**

- Real time wall conditioning with boron powder



IPD installed on WEST (C5)



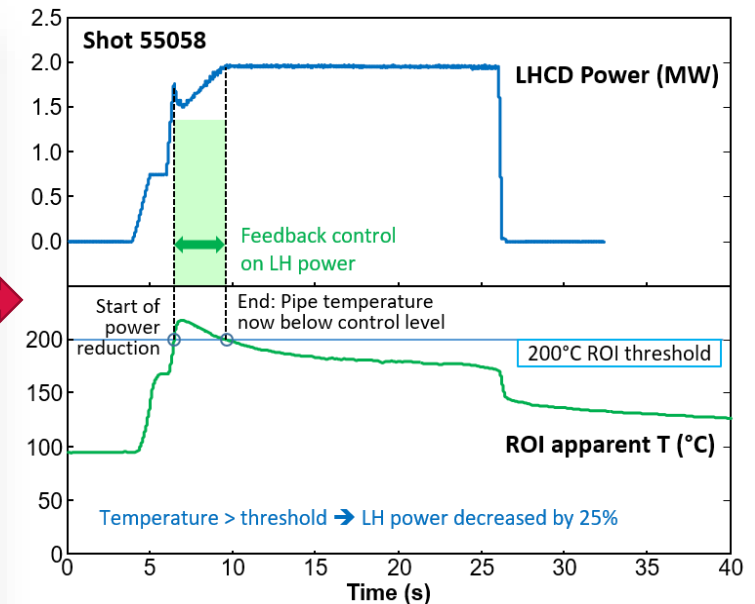
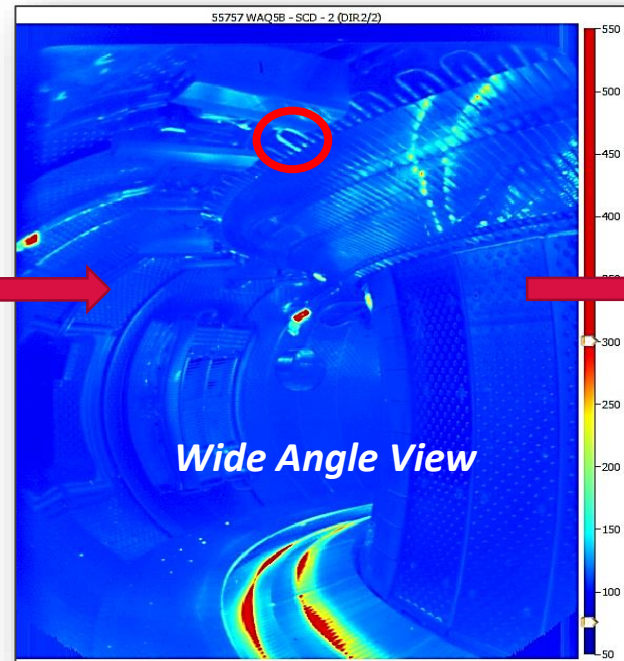
B powder injection

Reciprocating Lang. probe

Wall Monitoring System: crucial for safe Long Pulse Operation

- Multi diagnostics Wall Monitoring System: IR, spectro., calorimetry, Langmuir probes, ...
- Involves several diagnostics DAQs, WMS and PCS units
- Various real time feedback control strategies implemented (up to 32 Region Of Interests)

ROI	Lim	Max	LH1	LH2	IC1	IC2	IC3
LH1-Grill	220	270	X				
LH1-Grill eq. Plane	550	600	X				
LH2-Grill	220	270		X			
LH2-Grill eq. Plane	550	600		X			
WA-Udiv Pipes	235	275	X	X			
LH1-Side Limiter	650	700	X	X	X	X	X
LH2-Side Limiter	650	700	X	X	X	X	X
IC-Q2-Side Limiter	650	700	X	X	X	X	X
IC-Q4-Side Limiter	650	700	X	X	X	X	X
IC-Q1-Side Limiter	650	700	X	X	X	X	X



Real-time feedback control of the LHCD power, using IR system, to avoid the overheat of PFCs

- Real time image processing, thermal events detection (machine learning, scene simulation)

