EUROfusion

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Summary of RT04 proposals

M. Baruzzo, V. Igochine

On behalf of WPTE TFLs
M. Baruzzo, V Igochine, D. Keeling, A. Hakola, B. Labit, E. Tsitrone, N. Vianello

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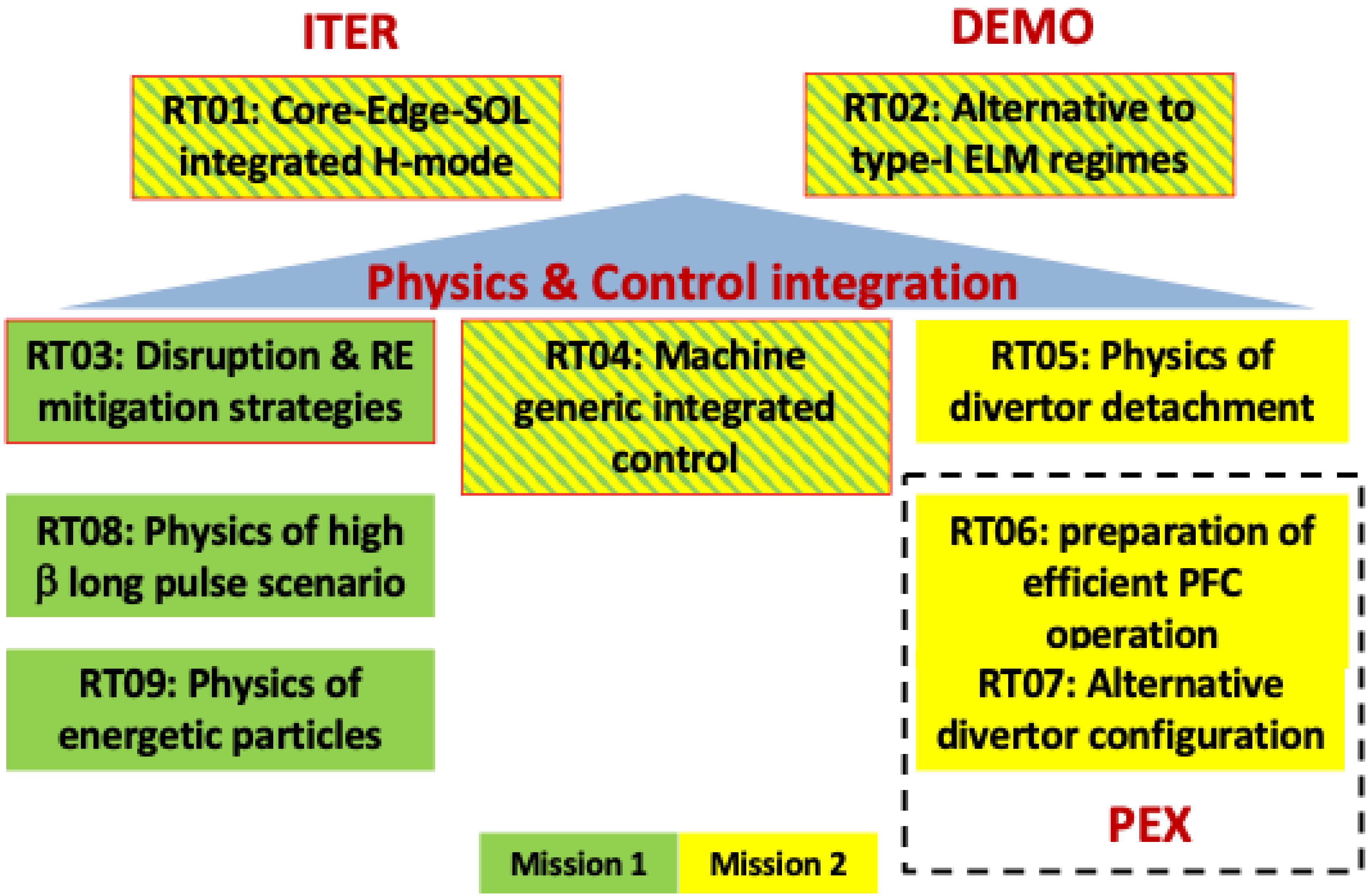
Introduction



Scientific Objectives and Machine Time

#	
D6	Develop generalized controllers and state observers designed for application to a variety of devices
D7	Develop integrated control algorithms and techniques for pulse trajectory optimization in view of possible applications to next step device controller
D8	Optimize off normal events handling and disruption avoidance strategies for machine protection
D9	Integrate machine learning and physics driven techniques for control augmentation and performance boosting

2025	AUG	TCV	MAST-U	WEST
Tentative allocation (26)	15	60	16	30
Tentative allocation (27)	32	110		30
Total proposed	138	410	139	212
Scientific/dev.	135/3	350/60	115/24	189/23

Proposal summary (37)

No	RT	Proposal name	Proposer
53	RT04	Stray radiation minimization via real-time polarization control	Fabio Graziano et al
54	RT04	Dynamic model-based Error Field correction	[mailto:leonardo.pigatto@igi.cnr.it Leonardo Pigatto]
55	RT04	Application of CREATE-ILC to alternative scenarios	Charles Vincent et al
56	RT04	Integration of RAPTOR and CREATE-ILC for advanced pulse design	Charles Vincent et al
57	RT04	Current optimised Trapped Particle Configuration for ICRF assisted start-up	Charles Vincent et al
58	RT04	Mitigation of tungsten dust ingress with ECRH	Patrick Maget et al
59	RT04	ICRF assisted plasma start-up in WEST (continuation)	Ernesto Lerche et al
60	RT04	Real-time ICRF coupling control for ITER	Ernesto Lerche et al
61	RT04	ICRH coupling control with density profiles from real-time reflectometry	Maylis Carrard et al
62	RT04	LH coupling control with density profiles from real-time reflectometry	Maylis Carrard et al
63	RT04	Electron density gradient control with real-time reflectometry	Maylis Carrard et al
64	RT04	Kinetic and q profile observer and control using RAPTOR	Simon Van Mulders et al
65	RT04	Standardization of camera based front control for physics studies	Gijs Derks
66	RT04	Design and test of a novel dud detection based on TFTR and JET DT plasmas	Lidia Piron et al
67	RT04	Face NTM position control toward ITER operation	Lidia Piron et al
68	RT04	Assess the role of a proxy EF in H mode entry, H-L exit perturbations in AUG and MAST-U	Lidia Piron et al
69	RT04	Role of rotation on EF shielding mechanism	Lidia Piron et al
70	RT04	Avoid rotation braking via n=2 RMP in MAST-U	Lidia Piron et al
71	RT04	Control n=1 mode onset via n=2 RMP in MAST-U	Lidia Piron et al
72	RT04	Test the non-disruptive compass scan in various q95 plasmas	Lidia Piron et al
73	RT04	Comparison of feedforward and feedback techniques for phase control of a wall-locked tearing mode.	Lidia Piron et al

Proposal summary

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74	RT04	Multimachine assessment of Locked Mode predictors: Machine Learning models vs empirical-based scaling laws	Matteo Gambrioli et al
75	RT04	MIMO controller for regulating electron density profile with gas puffing, pellet injection and magnetic coils	Loes Jansen et al
76	RT04	Optimization of TCV breakdown-burnthourgh and current ramp-up using Yfactory tool and validation with DYON-METIS coupling	Fabien Jaulmes et al
77	RT04	Continuation of exhaust control demonstration in ADCs	Paulo Figueiredo et al
78	RT04	Generalized radiator control via energy balance in the boundary	Hao Yang et al
79	RT04	Development of model predictive control for power exhaust	Paulo Figueiredo et al
80	RT04	Development of model-based internal profile control	Simon Van Mulders et al
81	RT04	First wall temperature estimation and heat load control	Federico Pesamosca et al
82	RT04	Reinforcement learning for NTM control	Luca Bonalumi et al
83	RT04	Integrated avoidance and control of NTM	Francesco Carpanese et al
84	RT04	Data-driven models to enhance real-time plasma state estimation	Cristina Venturini et al
85	RT04	Magnetic control developments	Adriano Mele et al
86	RT04	Integrated Control for Disruption-Free Operations and Robust Plasma Trajectory Optimization	Alessandro Pau et al
87	RT04	Psep/PLH control using heating power and impurity radiation	Spyridon Aleiferis et al
93	RT04	Continuous control from attachment to XPR	Pierre David (← coming from RT05
109	RT04	System identification of exhaust plasma using nitrogen and deuterium gas puffing in the XPR-regime	Juan Javier Pa ← coming from RT05

Proposal summary

NTM Control, Disruption Avoidance, Error field Control, Density Control, Assisted BD and ramp-up, XPR and HDL control, Shape and VS control, Integrated Control,

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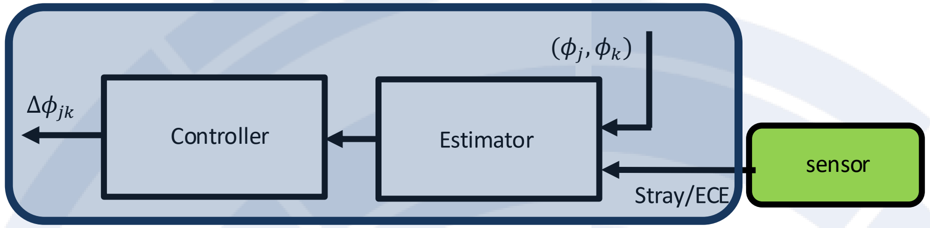
P53: Stray radiation minimization via RT polarization control

- **Scientific Background & Objectives**
  - Minimizing stray radiation is crucial to ensure efficient ECRH power coupling and prevent component damage, especially during long plasma pulses.
  - Testing advanced control strategies for proper beam alignment and polarization is essential for current and future devices such as DTT, ITER, and Wendelstein 7-X.
  - Develop and validate a real-time polarization control scheme for ECRH coupling optimization and stray radiation minimization, assessing its dynamics and performance on TCV.

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Commission the real-time ECRH polarization closed-loop control scheme using ECE diagnostics or stray detectors.
  - Start with a basic extremum seeking controller, then progressively integrate advanced features such as Kalman-based gradient estimation
  - Evaluation of ECE–stray data fusion algorithms.



- (ϕ_j, ϕ_k): mechanical polarizers angles
- $\Delta\phi_{jk}$: polarization corrective term

Proponents and contact person:

Fabio Graziano (fabio.graziano@polimi.it)
Natale Rispoli (natale.rispoli@istp.cnr.it)
Cristian Galperti (cristian.galperti@epfl.ch)
Saul Garavaglia (saul.garavaglia@istp.cnr.it)

Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV	10	
WEST		

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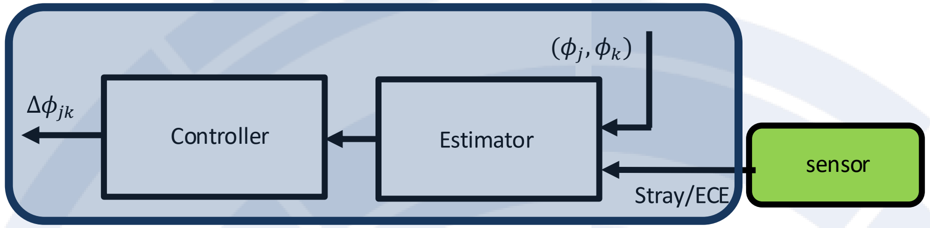
- TFL assessment: P1-TCV
- Aligned with D6



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Cristian Galperti (cristian.galperti@epfl.ch)
Saul Garavaglia (saul.garavaglia@istp.cnr.it)

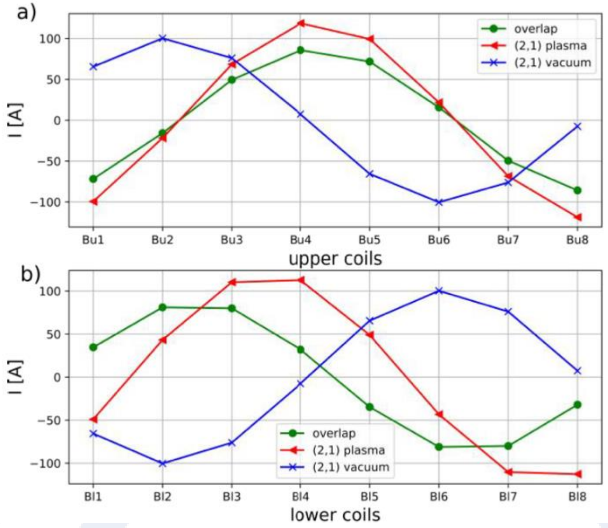
Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
[illegible]	10	
[illegible]T		

P54: Dynamic model-based Error Field Correction

- **Scientific Background & Objectives**
  - The presence of EFs affects energy confinement and plasma stability in multiple ways, e.g causing MHD modes (such as tearing modes) to develop and/or lock to the wall.
  - A presently accepted metric to quantify the EF effect including plasma response is the overlap field, from which the ITER correction criterion is derived.
  - This proposal aims at implementing time-dependent EFC:
    - Varying with current in EF source
    - Varying with plasma state (e.g. betaN)

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Verify robustness of past results by testing static model-based EF correction in target scenario
  - Test time varying EFC with flat-top plasma response but rescaled with EF source currents
  - Test correction on different plasma states with varying plasma response, possibly within the same discharge
    - Ip ramp or steps
    - betaN



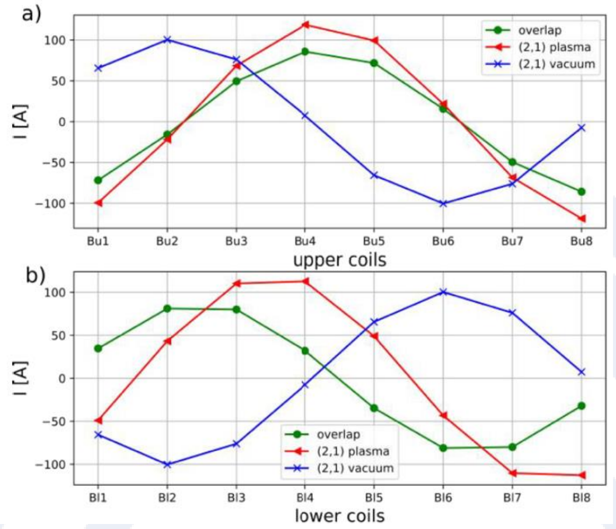
Proponents and contact person:

Leonardo Pigatto (leonardo.pigatto@igi.cnr.it)
Valentin Igochine
Lidia Piron
Tommaso Bolzonella

Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	
MAST-U		
TCV		
WEST		

P54: Dynamic model-based Error Field Correction



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  - Test time varying EFC with flat-top plasma response but rescaled with EF source currents
  - Test correction on different plasma states with varying plasma response, possibly within the same discharge
    - Ip ramp or steps
    - betaN

- TFL assessment: P2-AUG
- Aligned with D7

Proponents and contact person:

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Tommaso Bolzonella

Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	
MAST-U		
TCV		
WEST		

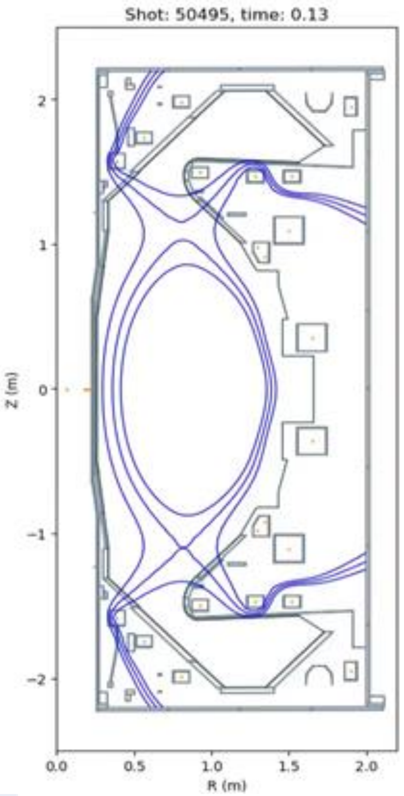
P55: Application of CREATE-ILC to alternative scenario

