DE LA RECHERCHE À L'INDUSTRIE

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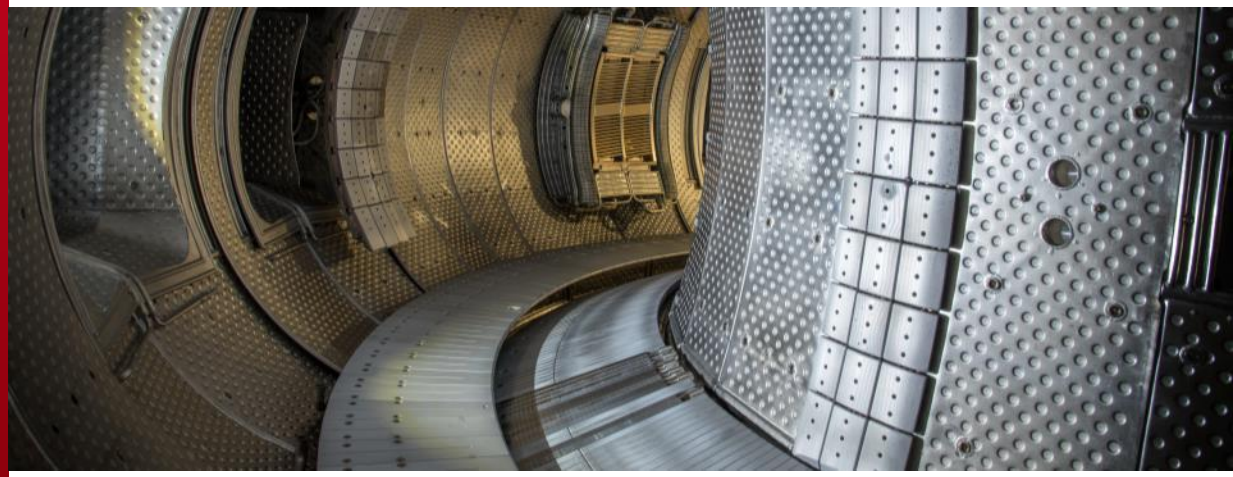
6th Meeting of the WEST Governing Board

OVERVIEW OF OPERATION FOR THE C3 CAMPAIGN

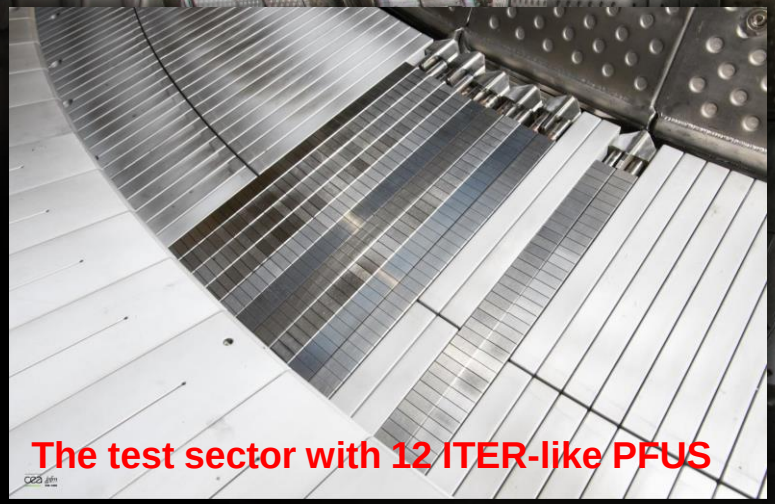


Jérôme BUCALOSSI, on behalf of the WEST team

Château de Cadarache – May 17, 2019

WEST IN MAY 2018
MACHINE CONFIGURATION FOR C3 CAMPAIGN

New features for C3:
4 add. IL-PFUs (F4E)
2 ICRH antennas
Divertor Vis. spectro
IR VHR endoscope
GEM (soft X-rays)
X2D
ORNL collector probe
NIFS samples