7:25 hours of plasma exposure (USN/LSN) including 50 minutes of He plasma

	Nb Plasma	I_p max (kA)	Duration max (s)	Cumul (s)	Disrup- tions	Disrup- tivity	LH (pulse)	LH max (MW)	W LH total (MJ)	IC (pulse)	IC max (MW)	W IC total (MJ)	Boro- nizations
C2 Nov17-Feb18	524	805	10.5	1553	355	68%	168	2.5	95.5	0	0	0	0
C3 July-Dec18	1076	818	37.5	7329	796	74%	572	5.3	4947	186	1.4	105	3
C4 – D2 July-Nov19	1112	1004	55	9678	763	69%	509	5.4	7823	339	5.7	1139	13
C4 - He Oct-Nov19	330	709	30	2991	279	85%	196	4.5	4300	21	0.3	3	0
C5 Nov20-Jan21	655	806	23	4630	460	70%	280	5.4	2625	145	3.7	182	2

Nb Plasma: pulse with $I_p > 10\text{kA}$, without taylor cleaning discharges

Cumul (s): duration of pulses with $I_p > 10\text{kA}$

Disruption: $dI_p/dt > 20\text{MA/s}$ and $I_p > 50\text{kA}$

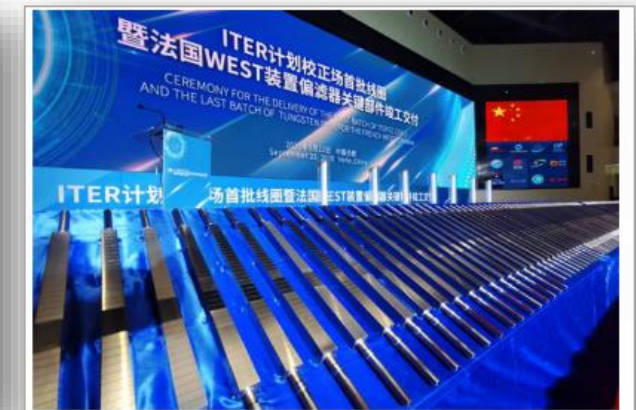
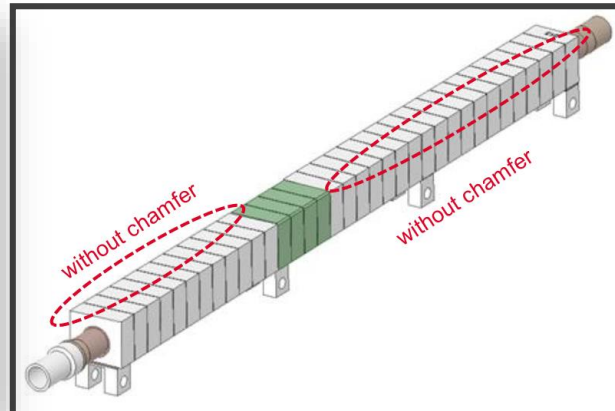
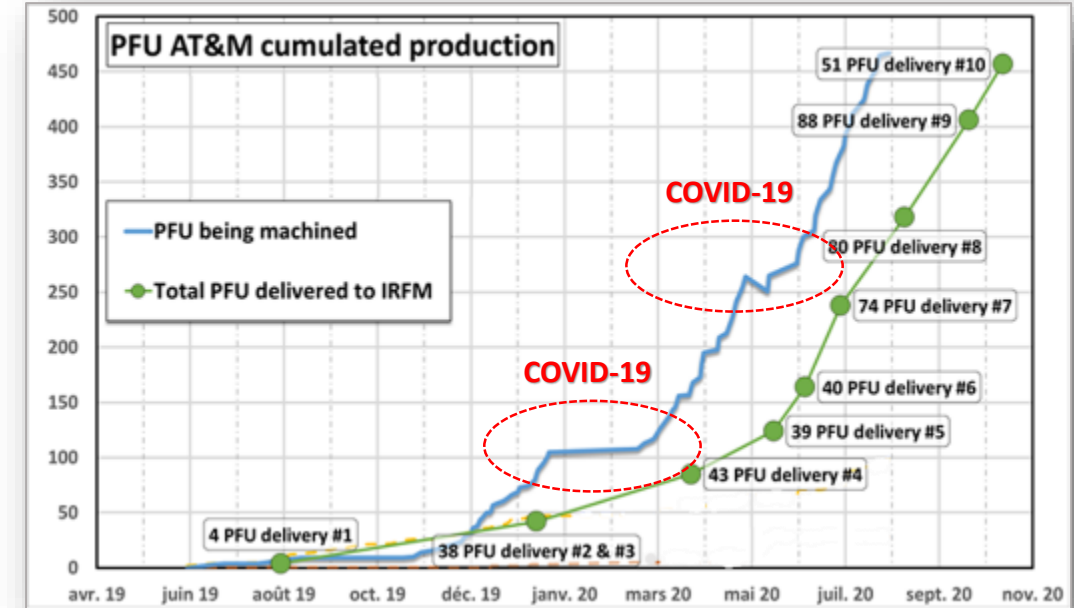
Disruptivity: Disruption/Nb Plasma

- ▶ Main achievements since last GB
- ▶ **The ITER-grade lower divertor manufacturing, reception tests and assembly**
- ▶ Heating and current drive systems
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456 PFU delivered at Cadarache!