- **Proponents and contact person:**

  C. Vincent, L. diGrazia, D. Frattolillo, M. Mattei, E. Viezzer …

- **Scientific Background & Objectives**
  - Development of integrated scenario design tools critical for ITER and other power plant scale devices
  - Requires demonstration of safe coil current trajectory codes that operate within machine limits with minimal disruption risk
  - Continuation of CREATE-ILC development on MAST-U with application to RT02 Scenario development
  - Objectives:
  - Demonstrate magnetic design of new scenario using CREATE-ILC without input of previous field configuration
  - Development of steady state NT scenario with long flat top and triangularity of less than -0.1

- **Exp. Strategy/Machine Constraints and diagnostics**
  - Utilise CREATE-ILC with new feedback contribution functionality to generate coil currents for NT startup and flat top.
  - Require IR camera configuration for safety limits on nose tiles



Initial demonstration of NT startup developed with CREATE

Proposed pulses

Device	# Pulses/Session	# Development
MAST-U	1 Session	All Scenario development

P55: Application of CREATE-ILC to alternative scenario

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  C. Vincent, L. diGrazia, D. Frattolillo, M. Mattei, E. Viezzer …
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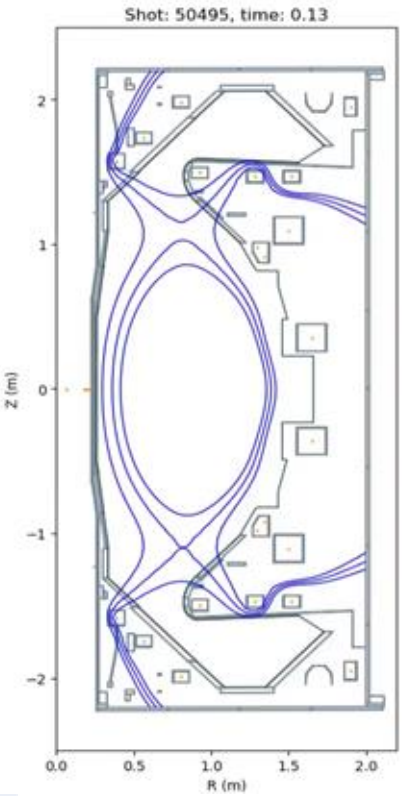


Initial demonstration of NT startup developed with CREATE

Proposed pulses

Device	# Pulses/Session	# Development
MAST-U	1 Session	All Scenario development

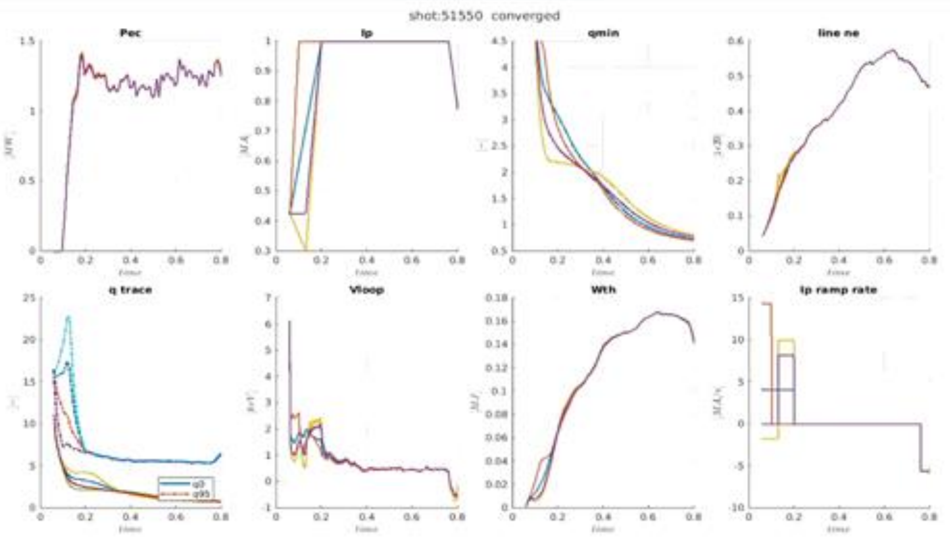
- TFL assessment: P2-MAST-U
- Aligned with D7

P56: Integration of RAPTOR and CREATE-ILC for advanced pulse design

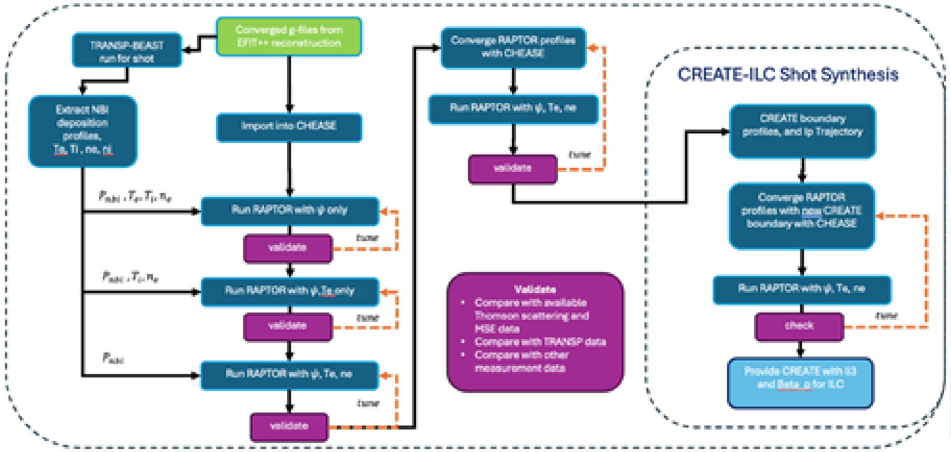
- **Proponents and contact person:**
  C. Vincent, L. diGrazia, D. Frattolillo, M. Mattei, J. Mitchell, O. Sauter, …

- **Scientific Background & Objectives**
  - Continued development of the RAPTOR/CREATE-ILC coupling framework
  - Stress testing of predictive capabilities of RAPTOR and plasma current overshoots for q min flattening
  - Demonstrate suitability of framework for use in RT08
  - Objectives:
  - Generate plasma current trajectory with RAPTOR to flatten q min for duration of a MAST-U pulse
  - More integrated coupling of CREATE-ILC and RAPTOR for optimisation of pulse performance

- **Exp. Strategy/Machine Constraints and diagnostics**
  - Utilise RAPTOR/CREATE-ILC framework to generate coil current trajectories and heating timing requirements
  - Critical use of MSE diagnostic for validating q min trajectory prediction from RAPTOR



Predictive modelling of current ramp-ups from RAPTOR



Proposed pulses

Device	# Pulses/Session	# Development
MAST-U	2 Sessions	1 Session

P56: Integration of RAPTOR and CREATE-ILC for advanced pulse design

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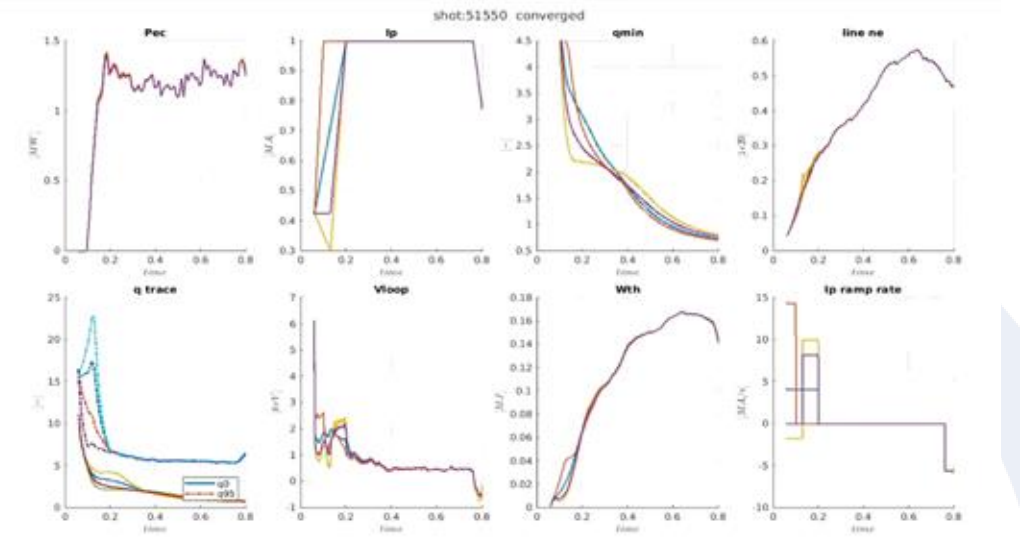

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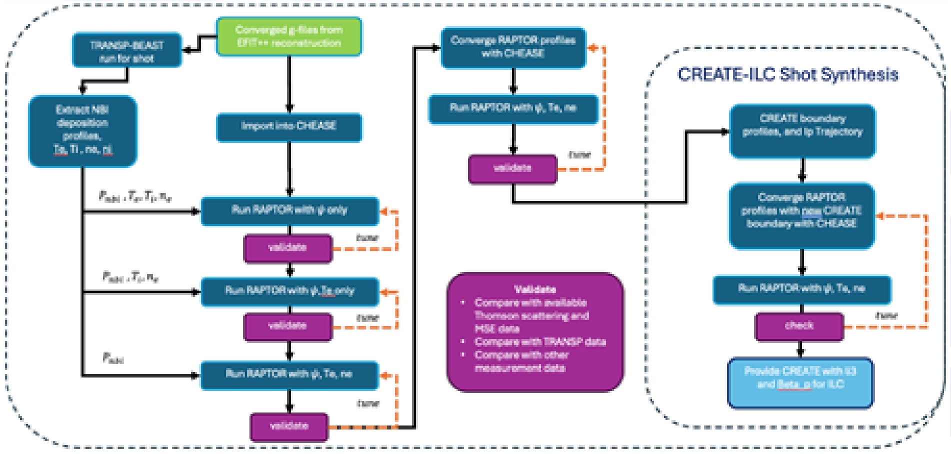


- **Exp. Strategy/Machine Constraints and diagnostics**
  - Utilise RAPTOR/CREATE-ILC framework to generate coil current trajectories and heating timing requirements
  - Critical use of MSE diagnostic for validating q min trajectory prediction from RAPTOR

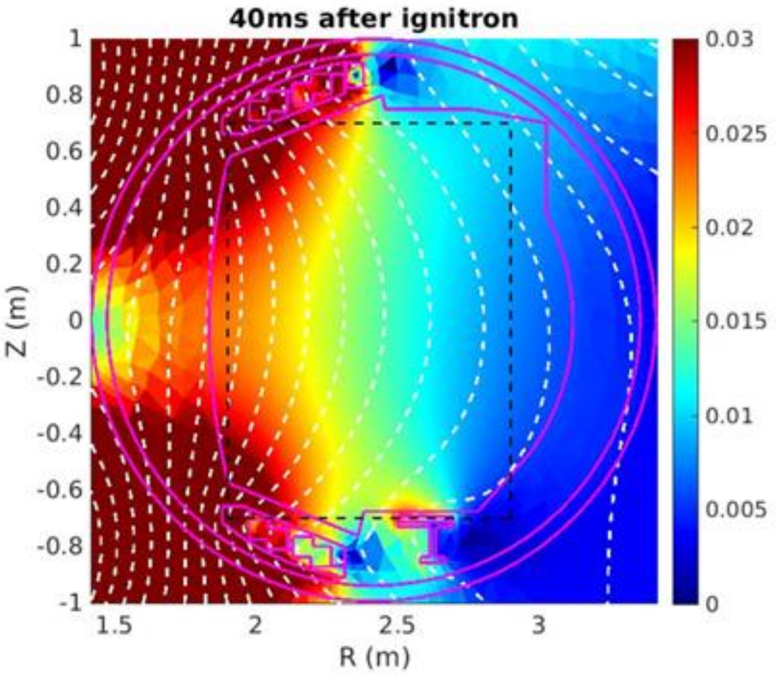
- TFL assessment: P2-MAST-U
- Aligned with D7
- Not compatible with available time

Proposed pulses

Device	# Pulses/Session	# Development
MAST-U	2 Sessions	1 Session

P57: Coil current optimisation for trapped particle configuration

- **Proponents and contact person:**
  C. Vincent, L. diGrazia, D. Frattolillo, M. Mattei, A. Fil, E. Lerche, J. Hillairet, T. Wauters, P. Maget, F. Maiden, S. Freethy
- **Scientific Background & Objectives**
  - Non-inductive heating assisted start-up critical for ITER to reduce v_loop requirements, with TPC showing potential for more efficient IC breakdown
  - WEST explored IC-assisted start-up v-loop limits but TPC attempts unsuccessful; CREATE-ILC proven effective on MAST-U
  - Apply CREATE-ILC to optimize TPC on MAST-U and WEST for cross-machine validation and demonstration on ITER-like device
  - Objectives:
  - Show breakdown and burnthrough of the TPC configuration with NBI assisted heating on MAST-U to validate the magnetic configuration for WEST
  - Apply CREATE-ILC to the TPC on WEST and compare to previous shots to compare the coil current trajectories
  - Successfully breakdown with TPC on WEST and apply IC pre-ionisation to show reduced vloop requirements for startup
- **Exp. Strategy/Machine Constraints and diagnostics**
  - Use WEST TPC to generate coil current trajectories for MAST-U
  - Use MAST-U optimised TPC field to generate coil current trajectories on WEST
  - Compare vloop lower limit with TPC and IC to conventional WEST null experiments already performed



WEST TPC field reconstruction with B_{pol}~15mT at centre

Proposed pulses

Device	# Pulses/Session	# Development
MAST-U	8 shots	8 shots
WEST	20 shots	10 shots

P57: Coil current optimisation for trapped particle configuration

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C. Vincent, L. diGrazia, D. Frattolillo, M. Mattei, A. Fil, E. Lerche, J. Hillairet, T. Wauters, P. Maget, F. Maiden, S. Freethy

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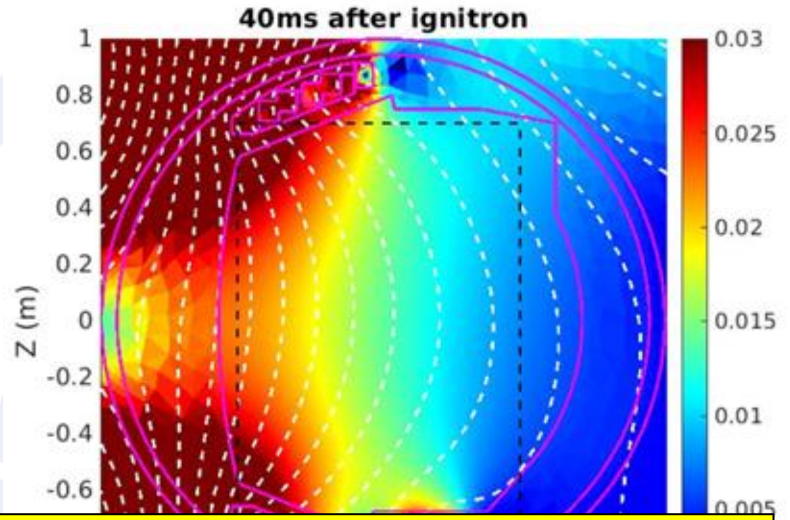


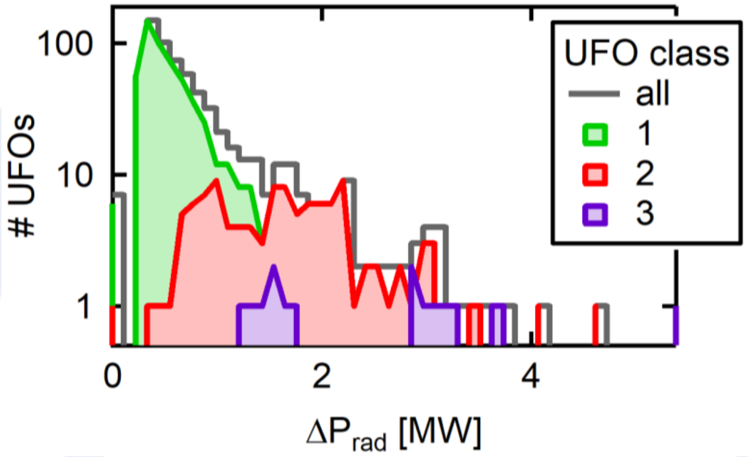
- TFL assessment: P2-MAST-U, P1-WEST
- Aligned with D7
- NBI in startup on MAST-U to be checked

Device	# Pulses/Session	# Development
MAST-U	8 shots	8 shots
WEST	20 shots	10 shots