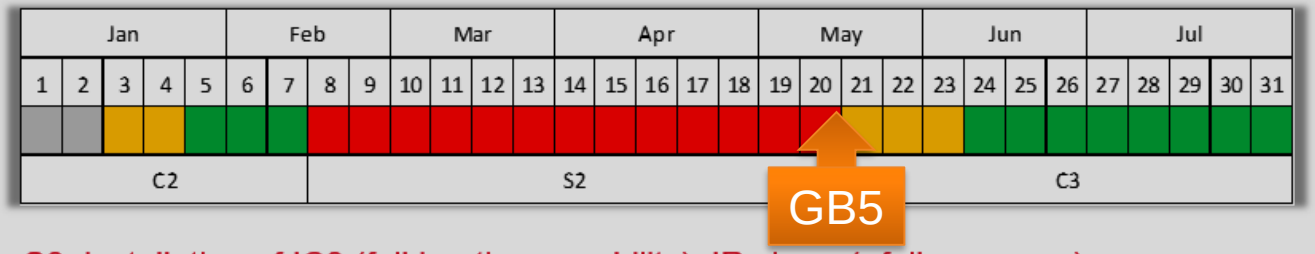


The test sector with 12 ITER-like PFUS

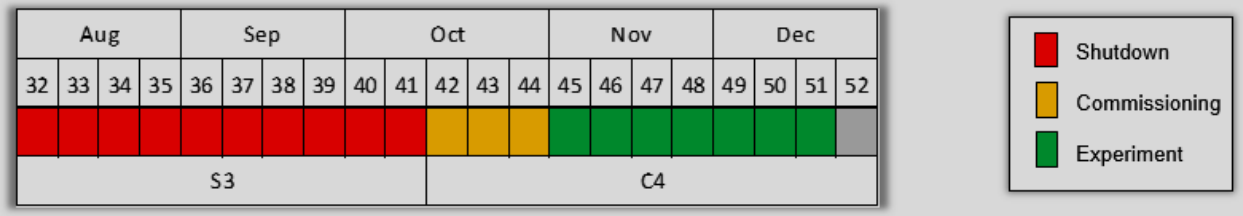
FORESEEN IN MAY 2018 (PREVIOUS GB)

EXPERIMENT TIMELINE FOR 2018 (END OF PHASE 1)

- **C3**: 11 weeks of plasma operations → **8 weeks of experiments** (~32 days)
  - Objective 1: increase injected power **towards 5 MW (H-mode)**
  - Objective 2: first experiments on ITER-like PFU prototypes **towards 10 MW/m²**



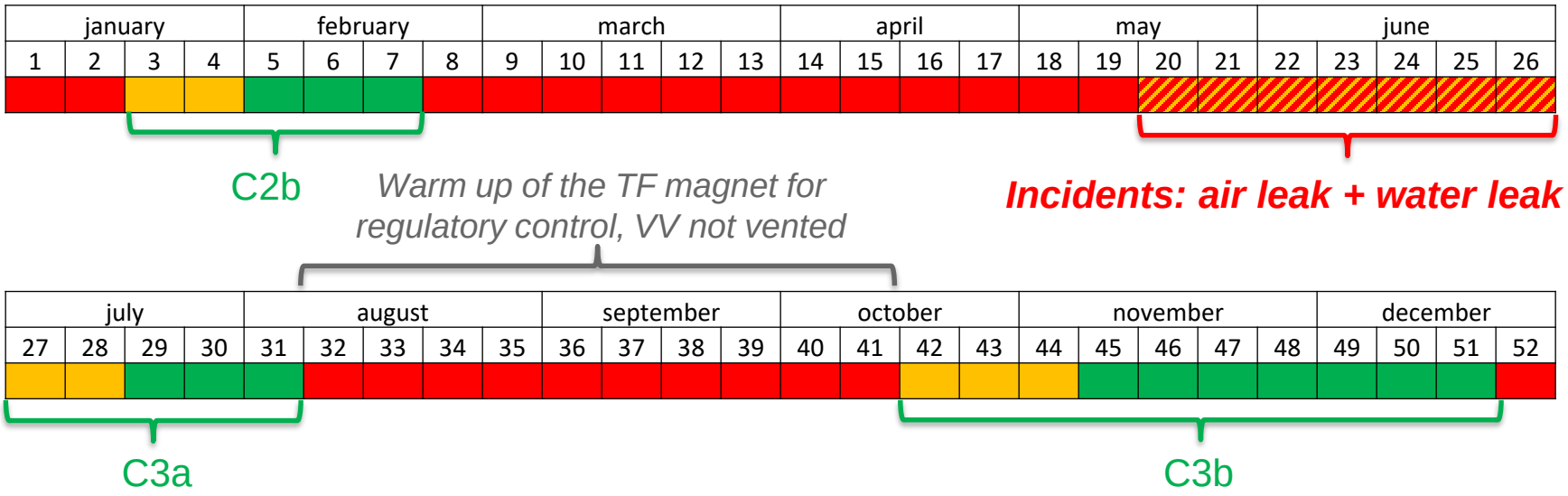
- S3: installation of IC3 (full heating capability), IR views (~full coverage)
- **C4**: 10 weeks of plasma operations → **7 weeks of experiments** (~28 days)
  - Objectives: **He campaign**, long pulse operations (upper divertor)



- **Contingency**: **11 weeks in 2019** (up to end of March 2019) → will depend on C3 and C4 results and PFU availability for phase 2

C2b+C3+C4 = 26 weeks of plasma operations in 2018

LEAKS DURING INITIAL BAKING
→ C3 EXTENDED, C4 POSTPONED TO 2019



C2b+C3 = 20 weeks of plasma operations / 26* initially planned

	2018	C2b	C3a	C3b
Number of days with plasma (except maintenance, technical and boronization days)	74	19	20	35
Number of sessions	138	37	38	63
Early Shift : 8h-14h30 (6h30)	63	18	17	28
Late Shift : 14h30-21h (6h30)	66	19	18	29
Standard shift = Early Shift + Contingency + Commissioning	9	0	3	6

Contingency=14h30-16h15 (1h45) / Commissioning=16h15-18h30 (2h15)

* C2b: 5 weeks, C3: 15 weeks → 20 weeks vs 26 initially planned ~75% availability (38% over the year)