- ▶ KOM: 4th of Dec. 2018 → last delivery Oct. 2020
→ 10 months later than the initial planning (COVID)
- ▶ Manufacturing follow up with SIFFER/ASIPP
- ▶ 397 standard, 59 with specific features
 - 2 with grooves on lateral faces for thermocouples
 - 5 with longitudinal groove for Fiber Bragg grating
 - 10 with grooves for Langmuir probes
 - 4 with special direction for the top face grinding, to help for erosion measurement
 - 38 without the 1x1mm chamfer for the shaped monoblocks (like in the Inner Vertical Target for ITER)



Very satisfying manufacturing quality of the ITER-grade PFU series

- ▶ 1900 reception tests performed: dimensional, visual, tightness, ability to sustain thermal solicitation
 - 1 PFU Rejected – Defect not detected during manufacturing phase
 - 12 PFUs derogated and placed at particular position in WEST
 - For 2.5% of the production (12 PFUs tested): no overheating during high heat flux tests at 10MW/m^2 (consistency with Infrared thermography and UT testing)

Hardness testing



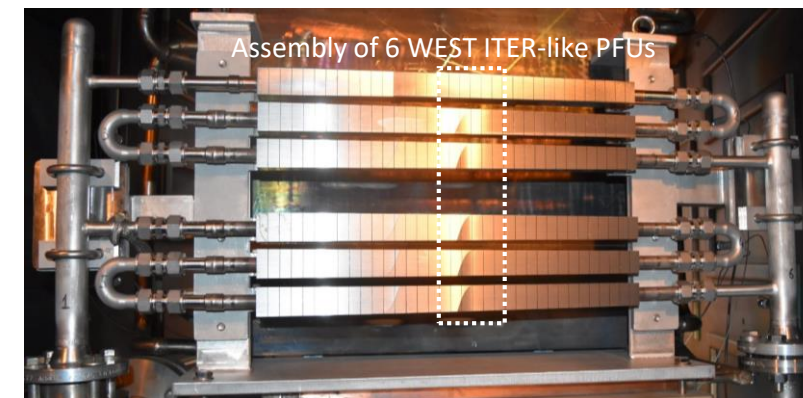
Cold and Hot He leak testing



Dimensional and visual testing



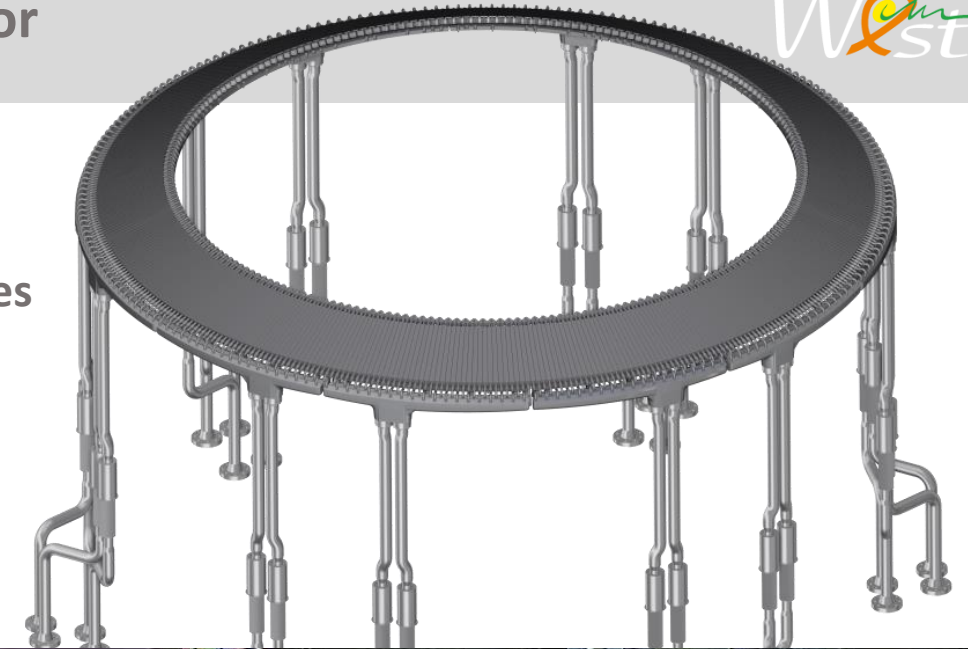
HHF testing



Installation of the 12 divertor sectors has started!