P58: Mitigation of tungsten dust ingress with ECRH

- **Proponents and contact person:** P. Maget (*patrick.maget@cea.fr*), R. Dumont, R. Guirlet, P. Manas, R. Nouailletas, S. Mazzi, P. Devynck, L. Delpech, E. Lascar (IRFM), J. Gaspar (AMU), M. Schneider (IO), R. Granetz & H. Wietfeldt (MIT)

- **Scientific Background & Objectives**
  - Tungsten deposits can generate dust ingresses with large operational impact *[Gaspar NME'24, Maget PPCF'25]*
    - ***These events could be mitigated with appropriate core ECRH heating***
  - Objectives :
    - ***Evaluate the scaling of the ECRH power needed with the dust size on WEST,***
    - ***Implement a control scheme dedicated to this issue in the PCS***
    - ***Design integrated simulations to extrapolate to larger devices***
  - WP TE RT04 (experiment), TSVV-H (modelling and extrapolation), ITPA-MDC-JA-4
- **Experimental Strategy/Machine Constraints and essential diagnostic**
- L-mode plasma with Laser Blow Off (LBO) on tungsten and Ni/Fe/Al targets
  - *Ohmic and LHCD / ICRH heated plasmas,*
  - *scan LBO intensity, ECRH power and delay (feedforward)*
  - *Test triggers for activating ECRH power in the PCS: core bolometry line / core ECE*
- Essential diagnostics: real time bolometry / ECE, VUV, standard diagnostics



Distribution of radiation peaks due to tungsten ingresses in WEST high fluence campaign (class 1 within scenario resilience domain, classes 2 / 3 lead to delayed / immediate disruptions)

Proposed pulses

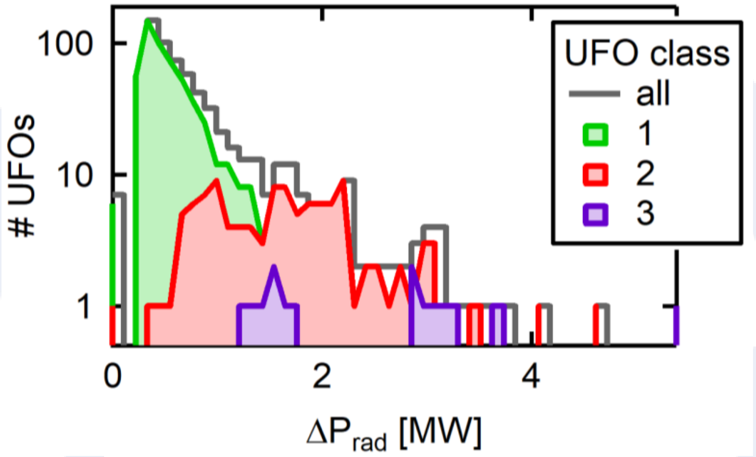
Device	# Pulses	# Develop
WEST	20	18

P58: Mitigation of tungsten dust ingress with ECRH

- TFL assessment: P1-WEST
- Aligned with D8
- Reduce by 50%, first part parasitic?

- **Proponents and contact person:** P. Maget (*patrick.maget@cea.fr*), R. Dumont, Guirlet, P. Manas, R. Nouailletas, S. Mazzi, P. Devynck, L. Delpech, E. Lascar (IRFM), Gaspar (AMU), M. Schneider (IO), R. Granetz & H. Wietfeldt (MIT)

- **Scientific Background & Objectives**
  - Tungsten deposits can generate dust ingresses with large operational impact *[Gaspar NME'24, Maget PPCF'25]*
    - ***These events could be mitigated with appropriate core ECRH heating***
  - Objectives :
    - ***Evaluate the scaling of the ECRH power needed with the dust size on WEST,***
    - ***Implement a control scheme dedicated to this issue in the PCS***
    - ***Design integrated simulations to extrapolate to larger devices***
  - WP TE RT04 (experiment), TSVV-H (modelling and extrapolation), ITPA-MDC-JA-4
- **Experimental Strategy/Machine Constraints and essential diagnostic**
- L-mode plasma with Laser Blow Off (LBO) on tungsten and Ni/Fe/Al targets
  - *Ohmic and LHCD / ICRH heated plasmas,*
  - *scan LBO intensity, ECRH power and delay (feedforward)*
  - *Test triggers for activating ECRH power in the PCS: core bolometry line / core ECE*
- Essential diagnostics: real time bolometry / ECE, VUV, standard diagnostics



Distribution of radiation peaks due to tungsten ingresses in WEST high fluence campaign (class 1 within scenario resilience domain, classes 2 / 3 lead to delayed / immediate disruptions)

Proposed pulses

Device	# Pulses	# Develop
WEST	20	18

P59: ICRF-assisted plasma start-up

In collaboration with ITPA-IOS JEX 2.4, WP-TSVV and ITER PWI group

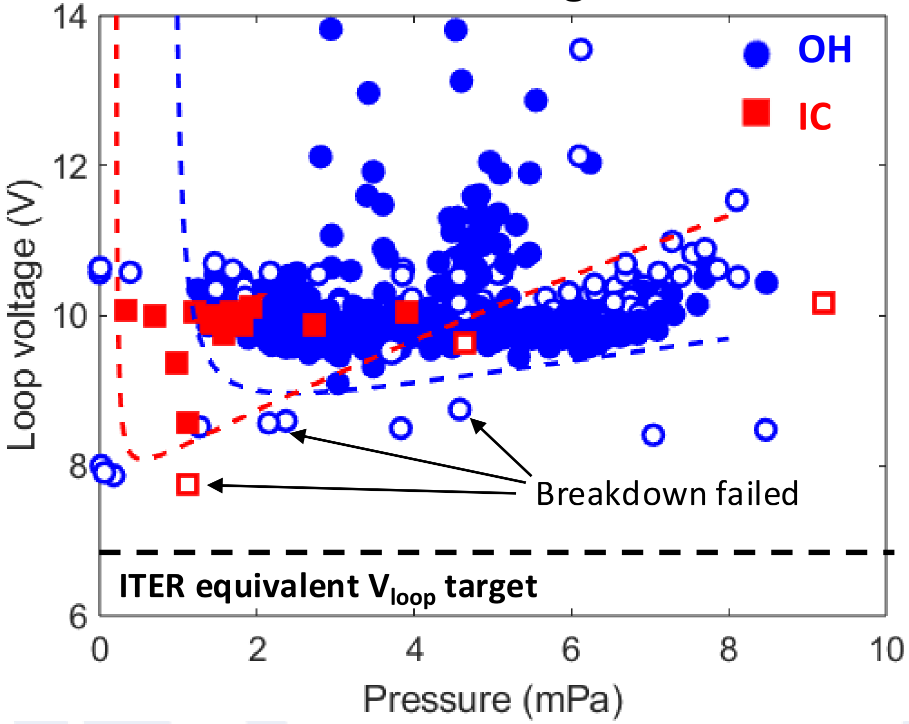
- **Proponents and contact person:**

  E. Lerche, J. Hillairet, T. Wauters, L. Colas, P. Dumortier, A. Fil, C. Vincent, …

- **Scientific Background & Objectives**
  - ITER considers IC-assisted start-up as one of the options for plasma breakdown at low V_{loop} or when the machine conditions are unfavorable
  - IC-assisted breakdown was successfully developed in WEST extending the pressure and V_{loop} domain w.r.t. to standard OH breakdown
  - However, the equivalent ITER target V_{loop} was not yet achieved and improved magnetic configurations (e.g. TPC) were not tested
  - Objectives:
    - Extend the IC-assisted breakdown results to lower V_{loop} values
    - Test more complex magnetic configurations for breakdown as the Trapped Particle Configuration (TPC); Collaboration with CREATE team.
    - Provide feedback to the ITPA-IOS task 2.4, to the TSVV breakdown modelling team and to the ITER PWI group

- **Exp. Strategy/Machine Constraints and diagnostics**
  - Start from previous results with low pressure (~1 mPa) and V_{loop}=10V.
  - Gradually reduce V_{loop} until reaching the ITER equivalent target (V_{loop}=7V); Adjust the prefil pressure if necessary.
  - Test / develop a more favorable magnetic configuration (TPC-like) and assess whether it's easier to reduce V_{loop} in these conditions
  - Study the benefits / drawbacks of IC-assisted start-up in the I_p ramp-up and flat-top phases

Paschen diagram



Paschen curve illustrating IC-assisted vs. OH breakdown parameter space explored in WEST

Proposed pulses

Device	# Pulses/Session	# Development
WEST	2 Sessions (two in 2026)	Scenario is ready

P59: ICRF-assisted plasma start-up

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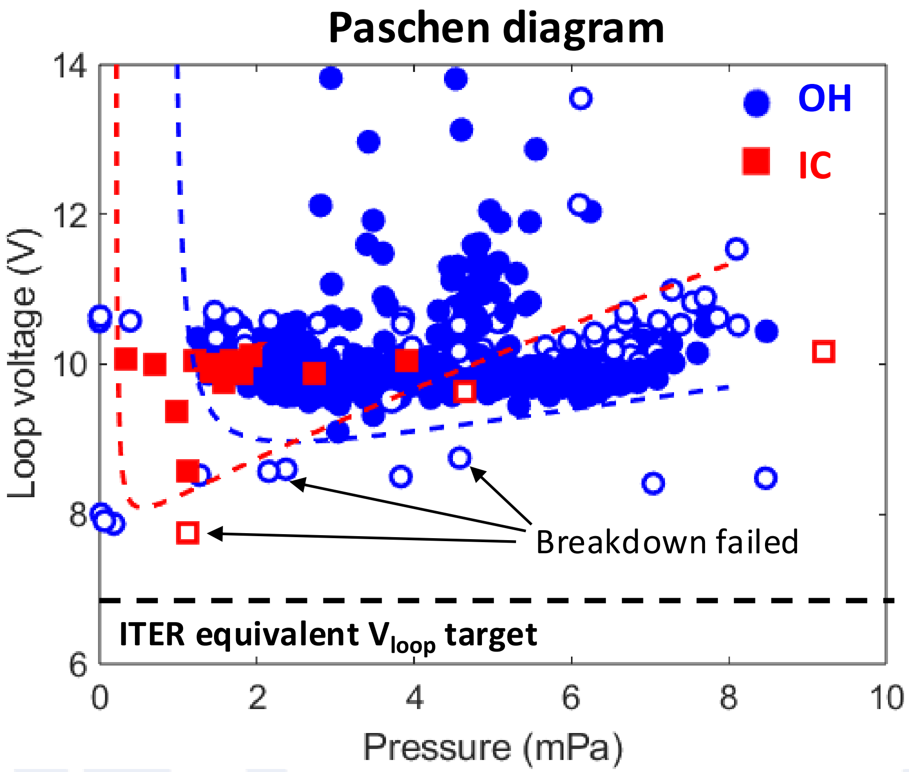


Paschen curve illustrating IC-assisted vs. OH … T

- TFL assessment: P1-WEST
- Aligned with D7
- Reduce by 50%

Device	# Pulses/Session	# Development
WEST	2 Sessions (two in 2026)	Scenario is ready

P60: Real time ICRF coupling control

In collaboration with ITPA-IOS JEX 5.1/5.2 and with ITER PCS development

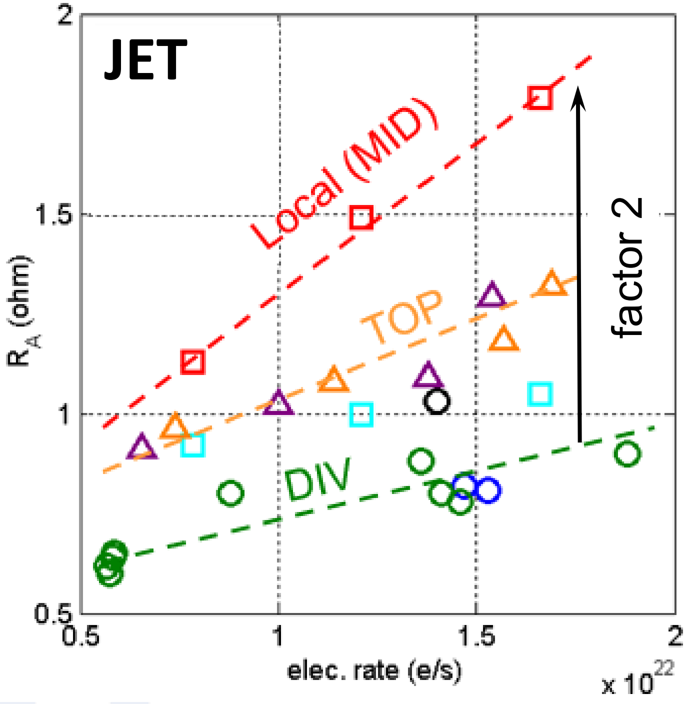
- **Proponents and contact person:**

  E. Lerche, L. Colas, J. Hillairet, V. Bobkov, R. Ochoukov, P. Dumortier, W. Helou, …

- **Scientific Background & Objectives**
  - Local gas injection is one of the main actuators for optimizing the ICRF coupling in tokamaks, but closed-loop real-time control based on this was never tested
  - ITER foresees local IC gas injection and they want to integrate this procedure in the PCS (Plasma Control System) controller in real-time
  - Objectives:
  - Implement real-time control of the IC coupling based on local gas injection
  - Study the dynamics and efficiency of the control systems in various devices and provide feedback to the ITPA-IOS tasks 5.1/5.2 and to the ITER team designing the global PCS control system

- **Exp. Strategy/Machine Constraints and diagnostics**
  - The first step is to develop & commission the real-time control network for IC coupling; This can be done off-line but requires ~1 week work with 2 specialist. The staff is available in WEST and in AUG and is aware of the strategy.
  - Start with the simplest possible RT network (input=R_c, output=gas rate) and increase complexity with time (2027), e.g. include outer gap control (ROG), PWI aspects, etc …
  - Plasma target: Standard plasma with large clearance; ROG/shape scans; Low ICRH power ~1MW.
  - Basic diagnostics only. IC coupling resistance available in real-time. Edge / PWI diagnostics desired.
  - In WEST, real-time information and control of the SOL density via reflectometry is available. This can add to the assessment and physics understanding of the real-time coupling control technique.