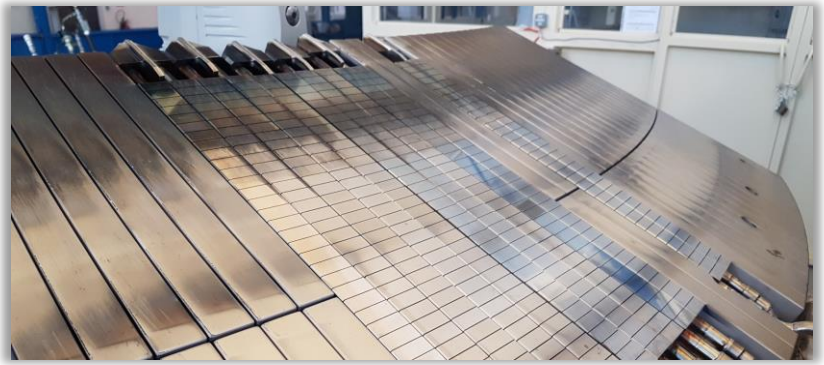
SIGNIFICANT PROGRESS IN C3

Main achievements

- **5.5 MW of total injected power** achieved
- First EUROfusion Key Performance Indicator (KPI) achieved
  - KPI#1: "*H-mode, 2s*" → up to 5.5MW injected, $P_{sep} \leq P_{LH}$ (~2.5MW?)
  - KPI#2: "*1MW/m^2 for 1MW of input*" → 1MW/m^2 for 2MW of input (L-mode)
  - KPI#3: "*1MW of ICRF in H-mode*" → 1.4MW ICRH obtained in L-mode
  - KPI#4: "30s flattop" → **37s pulse achieved**
  - KPI#5: "*H-mode, 10s, 5MW/m^2*"→ L-mode, 10s, 2MW/m^2 achieved
- 21 EUROfusion sessions executed
- **~2h plasma exposure**

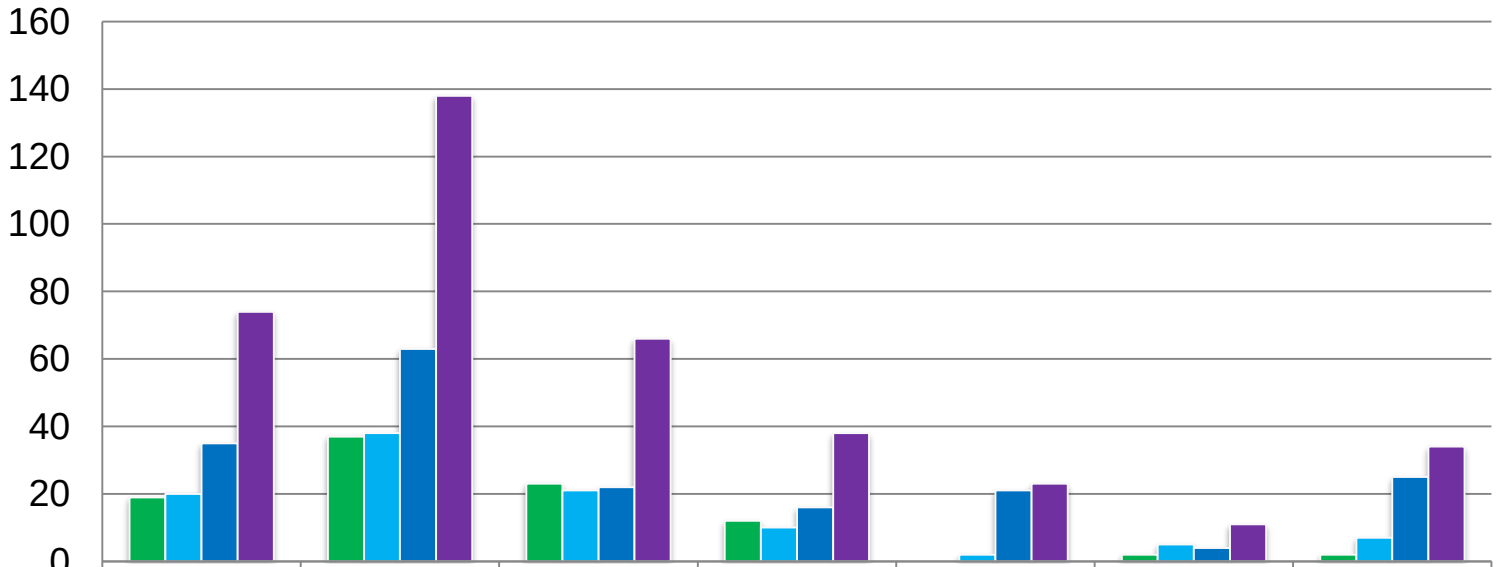
Issues

- High radiation level (50%), several boronizations performed
- MHD during current ramp-up due to central radiation (W)
- Disruptions in ramp-down