- All the PFUs have been mounted on their supporting sector plates
- Installation of the 12 sectors completed in June

	Available parts			Preparation	PFU mounting	Metrology	Welding	Cold He leak test	Hot He leak test	Metrology	Ready
	PFU	Manifold	Plate								
2A											
2B											
6A											
6B											
4A										wait	
4B										wait	
1A										wait	
1B								wait			
5A									wait		
5B										wait	
3A									wait		
3B						wait					

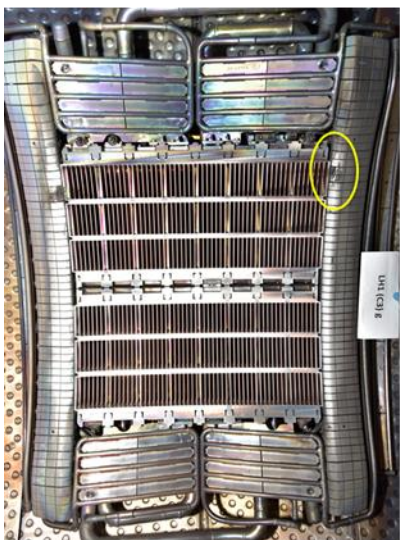


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- ▶ High heat flux technology based on VDE protection design
 - CuCrZr/316 L explosive bonding
- ▶ Coating on plasma facing surface: high Z (W cf. VDE) or low Z (boron)
 - R&D for boron coating on CuCrZr ongoing
- ▶ PDR completed: first set of 2 protection limiters expected for 2022
- ▶ Joint project with EAST (SIFFER/ASIPP)



Damages on the W coating of the CFC tiles of the LH launcher (arcing)