E. Lerche et al 2015 *Journal Nucl. Mat.* **463** p634



Example of IC coupling enhancement with local gas injection

Proposed pulses

Device	# Pulses/Session	# Development
AUG	2 Sessions (one 2026, one 2027)	1 week off-line and 1-2 days on plasma (parasitic)
WEST	2 Sessions (one 2026, one 2027)	1 week off-line and 1-2 days on plasma (parasitic)

P60: Real time ICRF coupling control

In collaboration with ITPA-IOS JEX 5.1/5.2 and with ITER PCS development

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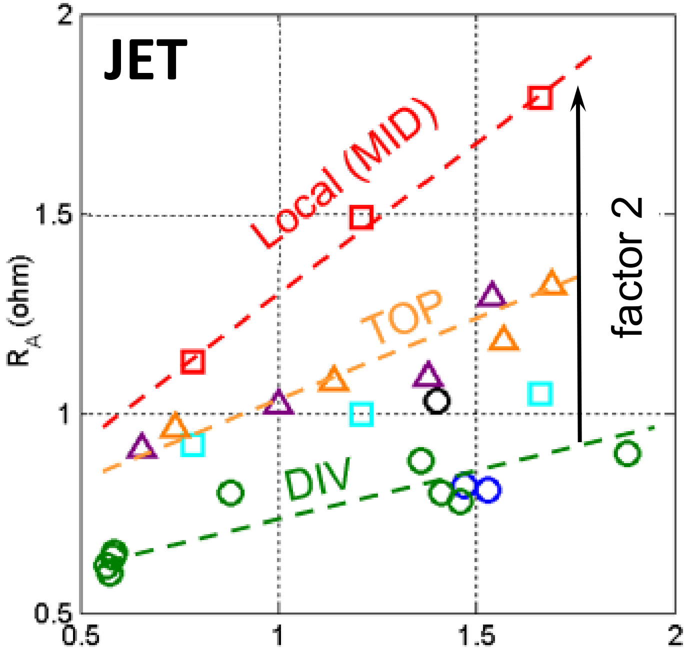


- TFL assessment: P1-2027-AUG,P1-WEST
- Aligned with D6

Device	# Pulses/Session	# Development
AUG	2 Sessions (one 2026, one 2027)	1 week off-line and 1-2 days on plasma (parasitic)
WEST	2 Sessions (one 2026, one 2027)	1 week off-line and 1-2 days on plasma (parasitic)

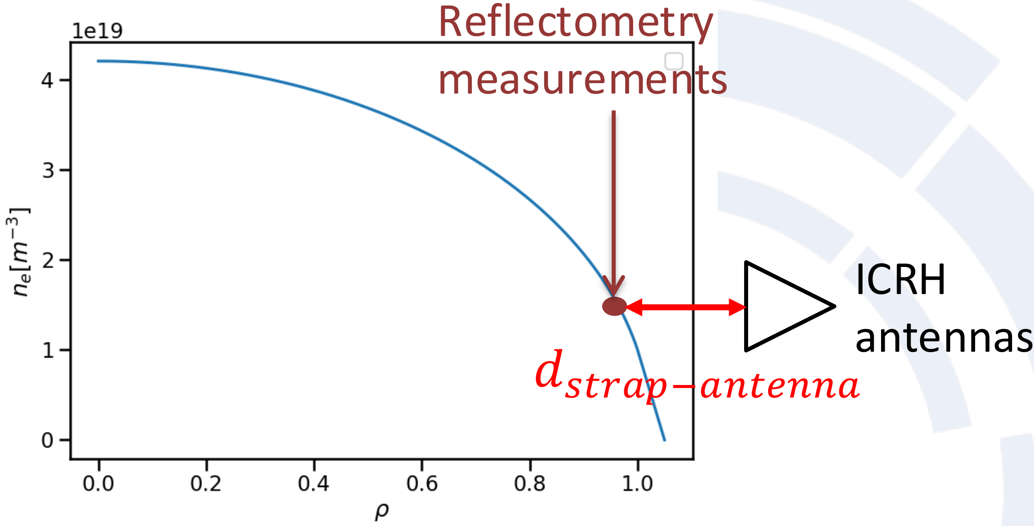
P61: ICRH coupling control with density profiles from real-time reflectometry

- **Proponents and contact person:**
- maylis.carrard@cea.fr
- laurent.colas@cea.fr

- **Scientific Background & Objectives**
  - Reflectometry envisaged as a multi-purpose sensor for real-time control in ITER.
  - ICRH wave coupling depends on distance $d_{strap-cutoff}$, the distance to the critical density $n_{e\ strap}$
  - WEST reflectometry provides in real-time local density profiles and radial position R_{cutoff} of the critical density layer. Proof-of-principle experiments carried out in 2025 [Carrard PPCF 2025]

→ Goal: As part of ITPA task IOS 5.2 & WP-TE RT04, control ICRH coupling using real-time estimates of R_{cutoff}

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Double real-time control of core density using interferometer and plasma position (R_{ext}) using reflectometer.
  - Fixed I_p, increase requested core density during pulse and request R_{ext} control to maintain fixed cutoff position R_{cutoff}, as measured in real-time by reflectometer.
  - Fixed core density, vary requested I_p during pulse and request R_{ext} control to maintain fixed cutoff position $R_{cutfoff}$, as measured in real-time by reflectometer.
  - Check variations of ICRH coupling resistance over the pulse.



Proposed pulses

Device	# Pulses/Session	# Development
WEST	1 session/16 pulses	2 pulses

P61: ICRH coupling control with density profiles from real-time reflectometry

- **Proponents and contact person:**
- maylis.carrard@cea.fr
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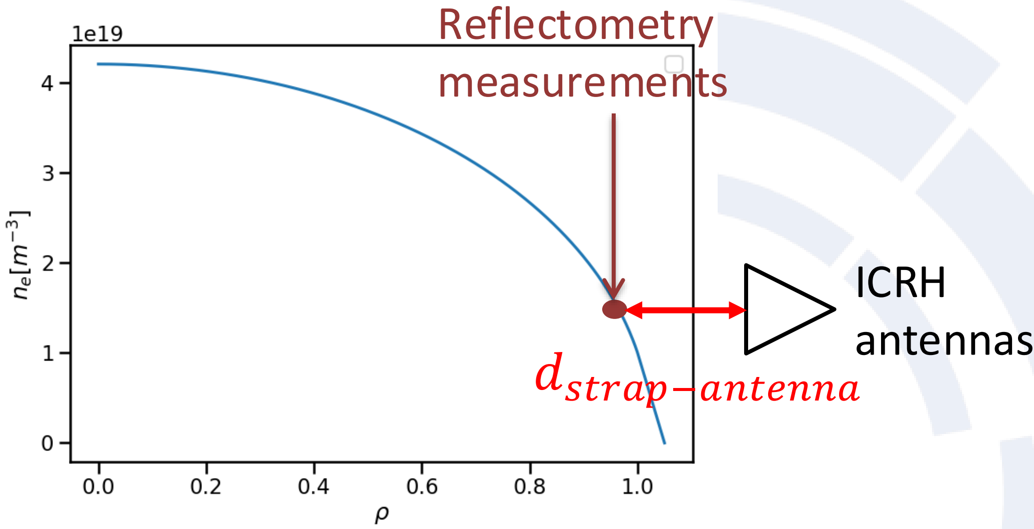
  - Fixed core density, vary requested I_p during pulse and request R_{ext} control to maintain fixed cutoff position R_{cutoff}, as measured in real-time by reflectometer.
  - Check variations of ICRH coupling resistance over the pulse.



Proposed pulses

Device	# Pulses/Session	# Development
WEST	1 session/16 pulses	2 pulses

- TFL assessment: P1-WEST
- Aligned with D6
- Combine with P60

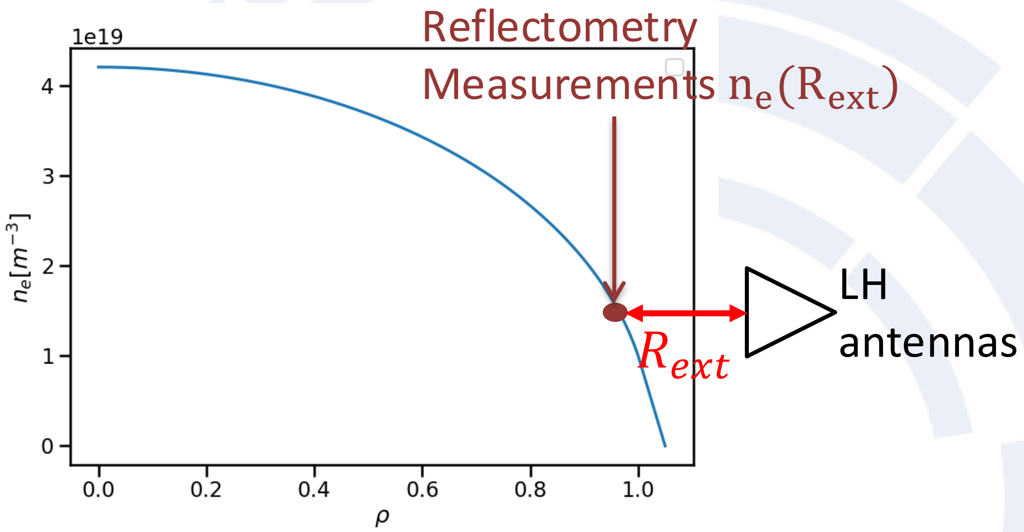
P62: LH coupling control with density profiles from real-time reflectometry

- **Proponents and contact person:**
- maylis.carrard@cea.fr

- **Scientific Background & Objectives**
  - Reflectometry envisaged as a multi-purpose sensor for real-time control in ITER.
  - LH wave coupling depends on the density in front of the antennas $n_e(R_{ext})$
  - WEST reflectometry provides in real-time local density profiles and radial position R_{ext} of fixed densities. Proof-of-principle experiments carried out in 2025 [Carrard PPCF 2025]

→ Goal: Control LH coupling using real-time estimates of $n_e(R_{ext})$

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Double real-time control of edge density $n_e(R_{ext})$ and plasma position (R_{ext}) using reflectometer.
  - Fixed core density, vary requested I_p during pulse and request R_{ext} control to maintain a high density at a fixed distance from the antennas, as measured in real-time by reflectometer.
  - Fixed core density, vary requested I_p during pulse and request $n_e(R_{ext})$ control to maintain a high density at the edge, as measured in real-time by reflectometer.
  - Check variations of LH coupling resistance over the pulse.



Proposed pulses

Device	# Pulses/Session	# Development
WEST	1 session/16 pulses	2 pulses

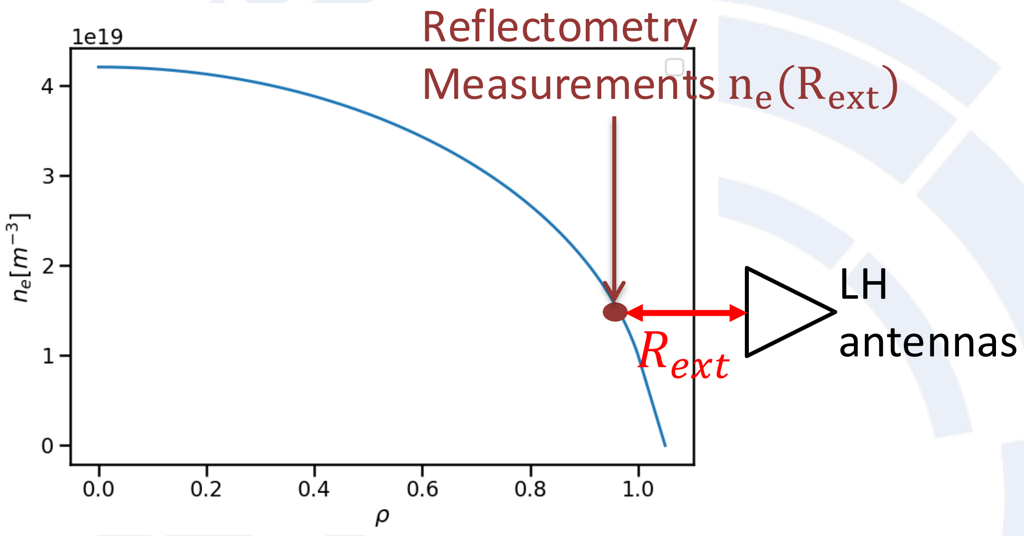
P62: LH coupling control with density profiles from real-time reflectometry

- **Proponents and contact person:**
- maylis.carrard@cea.fr

- **Scientific Background & Objectives**
  - Reflectometry envisaged as a multi-purpose sensor for real-time control in ITER.
  - LH wave coupling depends on the density in front of the antennas $n_e(R_{ext})$
  - WEST reflectometry provides in real-time local density profiles and radial position R_{ext} of fixed densities. Proof-of-principle experiments carried out in 2025 [Carrard PPCF 2025]

→ Goal: Control LH coupling using real-time estimates of $n_e(R_{ext})$

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Double real-time control of edge density $n_e(R_{ext})$ and plasma position (R_{ext}) using reflectometer.
  - Fixed core density, vary requested I_p during pulse and request R_{ext} control to maintain a high density at a fixed distance from the antennas, as measured in real-time by reflectometer.
  - Fixed core density, vary requested I_p during pulse and request $n_e(R_{ext})$ control to maintain a high density at the edge, as measured in real-time by reflectometer.
  - Check variations of LH coupling resistance over the pulse.

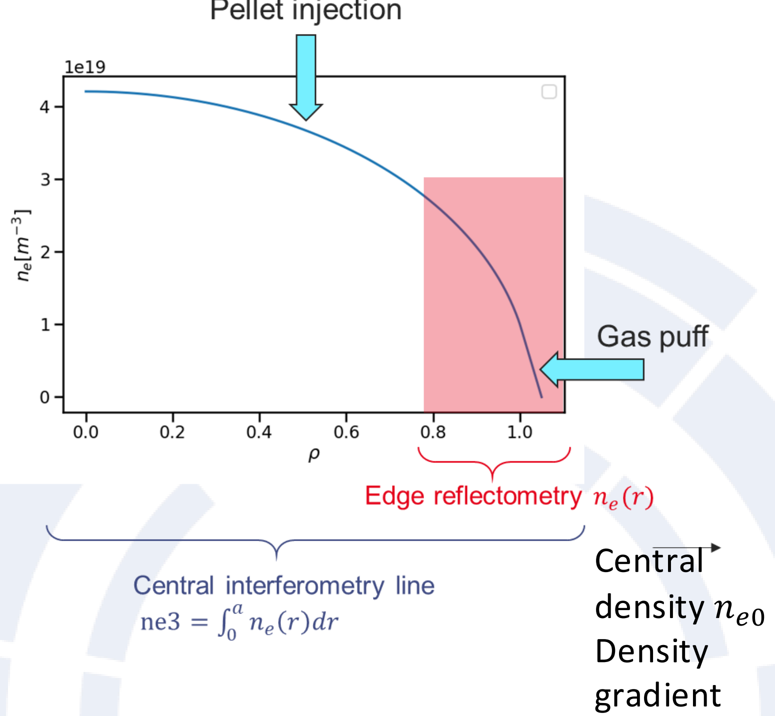


Proposed pulses

Device	# Pulses/Session	# Development
WEST	1 session/16 pulses	2 pulses

- TFL assessment: P2-WEST
- Aligned with D6

P63: Density gradient control with reflectometry



- **Proponents and contact person:**
- maylis.carrard@cea.fr

- **Scientific Background & Objectives**
- Reflectometry envisaged as a multi-purpose sensor for real-time control in ITER.
- WEST reflectometry provides in real-time local density profiles and radial position Rcutoff of the critical density layer. Proof-of-principle experiments carried out in 2025 [Carrard PPCF 2025].
- WEST interferometry provides averaged density value.
- Edge density gradient influences plasma performances.
- Control the averaged density gradient by using interferometry sensor with pellets actuator to control the core density ; and reflectometry sensor with gas injection actuator to control the edge density.
- Study the influence of density gradient control on the plasma performances.