Test sector showing plasma footprint after C3

2018 EXPERIMENTAL CAMPAIGNS SESSIONS BREAKDOWN

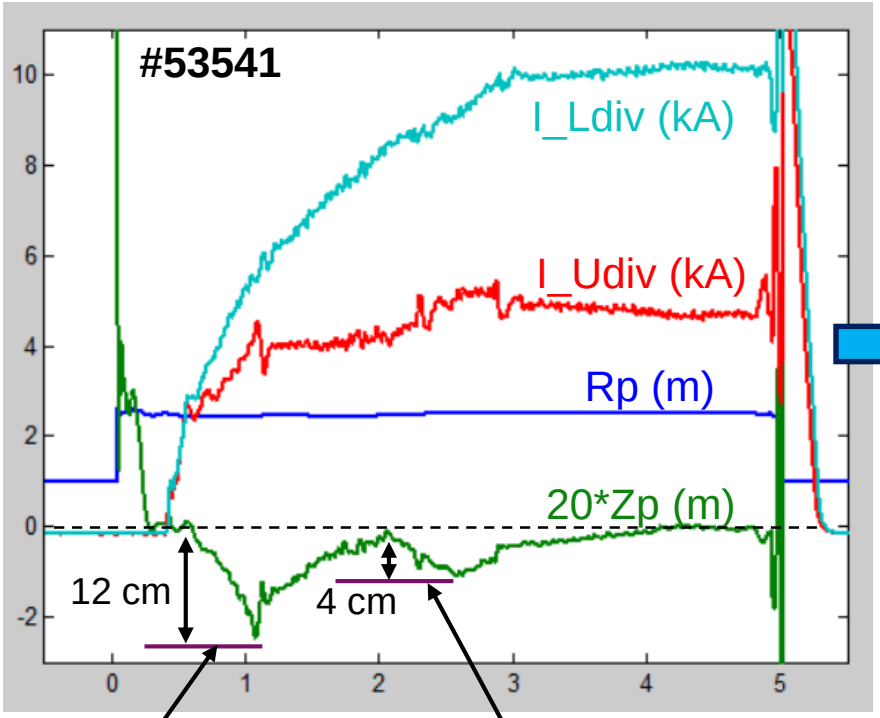


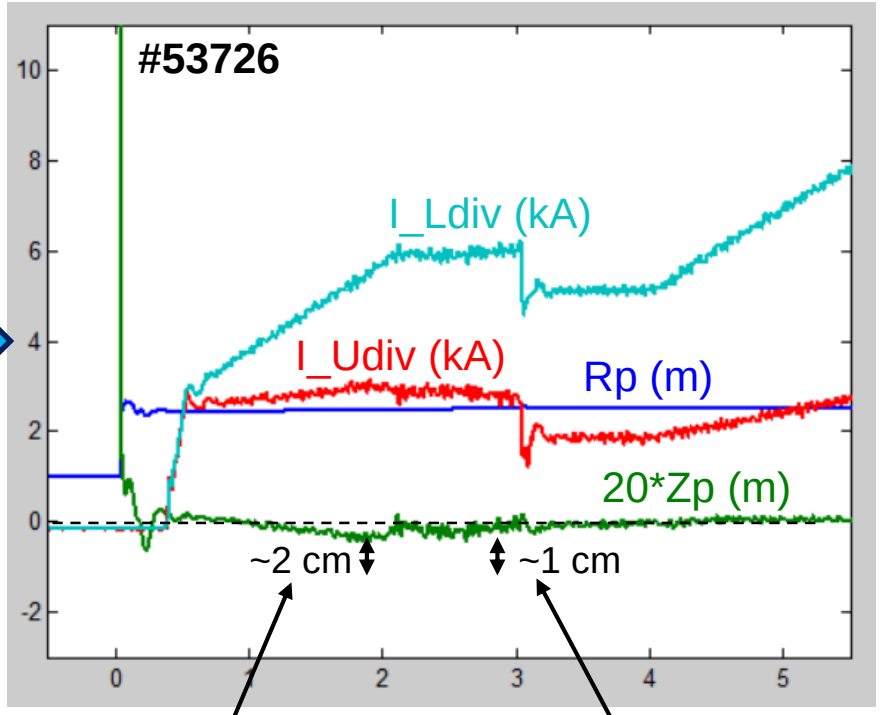
	Nb days	Nb sessions	Nb commis.	Nb W2-1	Nb W1	Nb W2 (w/o W2-1)	Nb Exp.
C2b	19	37	23	12	0	2	2
C3a	20	38	21	10	2	5	7
C3b	35	63	22	16	21	4	25
Total 2018	74	138	66	38	23	11	34

~50% of the sessions dedicated to commissioning, ~25% to baseline scenario development and ~25% to experiments

REAL TIME PLASMA BOUNDARY AVAILABLE IMPROVEMENT OF (R,Z) CONTROLLER

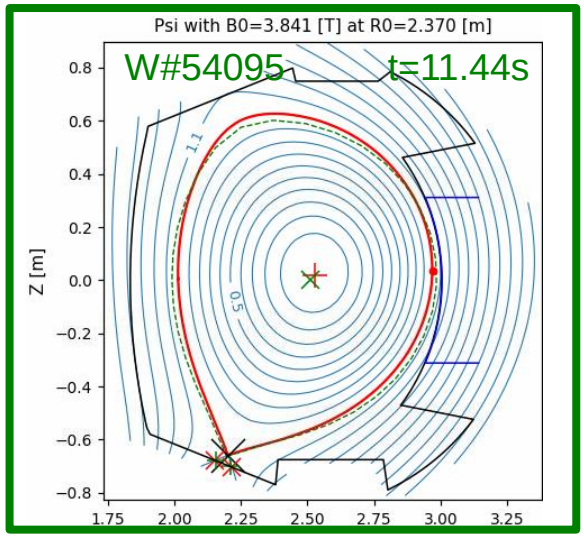
- **Improvement of the R, Z control** when ramping up divertor currents and when switching from (R, Z) to (EROG, Z) control: adjustment of feedforward divertor currents
- **Improvement of the coupling** of the heating systems (EROG control)