LH1 – post C5



post C4

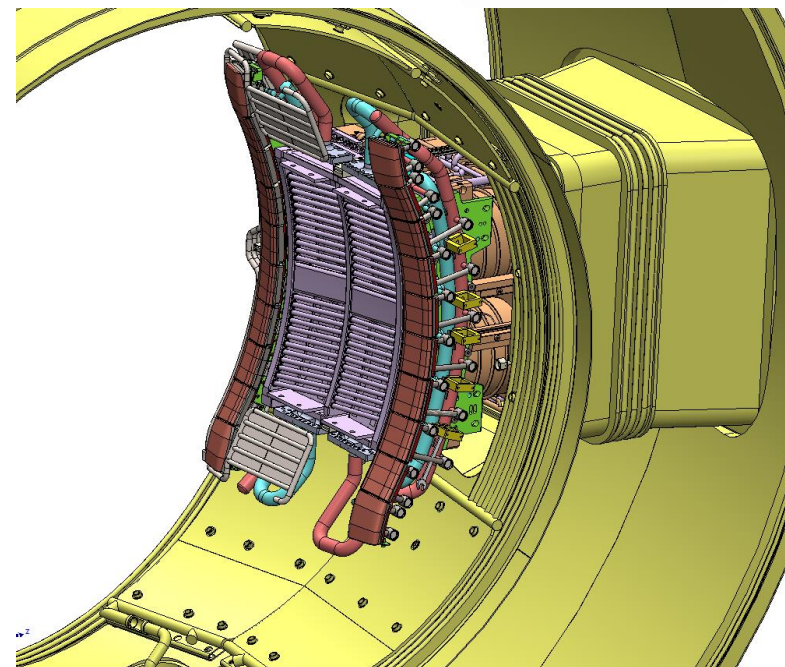


Post C5

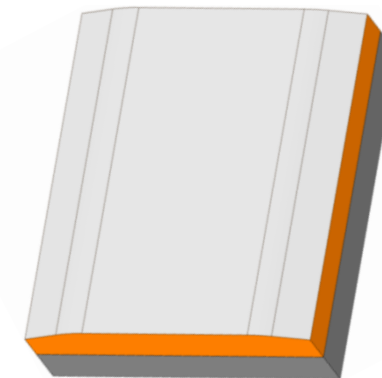


After cleaning – S4

New design

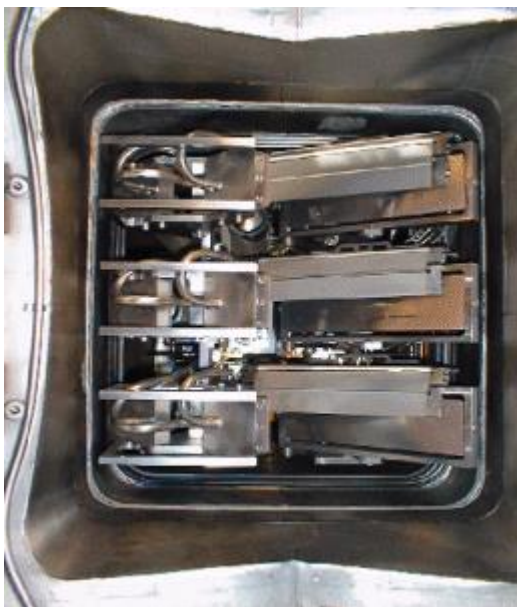


Conceptual module
(120mm*100mm)

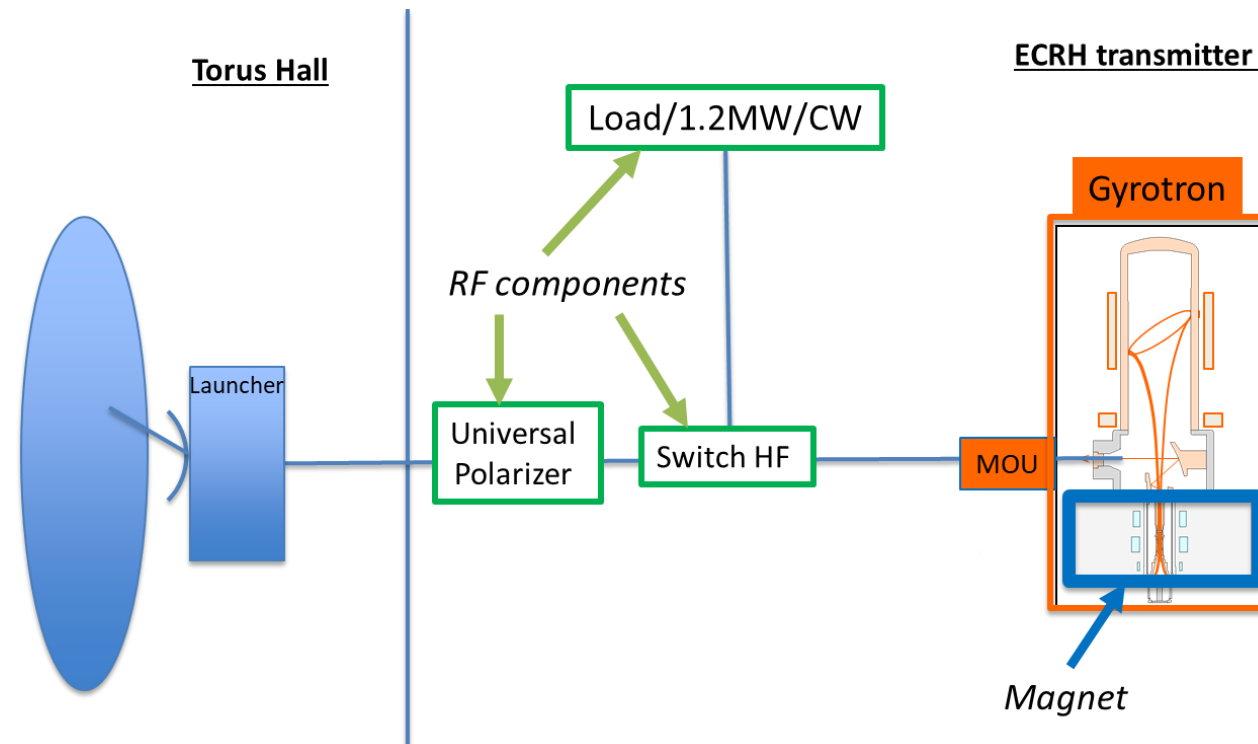


Staged installation of 3 MW/CW of ECRH, operational from 2023

- Replacement of the old Tore Supra gyrotrons (118 GHz/300 kW/5s) by 3 new gyrotrons (105 GHz /1 MW/CW)
- Antenna with RT mirrors steering: central deposition for W content control and/or off axis for MHD control
- Call for tender for the gyrotrons completed → contract to be awarded in July
- In collaboration with KIT, SPC, IPP, SIFFER (SWIP and ASIPP), discussions with ENEA