- **Experimental Strategy/Machine Constraints and essential diagnostic**
- Developpement and commisioning of the control with real-time reflectometry have been performed in WEST. Edge density control and plasma position control from real-time density profiles are available [Carrard PPCF 2025].
- Real-time control of core density using reflectometry during pellets injection to validate the use of reflectometry profile for control with the pellets. Can be done with any pellets discharge.
- Real-time estimation of the averaged density gradient with the averaged density provided by interferometry and the edge density provided by real-time reflectometry.
- Use of this real-time density gradient estimation to control the density gradient. Actuation of the core density with pellet injection and actuation of the edge density with gas injection

Proposed pulses

Device	# Pulses/Session	# Development
WEST	1/15 pulses	Any pellets discharge, 1 pulse

P63: Density gradient control with reflectometry

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- maylis.carrard@cea.fr

- **Scientific Background & Objectives**
- Reflectometry envisaged as a multi-purpose sensor for real-time control in ITER.
- WEST reflectometry provides in real-time local density profiles and radial position Rcutoff of the critical density layer. Proof-of-principle experiments carried out in 2025 [Carrard PPCF 2025].
- WEST interferometry provides averaged density value.
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- Real-time control of core density using reflectometry during pellets injection to validate the use of reflectometry profile for control with the pellets. Can be done with any pellets discharge.
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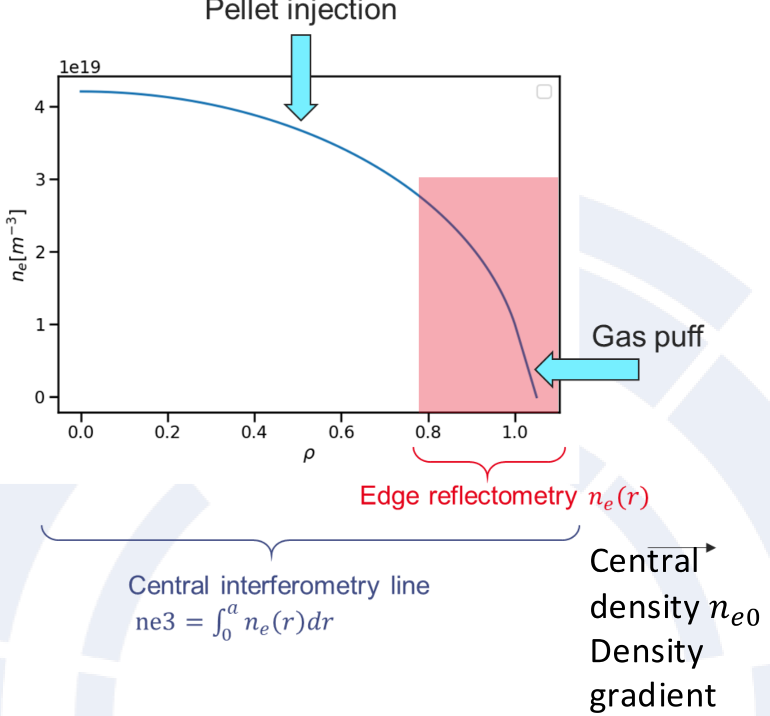


Proposed pulses

Device	# Pulses/Session	# Development
WEST	1/15 pulses	Any pellets discharge, 1 pulse

- TFL assessment: P2-WEST
- Aligned with D6,D7

P64: Model-based observer of the internal plasma profiles enabling integrated control over kinetic profiles and safety factor

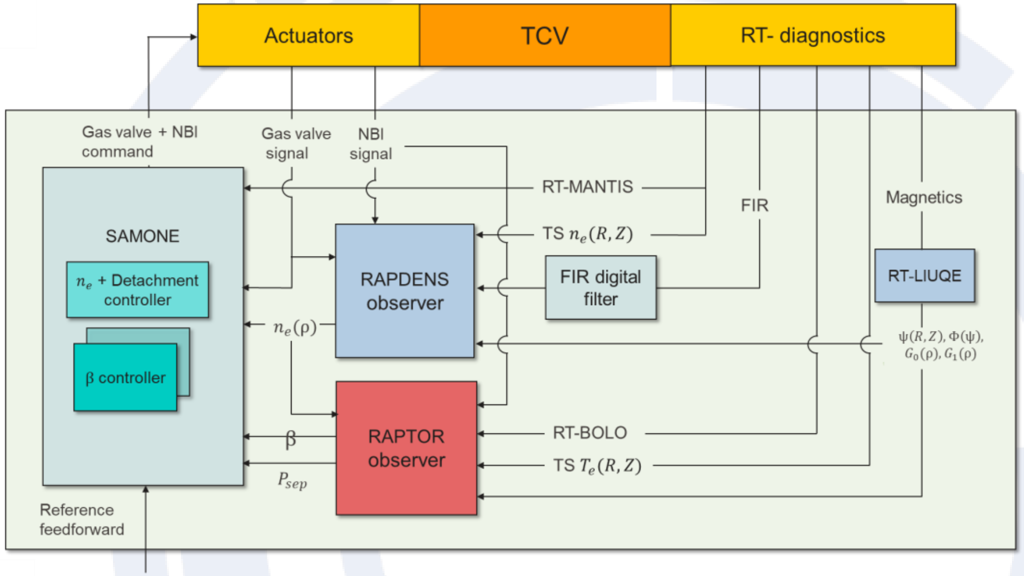
- **Proponents and contact person:**

  simon.vanmulders@epfl.ch et al.

- **Scientific Background:**
  - Model-based observers are essential for coordinated control of the dynamic evolution of kinetic and safety factor profiles.
  - The Extended Kalman Filter combines diagnostic data and physics models, improving real-time plasma state knowledge while accounting for uncertainties.
  - The RAPTOR solver enables faster-than-real-time profile prediction, supporting both feedforward scenario design and feedback control during experiments.

- **Objectives:**
  - **Real-time q min control:** Perform experiments on TCV (≈10 shots) to regulate $q$min between 0.9 and 1.2, observing sawtooth behavior. This controller will support access to flux pumping and high-$q$min/negative shear regimes (link with RT08 topic).
  - **Real-time Ti/Te control at constant Wmhd:** Extend previous inter-discharge RAPTOR results to real-time implementation on TCV (≈10 shots), maintaining constant total stored energy.
  - **Pre-LHCD profile shaping on WEST:** Simultaneous control of Te0 and q0 to achieve a peaked q-profile before lower hybrid heating, mitigating harmful MHD activity.
  - **Control of ne0 and Te0 at AUG:** Simultaneous control of density and temperature at AUG with the improved state observers, using pellets, gas valve and ECRH actuators.

- **Experimental Strategy/Machine Constraints and essential diagnostic:**
  - RT-RAPTOR, RT-CXRS, RT-TS, RT-ECE, RT-BOLOMETRY, ECRH, PELLETS (AUG)



Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	0
MAST-U	-	-
TCV	20	0
WEST	10	0

P64: Model-based observer of the internal plasma profiles enabling integrated control over kinetic profiles and safety factor

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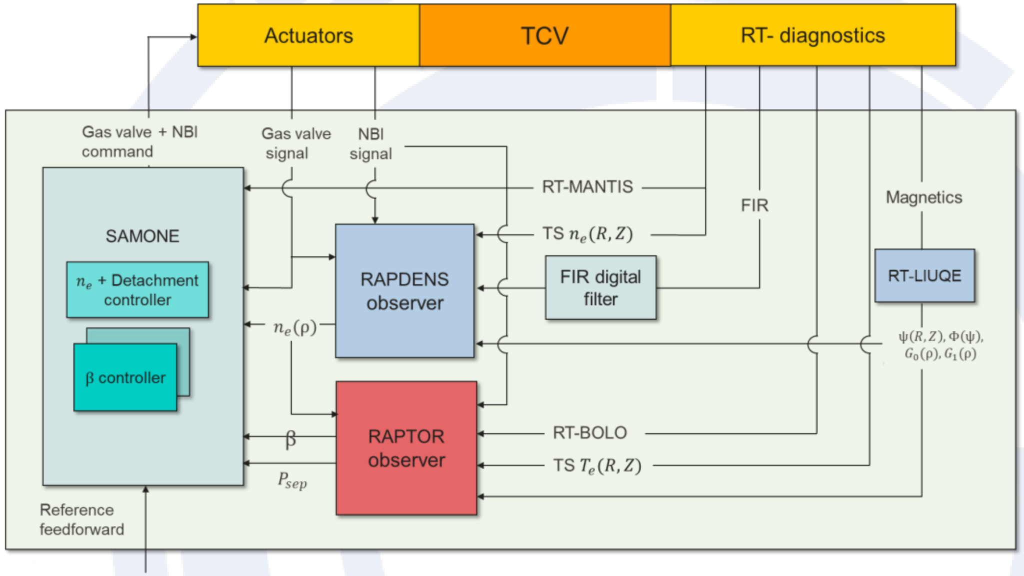


Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	0
MAST-U	-	-
TCV	20	0
WEST	10	0

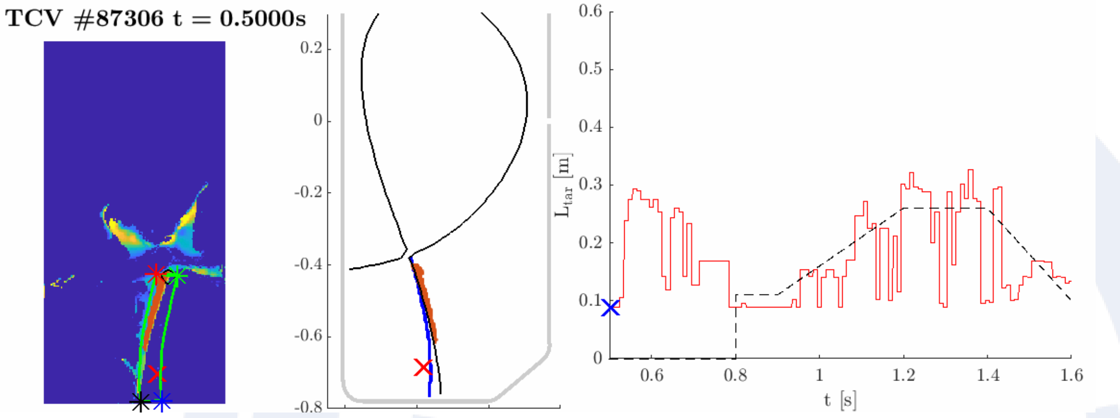
- TFL assessment: P1-2026-AUG,P1-WEST-2027,P1-TCV
- Aligned with D6,D7

P65: Standardisation of camera based front control

ENR11, WPTE RT05-2025 inference exhaust control

Multi-spectral camera system MANTIS may/will be installed on JT-60SA

- **Proponents and contact person:**
  - G.l.derks@differ.nl
- **Scientific Background & Objectives**
  - D6 - Develop generalized controllers and state observers designed for application to a variety of devices
  - D9 - Integrate machine learning and physics driven techniques for control augmentatior performance boosting
    - MANTIS real-time ML inversions and inferences used for front control on TCV.
    - Outcome ENR11 and last WPTE campaign.
    - Provide real-time 2D poloidal plasma reconstructions, Te, ne, nD, nHe, etc (3 at a time) .
    - Front tracking without shot2shot tuning for projection to poloidal plane.
    - Multi-Wavelength-Imaging pc (a copy of the MANTIS pc) on MAST-U will get GPU.
    - MAST-U cameras installed in upper and lower divertor and looking at Xpoint.
    - MANTIS installed on AUG and may be on JT-60SA
    - **Support: front control on TCV in (totally baffled) long-legged divertor, X-point target and H-mode with ELM filter and MARFE mitigation.**
    - **Support: front control on MAST-U SXD and possibly XPR with Xpoint imaging**
    - **Support: inversion and inference pipeline on AUG for physics analysis.**
- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - On TCV commission inversion based control in new shapes required by RT05 and RT07 and for H-mode (4 shots per config, LLD, TBLLD, XPT, H-mode) (16 shots total)
  - On MAST-U install GPU capabilities and commission front output to PCS. (given a scenario, 4 shots per camera MWI bottom, X-point imaging maybe rewired to bottom MWI pc for GPU) (8 shots total)
  - On AUG run density/impurity ramps to test inversion and inference from attached to disruption (4 shots)



Proposed pulses

Device	# Pulses/Session	# Development
AUG		4
MAST-U	8 pulses	RT05/RT07
TCV	16 pulses	RT05/RT07
WEST		

P65: Standardisation of camera based front control

ENR11, WPTE RT05-2025 inference exhaust control

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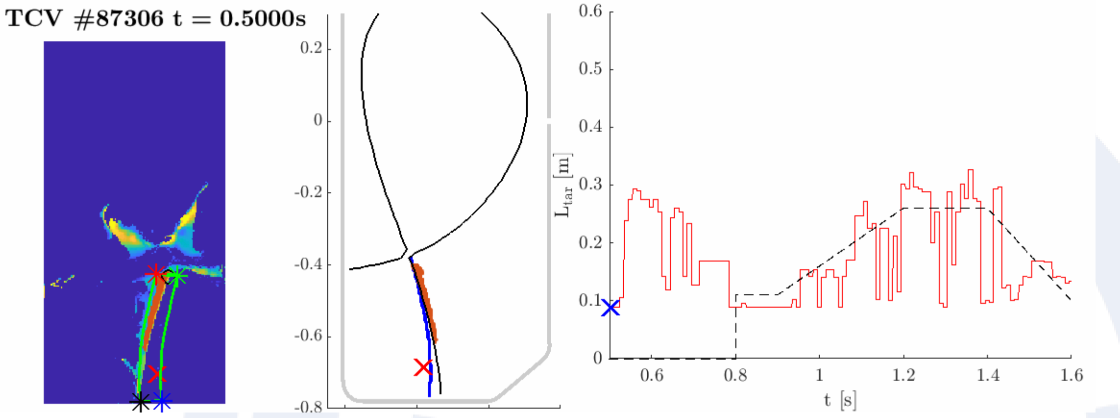
    - Outcome ENR11 and last WPTE campaign.
    - Provide real-time 2D poloidal plasma reconstructions, Te, ne, nD, nHe, etc (3 at a time) .
    - Front tracking without shot2shot tuning for projection to poloidal plane.
    - Multi-Wavelength-Imaging pc (a copy of the MANTIS pc) on MAST-U will get GPU.
    - MAST-U cameras installed in upper and lower divertor and looking at Xpoint.
    - MANTIS installed on AUG and may be on JT-60SA
    - **Support: front control on TCV in (totally baffled) long-legged divertor, X-point target and H-mode with ELM filter and MARFE mitigation.**
    - **Support: front control on MAST-U SXD and possibly XPR with Xpoint imaging**
    - **Support: inversion and inference pipeline on AUG for physics analysis.**
- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - On TCV commission inversion based control in new shapes required by RT05 and RT07 and for H-mode (4 shots per config, LLD, TBLLD, XPT, H-mode) (16 shots total)
  - On MAST-U install GPU capabilities and commission front output to PCS. (given a scenario, 4 shots per camera MWI bottom, X-point imaging maybe rewired to bottom MWI pc for GPU) (8 shots total)
  - On AUG run density/impurity ramps to tes disruption (4 shots)



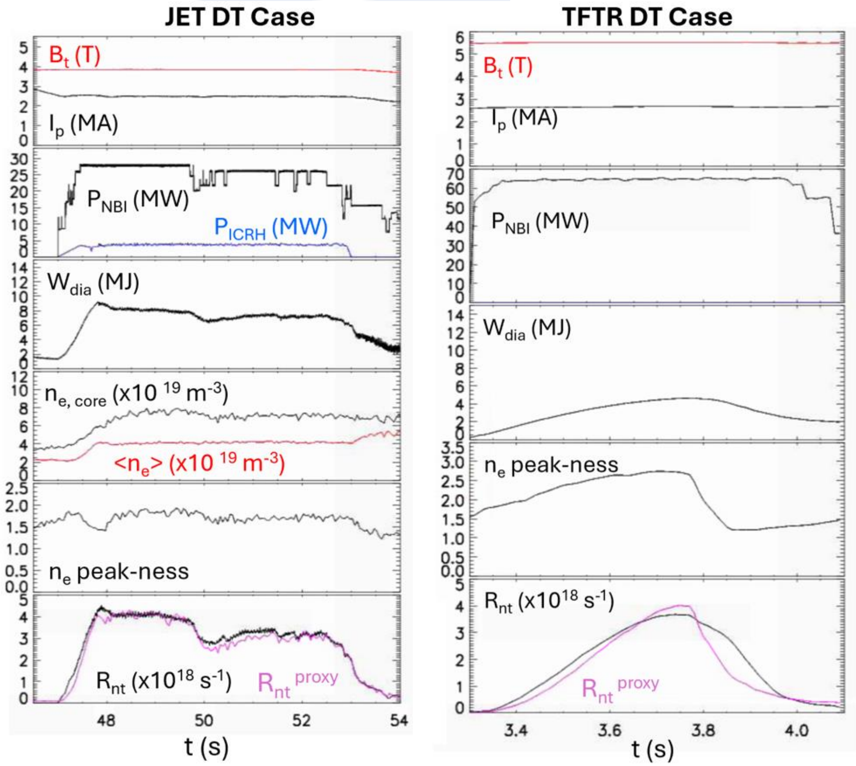
Proposed pulses

Device	# Pulses/Session	# Development
AUG		4
MAST-U	8 pulses	RT05/RT07
TCV	16 pulses	RT05/RT07
WEST		

- TFL assessment: P1-TCV, P2-MAST-U Aligned with D6

P66: Design and test of a novel dud detection based on TFTR and JET DT plasmas

- **Scientific Background & Objectives**
  - Among the burning plasma controllers for magnetic fusion reactors, the dud detector will be of primary importance as it will discriminate if the plasma is performing well or if it is a dud.
  - To this scope, a monitor which follows the plasma performance behavior will be included in the plasma control system of next step fusion reactors.
  - TFRT and JET Deuterium-Tritium plasmas have been analyzed with the scope of identifying new empirical dud detection methods. A new metric, based on the density peakedness and the diamagnetic energy, proves to be a good proxy of the neutron rate.



- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Design the empirical dud detection based on density peakedness, based on RAPDENS, and the diamagnetic energy.
  - Test this new dud detection algorithm in TCV, coupled with a save plasma termination.