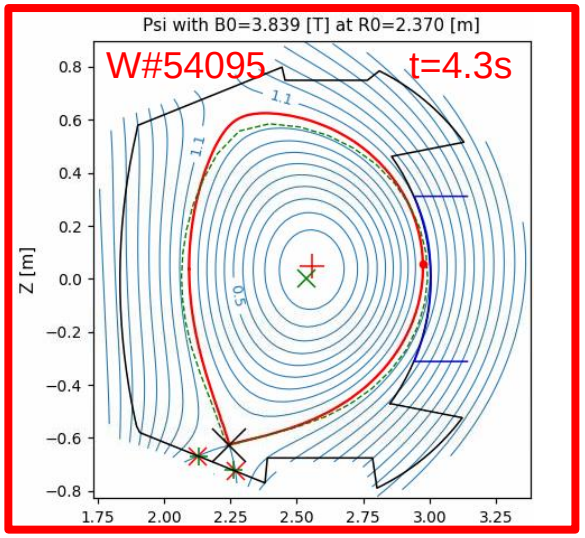


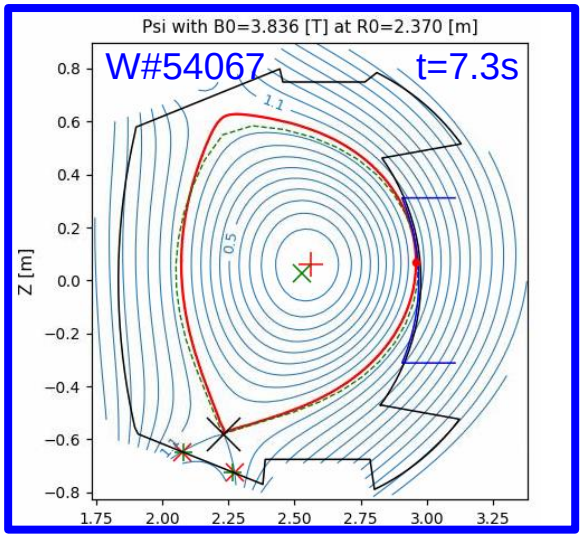


VARIATION OF X-POINT POSITION

- **Scan in X-point height** in feedforward I_{div}: stable up to 12 cm
- Design of specific equilibrium: Strike Points on pre-damaged monoblocks



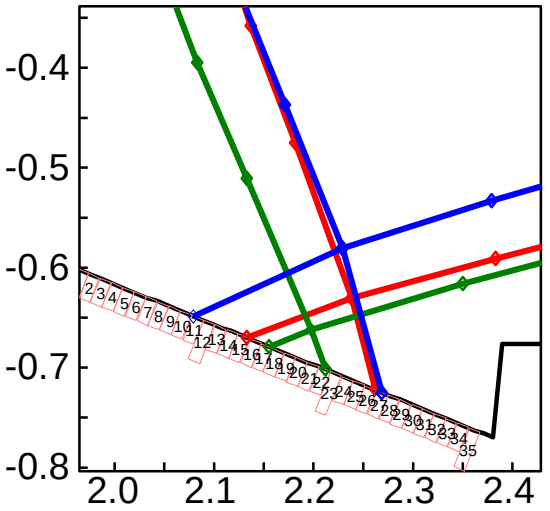




“Close” X-point (dx~3cm)

“Far” X-point (dx~8cm)

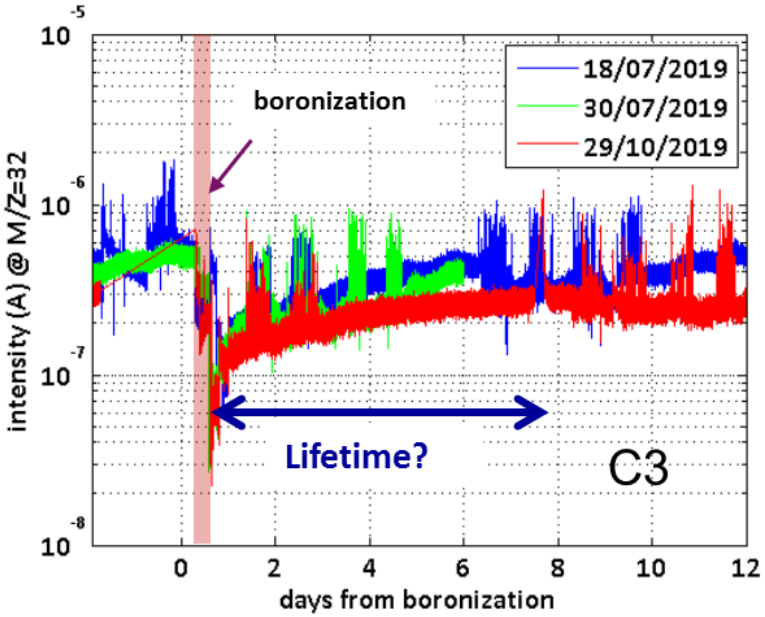
Strike point on pre-damaged monoblocks (dx~12cm)