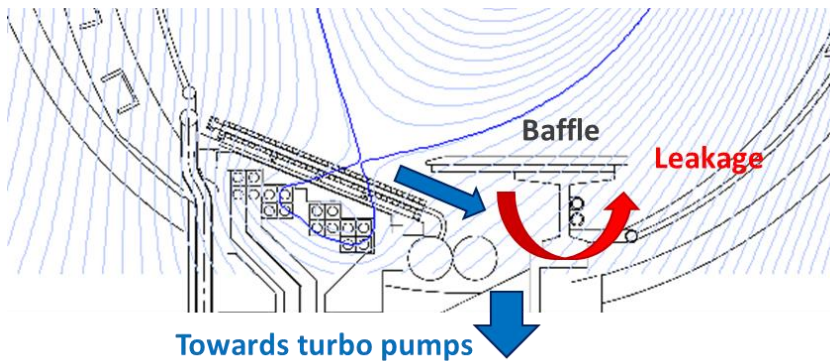
ECRH antenna used on Tore Supra



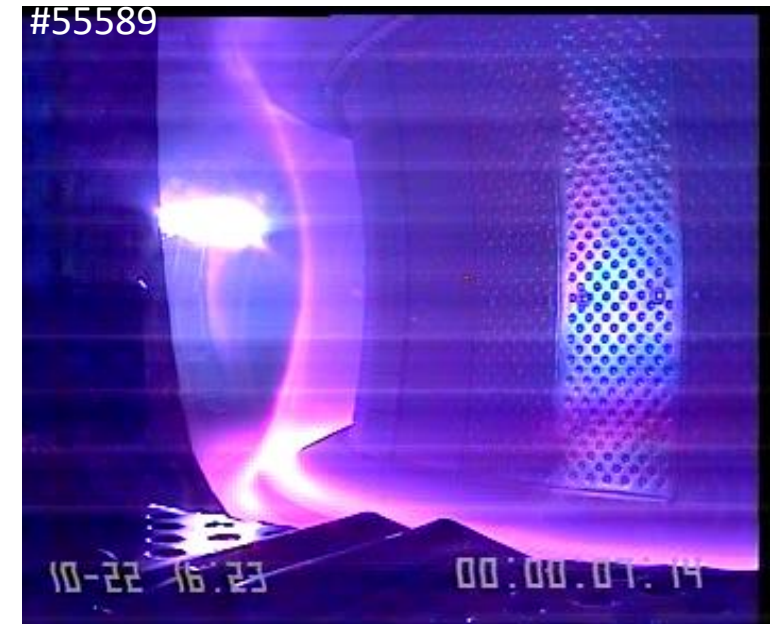
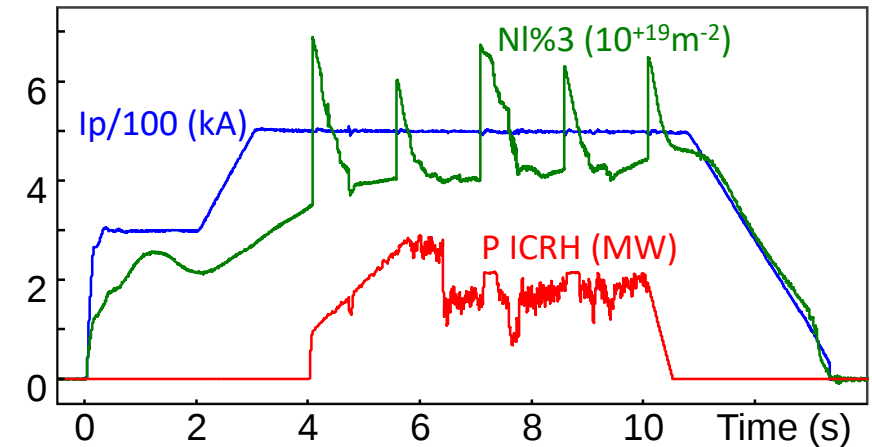
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More flexibility for particle control