Proponents and contact person:

Lidia Piron (lidia.piron@unipd.it), Alessandro Pau, Olivier Sauter, Nicolò Ferron,

Proposed pulses

Device	# Pulses/Session	# Development
TCV	5	

P66: Design and test of a novel dud detection based on TFTR and JET DT plasmas

- **Scientific Background & Objectives**
  - Among the burning plasma controllers for magnetic fusion reactors, the dud detector will be of primary importance as it will discriminate if the plasma is performing well or if it is a dud.
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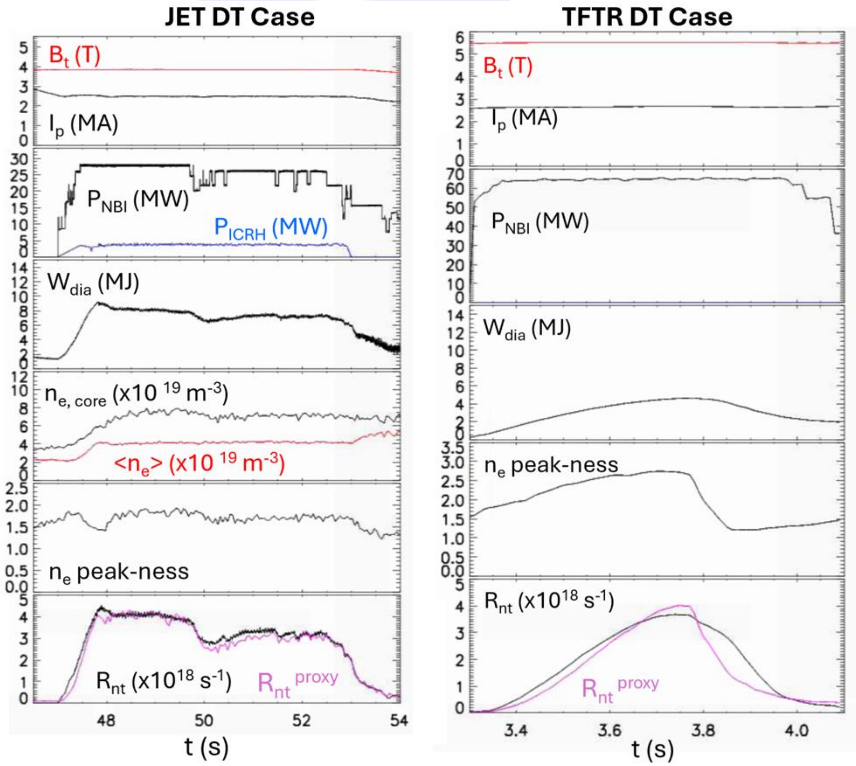

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Design the empirical dud detection based on density peakedness, based on RAPDENS, and the diamagnetic energy.
  - Test this new dud detection algo plasma termination.

- TFL assessment: P1-TCV
- Aligned with D8,D9

Proponents and contact person:

Lidia Piron (lidia.piron@unipd.it), Alessandro Pau, Olivier Sauter, Nicolò Ferron,

Proposed pulses

Device	# Pulses/Session	# Development
TCV	5	

P67: Face NTM position control toward ITER operation

- **Scientific Background & Objectives**
  - In tokamaks, NTMs typically rotate while maintaining a small magnetic island width. As the mode slows down, the island width increases, potentially leading to plasma disruption.
  - A robust and well-established technique used to stabilize NTMs involves using RF waves to drive current at the island O-point. Stabilizing the 2/1 NTM during its rotating phase can be particularly challenging in ITER due to rapid mode locking and the broadening of the radial current profile driven by RF waves, which is caused by edge density fluctuations.
  - A promising solution is to induce a proxy error field in front of the RF launcher. This enables the magnetic island to lock at the RF launcher, where the driven current can effectively suppress the mode. The proxy error field in TCV can be induced by increasing the ripple by using less TF coils.

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Establish a plasma scenario prone to locked NTM
  - Induce a magnetic ripple near the RF launcher and check if the NTM slows down and locks at that position
  - Test NTM control by RF

Proponents and contact person:

Lidia Piron (lidia.piron@unipd.it), Alessandro Pau, Olivier Sauter, Paolo Zanca, Anna Trang Vu

Proposed pulses

Device	# Pulses/Session	# Development
TCV	10	

P67: Face NTM position control toward ITER operation

- **Scientific Background & Objectives**
  - In tokamaks, NTMs typically rotate while maintaining a small magnetic island width. As the mode slows down, the island width increases, potentially leading to plasma disruption.
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- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Establish a plasma scenario prone to locked NTM
  - Induce a magnetic ripple near the RF launcher and check if the NTM slows down and locks at that position
  - Test NTM control by RF

- TFL assessment: P2-TCV
- Aligned with D6,D8

Proponents and contact person:

Lidia Piron (lidia.piron@unipd.it), Alessandro Pau, Olivier Sauter, Paolo Zanca, Anna Trang Vu

Proposed pulses

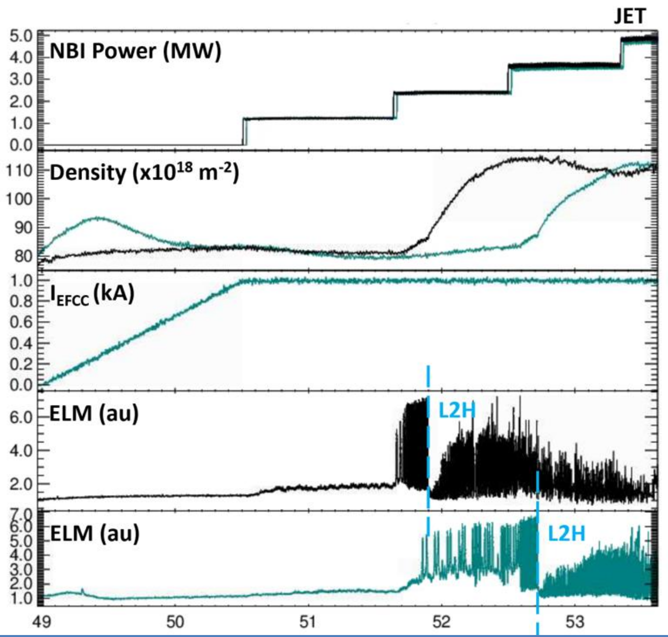
Device	# Pulses/Session	# Development
TCV	10	

P68: Assess the role of a proxy EF in H mode entry, H-L exit in AUG and MAST-U

- **Proponents and contact person:**
  - lidia.piron@igi.cnr.it & collaborators

- **Scientific Background & Objectives**
  - **investigate the role of a proxy EF in the L-H and H-L transitions,**
  - **analyze changes in the plasma rotation profile during L2H and H2L transients,**
  - **assess the maximum tolerable EF amplitude at which a LM is not triggered. This study is complementary to similar experiments carried out at JET.**

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Apply an n=1 magnetic field perturbations with different amplitude before the H mode entry and at H-L exit to study the role of a proxy EF in L-H transients.
  - This experiment will be performed in 1 MA/1.8 T AUG plasma scenario and 0.75 MA/0.5 T MAST-U plasmas



Proposed pulses

Device	# Pulses/Session	# Development
AUG	5	
MAST-U	5	
TCV		
WEST		

P68: Assess the role of a proxy EF in H mode entry, H-L exit in AUG and MAST-U

- **Proponents and contact person:**
  - lidia.piron@igi.cnr.it & collaborators

- **Scientific Background & Objectives**
  - **investigate the role of a proxy EF in the L-H and H-L transitions,**
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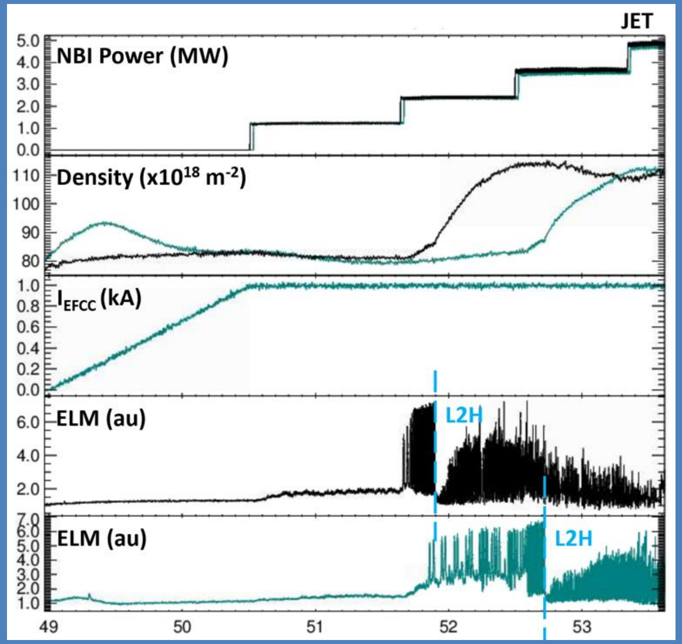


- TFL assessment: P2-AUG, P2-MAST-U Aligned with D7

Proposed pulses

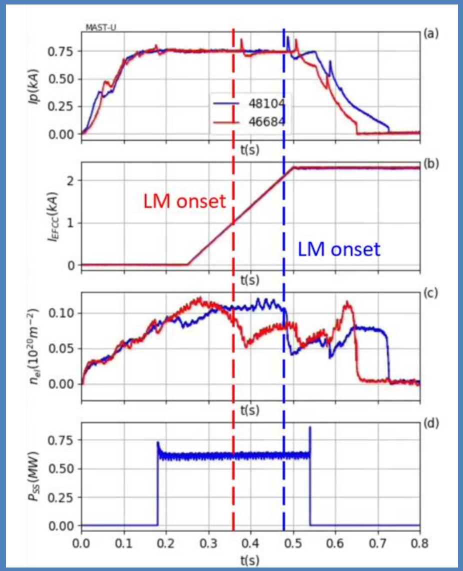
Device	# Pulses/Session	# Development
AUG	5	
MAST-U	5	
TCV		
WEST		

P69: Role of rotation on EF shielding

- **Proponents and contact person:**
  - lidia.piron@igi.cnr.it & collaborators

- **Scientific Background & Objectives**
  - **Assess the role of plasma rotation on magnetic field shielding**
  - **Perform cross-machine comparison (Similar experiments at JET and in MAST-U)**

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - In AUG, A proxy n=1 EF is applied by ramping up the current in the B coils when NBI power is injected at various levels. The NBI power needs to be low enough to keep the plasma in L-mode, without affecting the plasma density evolution.
  - This experiment envisages the use of B coils in AUG



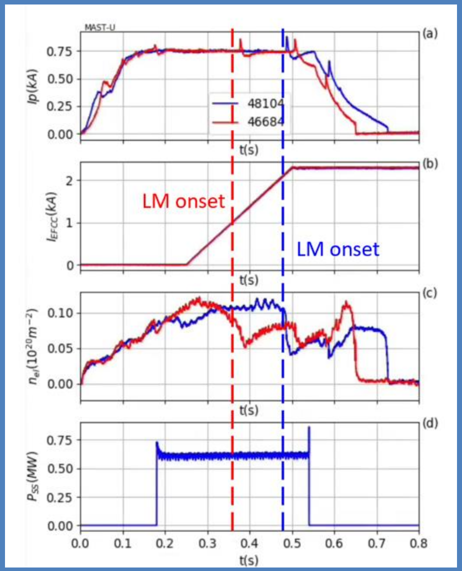
Proposed pulses

Device	# Pulses/Session	# Development
AUG	5	
MAST-U		
TCV		
WEST		

P69: Role of rotation on EF shielding

- **Proponents and contact person:**
  - lidia.piron@igi.cnr.it & collaborators

- **Scientific Background & Objectives**
  - **Assess the role of plasma rotation on magnetic field shielding**
  - **Perform cross-machine comparison (Similar experiments at JET and in MAST-U)**



- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - In AUG, A proxy n=1 EF is applied by ramping up the current in the B coils when NBI power is injected at various levels. The NBI power needs to be low enough to keep the plasma in L-mode, without affecting the plasma density evolution.
  - This experiment envisages the use of B coils in AUG

Proposed pulses

Device	# Pulses/Session	# Development
AUG	5	
MAST-U		
TCV		
WEST		

- TFL assessment: P2-AUG
- Aligned with D7

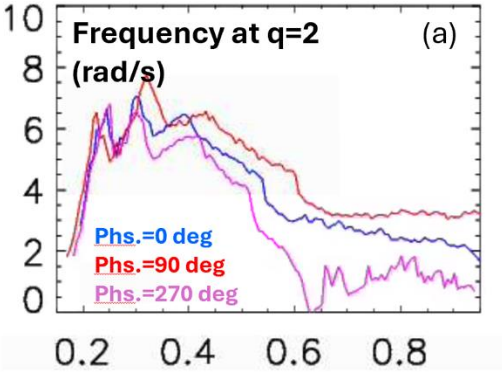
P70: Avoid rotation breaking by n=2 3D fields

- **Proponents and contact person:**
  - lidia.piron@igi.cnr.it & Collaborators

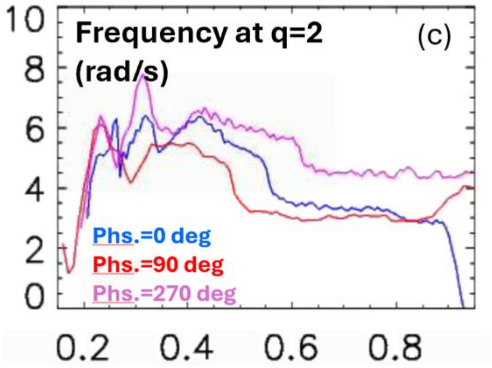
- **Scientific Background & Objectives**
  - During MU04, the n=2 compass scan with ELM coil upper phase equals to 315 deg has been executed. This set of experiments suggested a possibly recipe that can avoid rotation breaking

- **Experimental Strategy/Machine Constraints and essential diagnostic**
- Test if rotation breaking can be avoided by applying n=2 3D fields with phase =270 deg and Upper ELM coil phase=315 deg

Upper ELM coil phase=135 deg
With Cryo



Upper ELM coil phase=315 deg
With Cryo



Proposed pulses

Device	# Pulses/Session	# Development
MAST-U	7	

P70: Avoid rotation breaking by n=2 3D fields

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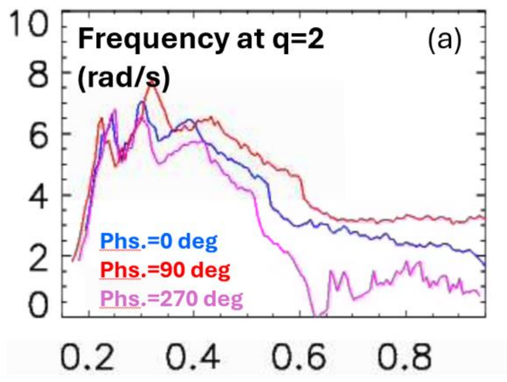
  - lidia.piron@igi.cnr.it & Collaborators

- **Scientific Background & Objectives**
  - During MU04, the n=2 compass scan with ELM coil upper phase equals to 315 deg has been executed. This set of experiments suggested a possibly recipe that can avoid rotation breaking

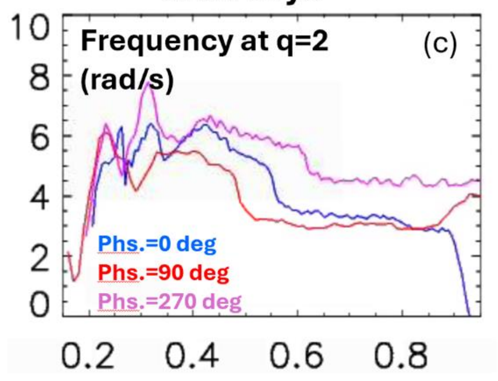
- **Experimental Strategy/Machine Constraints and essential diagnostic**
- Test if rotation breaking can be avoided by applying n=2 3D fields with phase =270 deg and Upper ELM coil phase=315 deg

- TFL assessment: P2-MAST-U Aligned with D7

Upper ELM coil phase=135 deg With Cryo



Upper ELM coil phase=315 deg With Cryo



Proposed pulses

Device	# Pulses/Session	# Development
MAST-U	7	

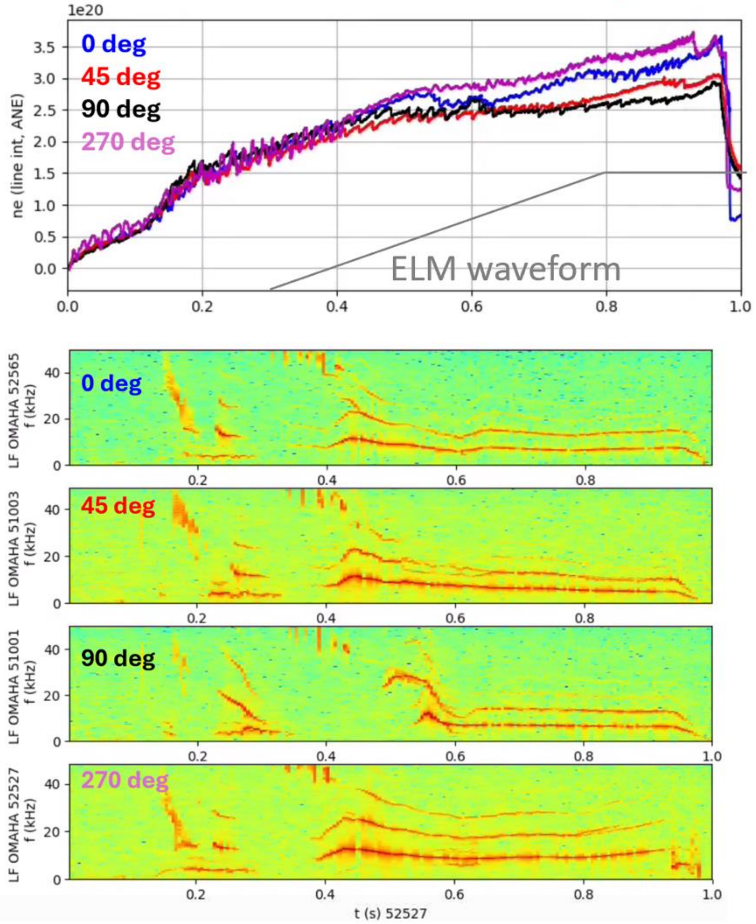
P71:Delay/avoid the n=1 mode onset by n=2 3D fields

- **Proponents and contact person:**
  - lidia.piron@igi.cnr.it & Collaborators

- **Scientific Background & Objectives**
  - During the execution of the n=2 compass scan in MU04, it has been observed that when n=2 3D fields with phase=90 deg can delay the onset of the n=1 MHD mode.