J. BUCALOSSI et al., C3 operation ov

WALL CONDITIONING AND BORONIZATION

- Wall temperature limited to 120°C during C3 due to divertor casing leaks (resin outg.)
- **3 boronizations** performed (He+10% B_2H_6 glow discharge)
  - Reduction of the oxygen level on the RGA
  - Reliable plasma startup → long lasting effect
  - **Extension of the operational domain** (higher n_e) → long lasting effect
  - Reduction of the radiated power fraction → short term effect (few pulses)

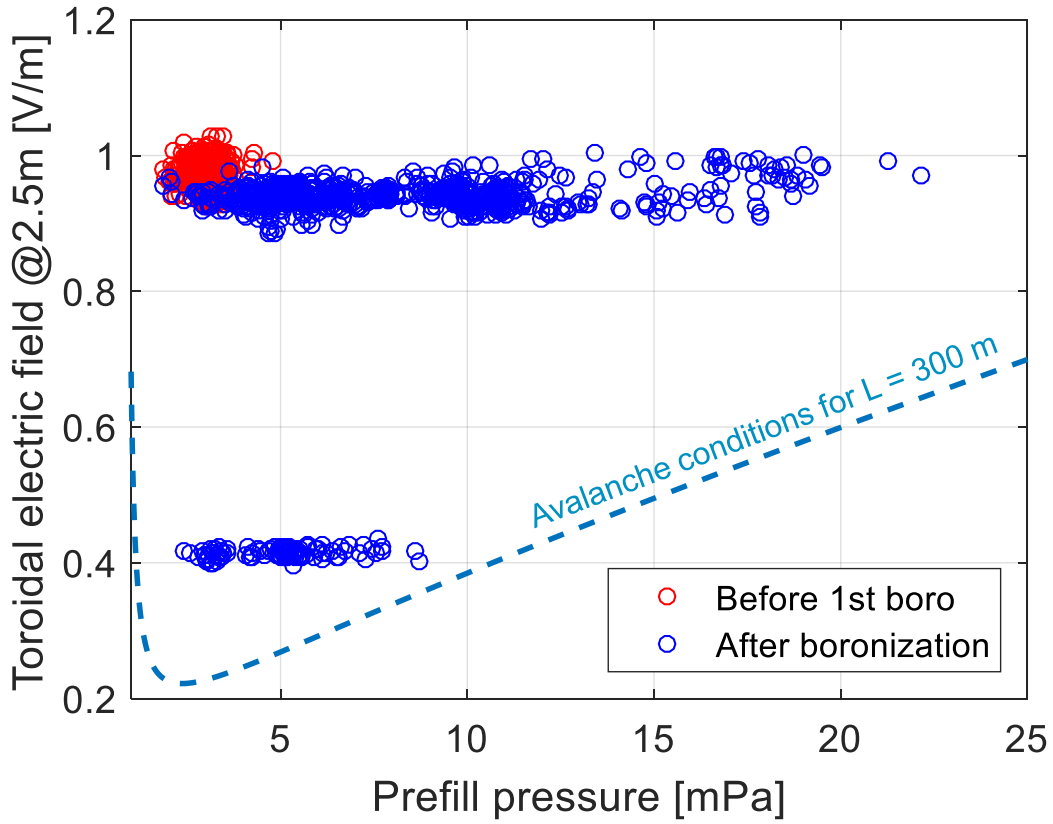


Oxygen level from the residual gas analyser (RGA) after the 3 boronizations performed during C3

- For C4: **200°C baking and more frequent boronization**

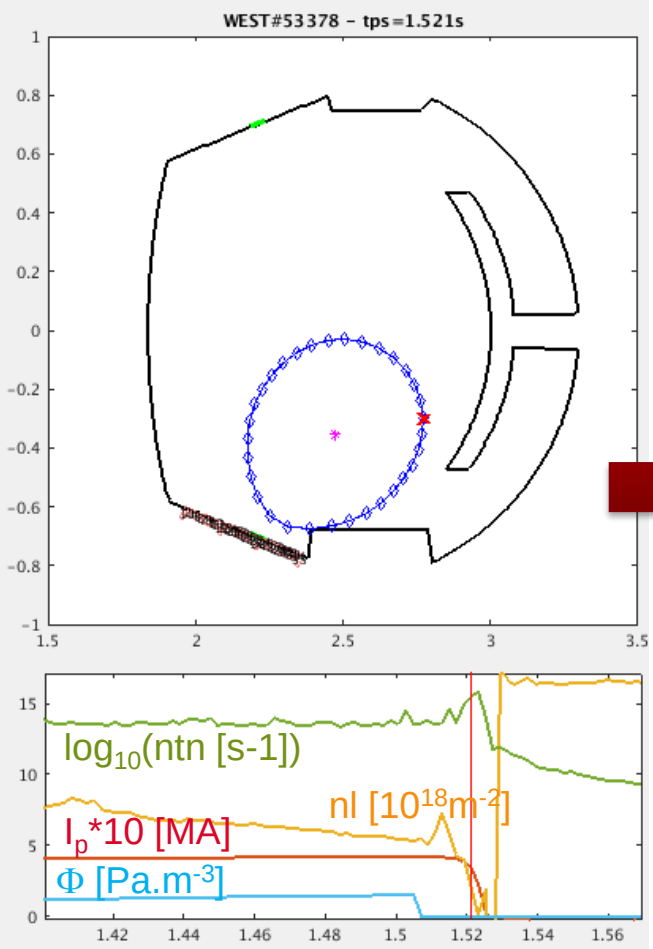
IMPROVED PLASMA INITIATION CONDITIONS AFTER BORONIZATION