- ▶ New gas injection line to feed a 3rd impurity
- ▶ New injection point in the lower divertor private area
- ▶ 10 Hz pellet injector commissioned
 - 4 tracks can be selected during the pulse: LFS, Vert, 2xHFS
 - 2 tracks qualified: the LFS and 1 HFS
 - ICRH antenna load-resilience validated
- ▶ Pumping capability improved in C5
 - 5 lower vertical ports equipped with turbo pumps (2.2m³/s each)
 - Outer baffle neutral compression improved with gas leakage shield



- ▶ Full pumping capability (10 ports) expected in 2022 (C7)



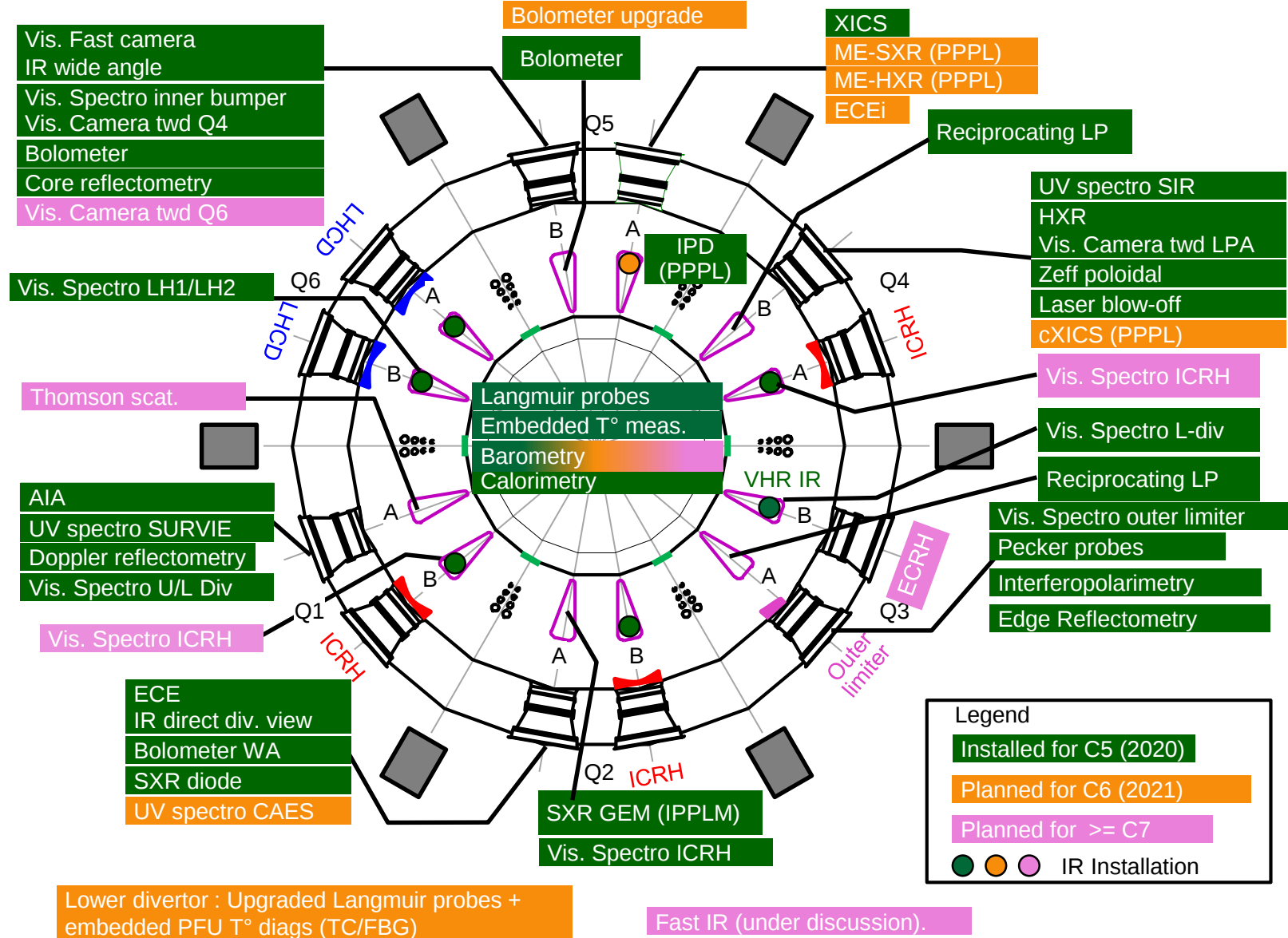
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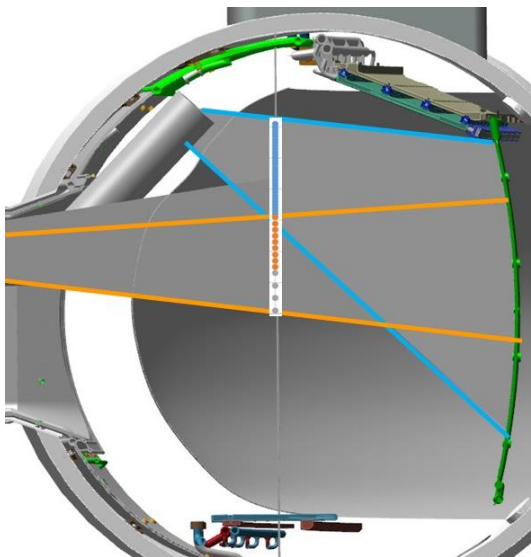
WEST key diagnostics