- **Experimental Strategy/Machine Constraints and essential diagnostic**
- Test the mode onset can be avoided/delayed by applying n=2 3D fields with phase=90 deg and ad-hoc n=2 ELM coil current

n=1 onset MHD delayed



Proposed pulses

Device	# Pulses/Session	# Development
MAST-U	5	

P71:Delay/avoid the n=1 mode onset by n=2 3D fields

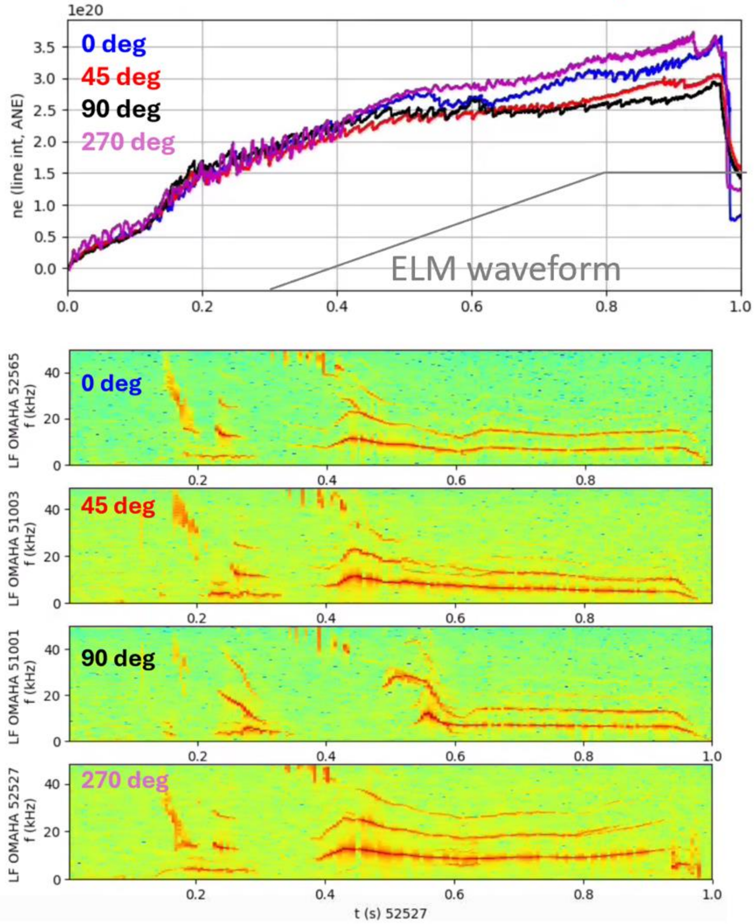
- **Proponents and contact person:**
  - lidia.piron@igi.cnr.it & Collaborators

- **Scientific Background & Objectives**
  - During the execution of the n=2 compass scan in MU04, it has been observed that when n=2 3D fields with phase=90 deg can delay the onset of the n=1 MHD mode.

- **Experimental Strategy/Machine Constraints and essential diagnostic**
- Test the mode onset can be avoided/delayed by applying n=2 3D fields with phase=90 deg and ad-hoc n=2 ELM coil current

- TFL assessment: P2-MAST-U Aligned with D7, D8

n=1 onset MHD delayed



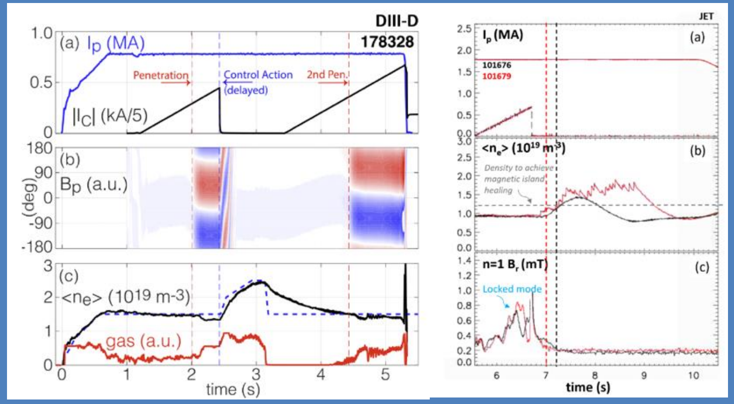
Proposed pulses

Device	# Pulses/Session	# Development
MAST-U	5	

P72: EF detection studies in AUG and MAST-U in preparation to ITER operation

- **Proponents and contact person:**
  - lidia.piron@igi.cnr.it & Carlos Paz-Soldan

- **Scientific Background & Objectives**
  - **Test the non-disruptive compass scan method in plasmas with various q=2 positions in AUG and in MAST-U**
  - **Test the magnetic island healing by RF in AUG**



- **Experimental Strategy/Machine Constraints and essential diagnostic**

  - In AUG, starting from the Ohmic 0.8MA/1.5T scenario,
    - execute the non-disruptive compass scan and test magnetic island healing by gas and by pellet
    - execute the non-disruptive compass scan and test magnetic island healing by ICRH and ECRH
    - execute the non-disruptive compass scan in plasmas with q=2 at various radial positions
  - In MAST-U, starting from the Ohmic 0.75MA/1.5T scenario,
    - execute the non-disruptive compass scan in plasmas with q=2 at various radial positions
  - This experiment envisages the use of B coils in AUG and ELM coils &EFCCs in MAST-U

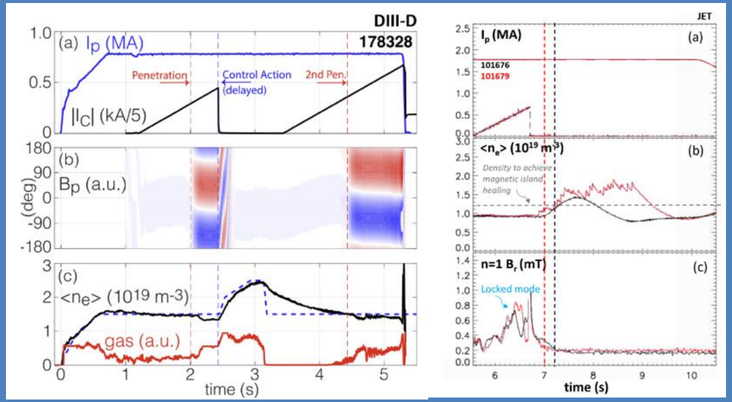
Proposed pulses

Device	# Pulses/Session	# Development
AUG	12	
MAST-U	6	
TCV		
WEST		

P72: EF detection studies in AUG and MAST-U in preparation to ITER operation

- **Proponents and contact person:**
  - lidia.piron@igi.cnr.it & Carlos Paz-Soldan

- **Scientific Background & Objectives**
  - **Test the non-disruptive compass scan method in plasmas with various q=2 positions in AUG and in MAST-U**
  - **Test the magnetic island healing by RF in AUG**



- **Experimental Strategy/Machine Constraints and essential diagnostic**

  - In AUG, starting from the Ohmic 0.8MA/1.5T scenario,
    - execute the non-disruptive compass scan and test magnetic island healing by gas and by pellet
    - execute the non-disruptive compass scan and test magnetic island healing by ICRH and ECRH
    - execute the non-disruptive compass scan in plasmas with q=2 at various radial positions
  - In MAST-U, starting from the Ohmic 0.75MA/1.5T scenario,
    - execute the non-disruptive compass scan in plasmas with q=2 at various radial positions
  - This experiment en

- TFL assessment: P1-2027-AUG,P2-MAST-U
  Aligned with D7, D8

Proposed pulses

Device	# Pulses/Session	# Development
AUG	12	
MAST-U	6	
TCV		
WEST		

P73: Comparison of feedforward and feedback techniques for phase control of a wall-locked tearing mode.

- **Proponents and contact person:**
  - lidia.piron@igi.cnr.it, Paolo Zanca and Giuseppe Marchiori

- **Scientific Background & Objectives**
  - **Assess the optimal strategy for wall locked tearing mode control**

- **Experimental Strategy/Machine Constraints and essential diagnostic**

  - A simple proportional control will be implemented as control algorithm. Shot plan consists in the execution of the following discharges:
    - Test feedforward control: phase and amplitude scans of feedforward currents (5 shots)
    - Test active control with Proportional gain, amplitude and phase scan of non-zero reference

  - This experiment
    - envisages the use of B coils in AUG.
    - requires a locked mode detector (amplitude and phase), with real-time compensation of the vacuum field produced by the coils in order to provide a reliable detection of phase of the wall-locked tearing mode.

Proposed pulses

Device	# Pulses/Session	# Development
AUG	15	
MAST-U		
TCV		
WEST		

P73: Comparison of feedforward and feedback techniques for phase control of a wall-locked tearing mode.

- **Proponents and contact person:**
  - lidia.piron@igi.cnr.it, Paolo Zanca and Giuseppe Marchiori

- **Scientific Background & Objectives**
  - **Assess the optimal strategy for wall locked tearing mode control**

- **Experimental Strategy/Machine Constraints and essential diagnostic**

  - A simple proportional control will be implemented as control algorithm. Shot plan consists in the execution of the following discharges:
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  - This experiment
    - envisages the use of B coils in AUG.
    - requires a locked mode detector (amplitude and phase), with real-time compensation of the vacuum field produced by the coils in order to provide a reliable detection of phase of the wall-locked tearing mode.

- TFL assessment: P2-AUG
- Aligned with D7, D8
- Difficult to control finite amplitude on AUG 3D coils

Proposed pulses

Device	# Pulses/Session	# Development
AUG	15	
MAST-U		
TCV		
WEST		

P74: Multimachine assessment of Locked Mode predictors: Machine Learning models vs empirical-based scaling laws

- **Proponents and contact person:**
  - matteo.gambrioli@phd.unipd.it
  - lidia.piron@igi.cnr.it
  - alessandro.pau@epfl.ch

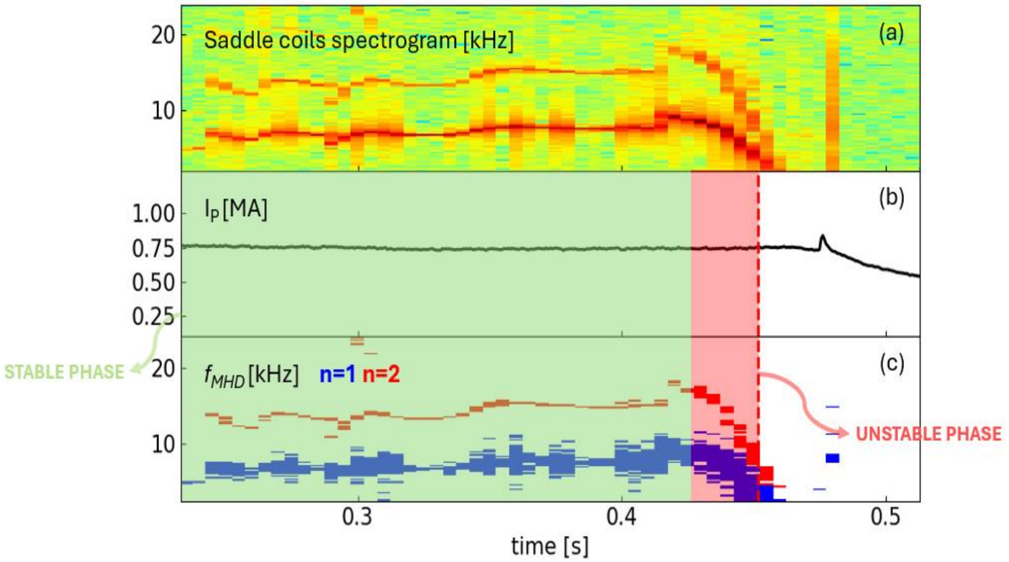
- **Objectives**
  - Build cross-machine ML models for LM prediction for: TCV, AUG, MAST-U and JET/Integrate ongoing efforts on this field.
  - Derive empirical based scaling laws, as the one proposed in P.C. de Vries et al 2016 Nuclear Fusion **56** 026007
  - Real-time assessment of ML vs empirical LM predictors

- **Experimental Strategy**

In preparation for the real-time assessment, we aim to:

- Develop ML models for LM prediction.
- Identify empirical scaling laws for LM amplitude.
- Test conventional LM metrics based on normal and tangential magnetic field measurements.

Such studies will be carried out using the DEFUSE framework and applied to MAST-U, TCV and AUG databases. JET will be included as well for the sake of comparison. Once these initial steps have been finalized, we propose to perform an assessment of LM prediction exploiting ML models and empirically derived metrics. Such assessment will require real-time implementation of these two approaches.