- The avalanche phase easily achieved (poorly affected by plasma facing materials)
  ➔ burn-through phase hard to pass during C2
- The first boronization performed in C3 strongly ease the burn-through phase
- Low loop voltage ohmic startup (down to 0.4V/m) achieved after boronization

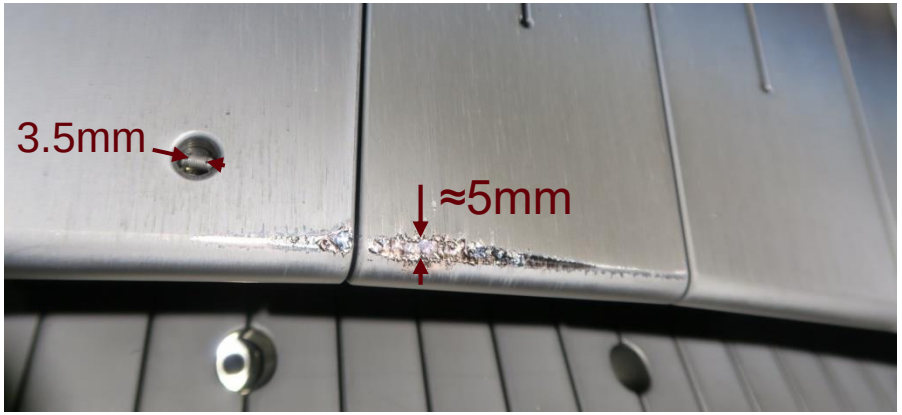


Successful plasma initiation conditions before and after boronization

LESS DAMAGE FROM RUNAWAY ELECTRONS DURING C3



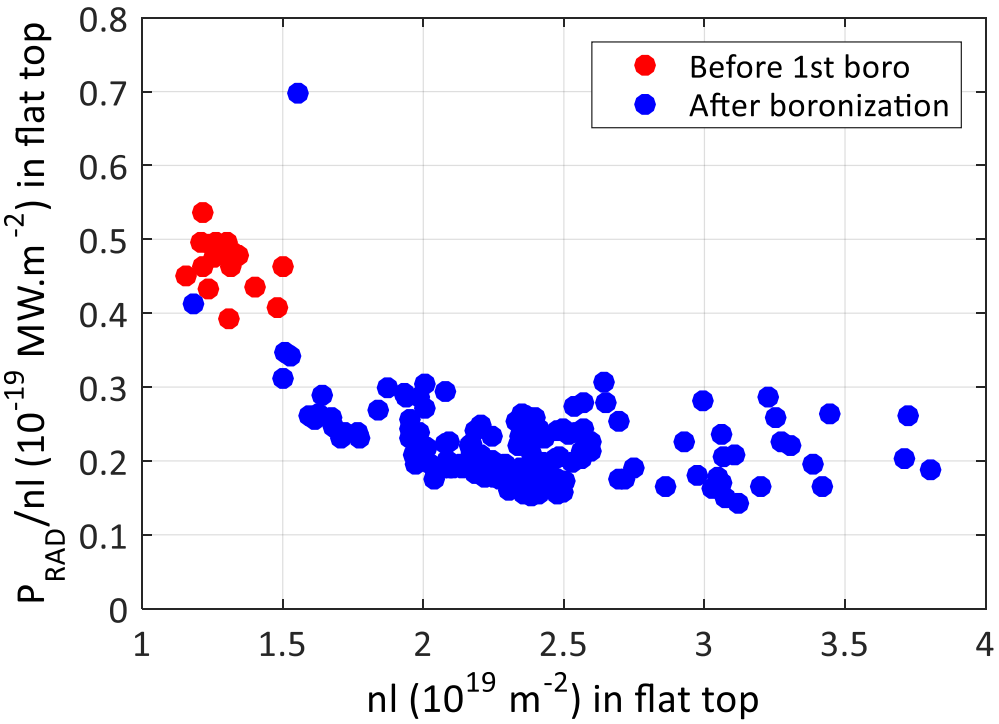
- Boronizations significantly reduce the occurrence of runaway electrons (RE)
- Anti-RE strategy implemented during C2 not 100% safe (startup conditions changed by the boronization)
- One RE beam impact on the baffle (#53378, 400kA)



- Real time protection on neutron production has been implemented for C4 (10ms above a threshold)

IMPROVED OPERATION DOMAIN AFTER BORONIZATION

- Higher density achievable → nl = 1.5 $10^{19}m^{-2}$ before boronization, 4 $10^{19}m^{-2}$ achieved