- ▶ Visible spectroscopy (ORNL)
- ▶ VUV spectroscopy
- ▶ SXR, SXR-GEM (IPPLM), HXR
- ▶ Reflectometers (Doppler, profile, fluctuations)
- ▶ Langmuir Probes (IPP.CR, KIT)
- ▶ IR thermography (extensive in vessel monitoring, VHR divertor view)
- ▶ Thermocouples and Fibber Bragg Grating
- ▶ Calorimetry
- ▶ Articulated Inspection Arm (AIA)

Main upgrades for Phase 2

- ▶ Thomson Scattering (PPPL)
- ▶ Fast IR camera
- ▶ New Soft/Hard X-ray/cXICS (PPPL)
- ▶ Vertical bolometer
- ▶ New HR VUV spectrometer CAES (Korea)



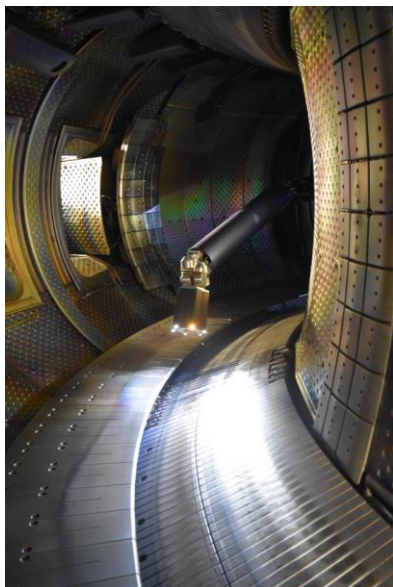
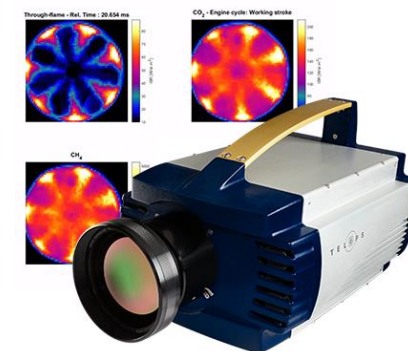


Pedestal physics: Thomson scattering

- ▶ Edge (2022): 30 lines of sight (far SOL to pedestal top), 6 mm spatial resolution
- ▶ Core (2023): 20 lines of sight

Transient heat loads: fast IR camera

- ▶ Thermal load analysis during ELMs and Disruptions
- ▶ Analysis of synchrotron radiation during RE
- ▶ 3 kHz full frame, up to 100 kHz in windowing mode
- ▶ 8 selectable wavelengths in 1.5-5 μm range
- ▶ Wide Angle view for 2022, dedicated divertor view under study for 2023



Fuel retention monitoring: LIBS on AIA

- ▶ Laser Induced Breakdown Spectroscopy (LIBS) system assembled on the robotic arm for in situ measurements
- ▶ Project pending on budget availability
- ▶ Other upgrades on AIA: in situ IR calibration (feasibility study in 2021), leak detection (longer term, under discussion)

Under discussion: portable diagnostics in the EUROfusion framework

- ▶ X ray diags (ENEA): feasibility study ongoing



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**WEST successfully completed its phase 1
(commissioning) and is ready to take off
for phase 2**

WEST #56923 – Boron powder injection and reciprocating probe (4MW of LHCD)



Thank you for your attention



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