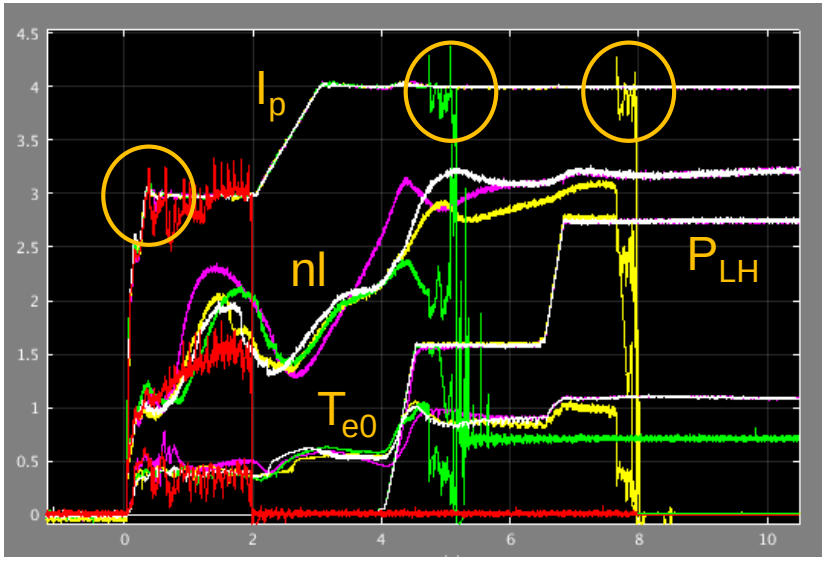


Radiated power normalized to the line integrated density as a function of the line integrated density

- Higher LH power and IC power achievable → 5.5MW of LH and 1.4MW of IC achieved
- Reduced edge radiation → higher heat fluxes on the divertor targets, 2.5MW/m^2 achieved

BUT MHD ISSUE DURING CURRENT RAMP UP AFTER BORONIZATION

- Hotter plasma edge leads to contaminated core plasma ➔ **hollow temperature profile**
  - can prevent q=1 appearance or lead to off-axis sawteeth that do not clean the core
  - evidence of plasma cleaning by Double-Tearing Mode crash

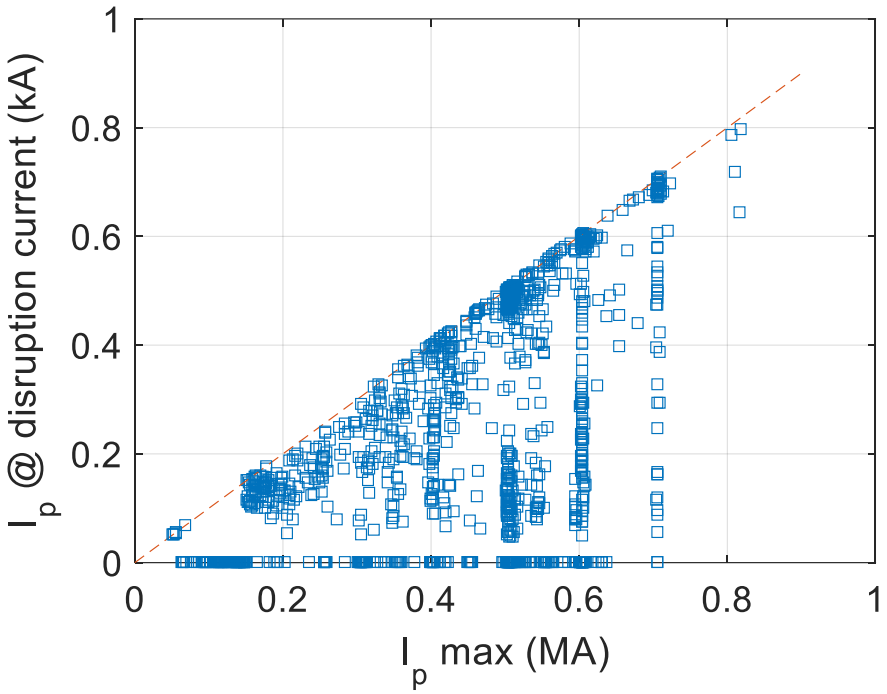


5 consecutive discharges with the same setup and different MHD behaviours (white and magenta are successful!)

- Crucial role of (2,1) mode in the preforming
  - locked (2,1) not lethal but prevents successful LH application
  - (2,1) can be stabilized when approaching sawtooth regime
- **~33% of the pulses stopped due to MHD modes during C3** ➔ plasma startup optimization/preforming studies planned during C4

PLASMA CURRENT RAMP-DOWN ISSUES

- Disruption at the end of the heating phase or early in the current ramp-down
- No significant impact on the following pulse



- Ramp down sequence to be addressed during C4

2018 PLASMA PERFORMANCE SUMMARY

	Nb Plasma	Nb sust-ained	Ip 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)
C2a 2017	*416*	*26%*	*425*	*2.96*	*58*	*45*	*79%*	*21*	*0.24*	*0.42*	*0*	*0*	*0*
C2b	*300*	*88%*	*805*	*10.52*	*1495*	*237*	*92%*	*147*	*2.47*	*95.1*	*0*	*0*	*0*
C3a	357	84%	710	16.5	1244	181	72%	142	3.38	163.8	40	0.74	7.6
C3b	719	**96%**	818	**37.51**	6058	549	**81%**	430	**5.34**	4783	146	**1.42**	97
All	1792	76%	818	37.51	**8855**	**1012**	82%	**740**	5.34	**5042**	**186**	1.42	**104.6**

Thermal pulses!

2h30* of plasma exposure, 5 GJ** of energy injected

**corresponding to ~9 WEST nominal pulses (1000s)*
***corresponding to ~50% of one WEST nominal pulse (10MW, 1000s)*

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