Proposed pulses

Device	# Pulses/Session	# Development
AUG	5	# Technical Pulses proposed
MAST-U	5	# Technical Pulses proposed
TCV	5	# Technical Pulses proposed

P74: Multimachine assessment of Locked Mode predictors: Machine Learning models vs empirical-based scaling laws

- **Proponents and contact person:**
  - matteo.gambrioli@phd.unipd.it
  - lidia.piron@igi.cnr.it
  - alessandro.pau@epfl.ch

- **Objectives**
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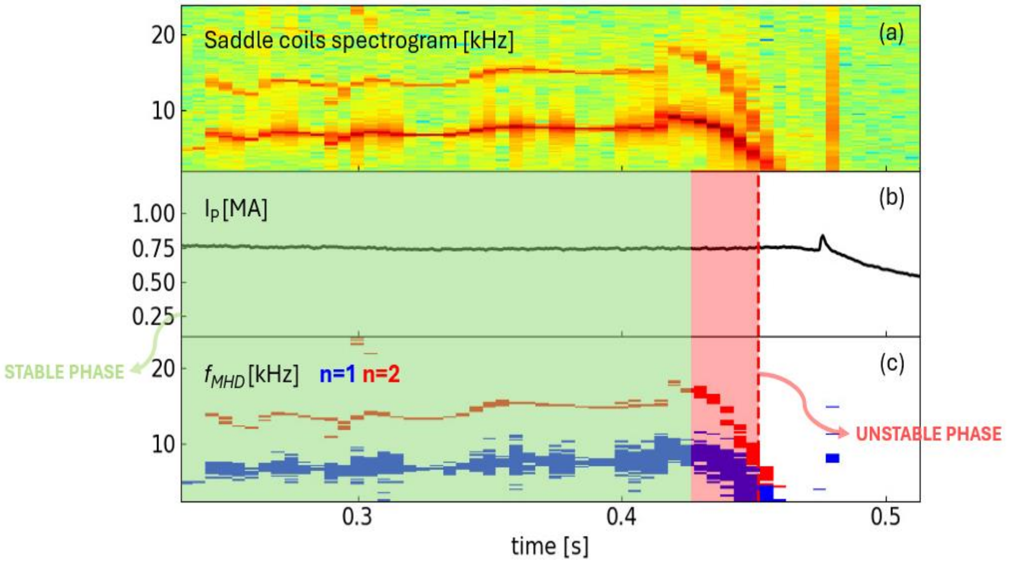


- Parasitic
- Aligned with D8

Device	# Pulses/Session	# Development
AUG	5	# Technical Pulses proposed
MAST-U	5	# Technical Pulses proposed
TCV	5	# Technical Pulses proposed

P75: MIMO controller for regulating electron density profile with gas puffing, pellet injection and magnetic coils

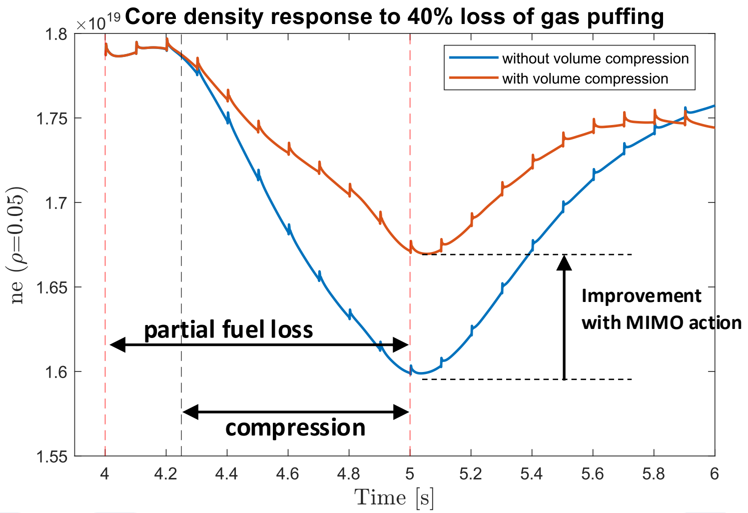
Proponents and contact person: L. Jansen(L.L.T.C.Jansen@differ.nl), H. Varadarajan(h.varadarajan@differ.nl), L. Ceelen, C. Orrico, M. van Berkel, D. Frattolillo, L. Di Grazia, M.Mattei, O. Kudlacek

Scientific Background & Objectives

Core density control is done with gas and pellets. However, the magnetic topology (plasma boundary and shape) also influences the density, which is currently underexplored. Combining these actuators that work on different timescales and locations requires an integrated MIMO (Multi-Input Multi-Output) controller.

This proposal aims to

- Quantify **coupling** between gas, pellet and magnetic actuators.
- Develop/validate **control-relevant models** across different machines.
- Develop new strategies to enhance the control of the fusion **power output** and to regulate **exhaust** under **off-normal events**.
- Design **integrated (MIMO) controllers** that distribute control effort among actuators with different dynamic responses.



Preliminary simulation results of magnetic actuators compressing the plasma volume, compensating the density decrease due to loss of gas fuelling.

Experimental Strategy

System Identification

Measure dynamic core response to:
(i) gas puffing
(ii) pellets
(iii) plasma boundary position

→

Model validation & controller development

(i) Validate control-oriented models and observer.
(ii) Design MIMO controller.
(iii) Test controller in flight simulator.

(no shots required for this block)

→

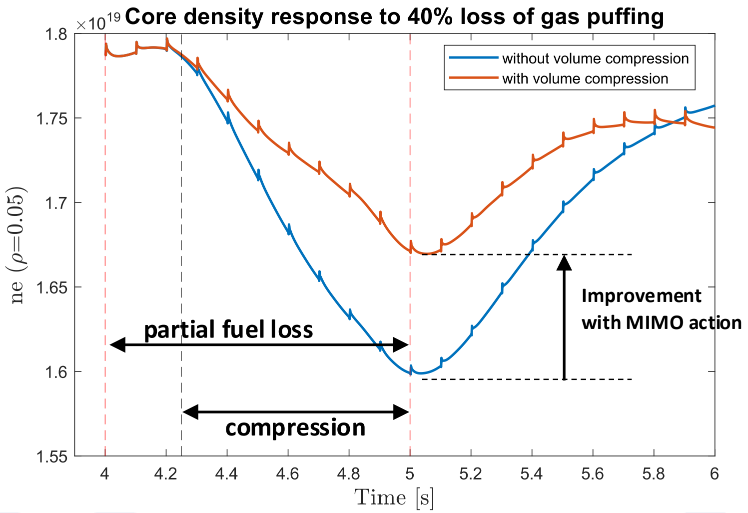
Experimental validation of controllers

(i) Independent controllers.
(ii) Integrated MIMO controller.
(iii) Explore ramp-down control if (i) and (ii) success.

Proposed pulses

Device	# Pulses/Session	# Development
AUG	19	0
MAST-U	0	0
TCV	22	0
WEST	19	0

P75: MIMO controller for regulating electron density profile with gas puffing, pellet injection and magnetic coils



Proponents and contact person: L. Jansen(L.L.T.C.Jansen@differ.nl), H. Varadarajan(h.varadarajan@differ.nl), L. Ceelen, C. Orrico, M. van Berkel, D. Frattolillo, L. Di Grazia, M.Mattei, O. Kudlacek

Scientific Background & Objectives

Core density control is done with gas and pellets. However, the magnetic topology (plasma boundary and shape) also influences the density, which is currently underexplored. Combining these actuators that work on different timescales and locations requires an integrated MIMO (Multi-Input Multi-Output) controller.

This proposal aims to

- Quantify **coupling** between gas, pellet and magnetic actuators.
- Develop/validate **control-relevant models** across different machines.
- Develop new strategies to enhance the control of the fusion **power output** and to regulate **ex** under **off-normal events**.
- Design **integrated (MIMO) controllers** that distribute control effort among actuators w different dynamic responses.

- P1-AUG 2027, P1-TCV, WEST combine with 63
- Aligned with D7
- Reduce AUG by 50%

Experimental Strategy

System Identification
Measure dynamic core response to:
(i) gas puffing
(ii) pellets
(iii) plasma boundary position

Model validation & controller development
(i) Validate control-oriented models and observer.
(ii) Design MIMO controller.
(iii) Test controller in flight simulator.
(no shots required for this block)

Experimental validation of controllers
(i) Independent controllers.
(ii) Integrated MIMO controller.
(iii) Explore ramp-down control if (i) and (ii) success.

Device	# Pulses/Session	# Development
AUG	19	0
MAST-U	0	0
TCV	22	0
WEST	19	0

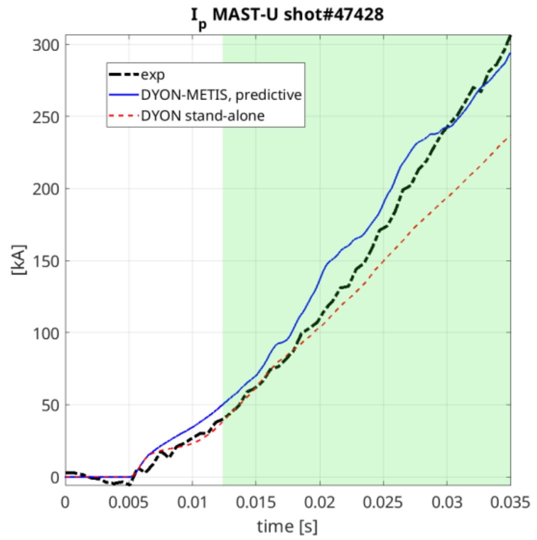
P76: Validation of breakdown+burnthrough modelling in TCV

- **Proponents and contact person:**
  Fabien Jaulmes (jaulmes@ipp.cas.cz)

- **Optimization of breakdown, burn-through and limiter current ramp-up** Implementation in TCV of 1D workflow involving DYON-FIESTA and METIS.
  - Application of Y-factory optimization routine to the breakdown
  - Study experimentally the effect of specific input loop voltage on the Ip growth rates and the onset of early MHD activity.

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Use the Y-factory optimization routine to prepare experiments and compare pre/post-discharge simulations.
  - Thomson scattering triggering can be changed to improve temporal resolution
  - Special startup diagnostics are required: DSS (Ti), CXRS (Ti), APG, MANTIS, FastCam
  - Give interpretation of q-profile evolution in limiter phase using 1D modelling tool

MAST Upgrade breakdown reproduced with METIS-DYON + 1D profiles obtained



Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV	25	15
WEST		

P76: Validation of breakdown+burnthrough modelling in TCV

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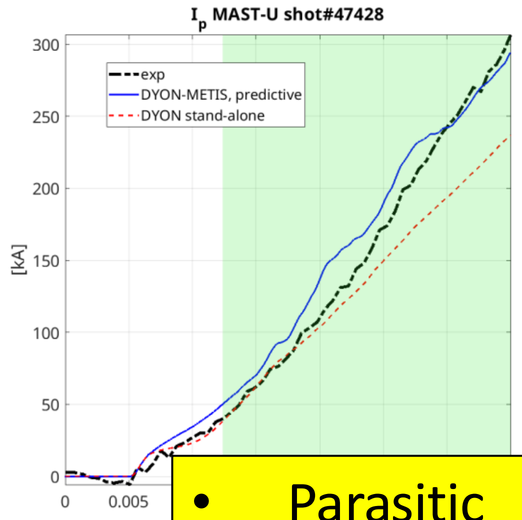


- Parasitic
- Aligned with D7

Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV	25	15
WEST		

P77: Continuation of exhaust control demonstration in ADCs

- **Proponents and contact person:**

Paulo Figueiredo (p.a.marinhofigueiredo@differ.nl), Jorn Veenendaal, Gijs Derks, Matthijs Van Berkel

- **Scientific Background & Objectives**

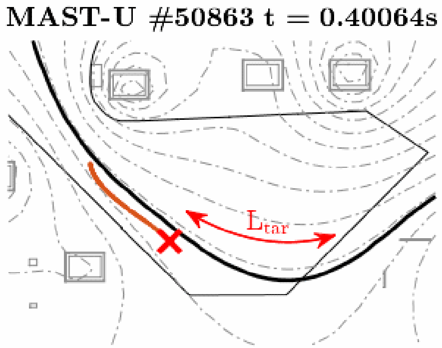
Alternative divertor configurations (ADCs) have been shown to offer larger operational ranges and improved buffering of transients. Control of divertor emission fronts, used as detachment proxies, has been demonstrated on ADCs in TCV and MAST-U. To apply these controllers in future reactors, they must be demonstrated in high-power conditions (H-mode), use reactor relevant diagnostics and integrate with other control systems, such as core density control.

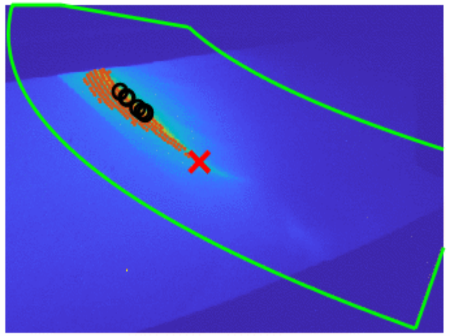
Within this proposal we aim to :

- Demonstrate the application of detachment control to high power H-mode scenarios
- Demonstrate combined control of core density and detachment front position upper and lower divertors
- Explore the possibility of ELM-buffering control with reactor relevant diagnostics

- **Experimental strategy and essential diagnostics**

  - Using spectroscopic imaging:
    - H-mode exhaust control using D_2 divertor gas injection;
    - Simultaneous control of core density and upper and lower divertor exhaust control using deuterium fueling;
    - Simultaneous control of upper and lower divertor exhaust control using nitrogen seeding to demonstrate decoupling extension to impurity species injection.
  - Using line-of-sight spectroscopy:
    - Inter-ELM detachment control resorting to a high acquisition rate;
    - Exploration of ELM-buffering control, where the minimum distance to target or the burn-through times are kept at a given value through feedback control.
  - Real-time capable MWI, UDI, UFDS and interferometry are essential diagnostics.





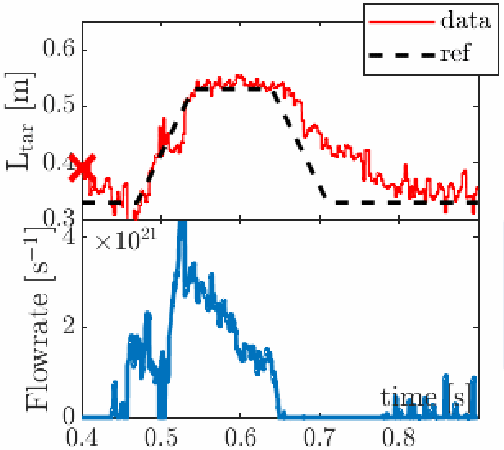


Fig: MU04 L-mode Exhaust control (by B. Kool et al.)

Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U	20	-
TCV		
WEST		

P77: Continuation of exhaust control demonstration in ADCs

- **Proponents and contact person:**

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- Explore the possibility of ELM-buffering control with reactor relevant diagnostics

- **Experimental strategy and essential d**

- **P2-MAST-U**
- **Aligned with D7**

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  - H-mode exhaust control using D_2 divertor gas injection;
  - Simultaneous control of core density and upper and lower divertor exhaust control using deuterium fueling;
  - Simultaneous control of upper and lower divertor exhaust control using nitrogen seeding to demonstrate decoupling extension to impurity species injection.
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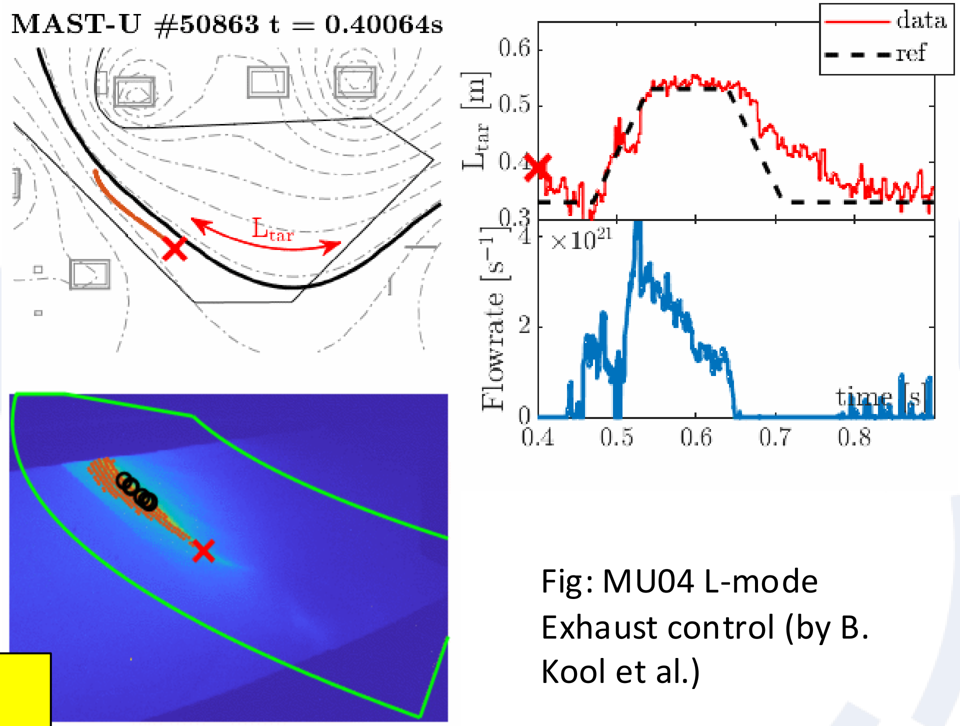

Fig: MU04 L-mode Exhaust control (by B. Kool et al.)

Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U	20	-
TCV		
WEST		

P78: Generalized radiator control via energy balance in the boundary

Proponents and contact person:

- Hao YANG (hao.yang@univ-amu.fr), Nicolas Fedorczak, Nicolas Rivals, Eric Serre, Guido Ciraolo, Umar Sheikh, Olivier Février, Galperti Cristian, Ou Pan

Scientific Background & Objectives (RT04-D6, D9)

- Reliable control of divertor detachment is crucial for divertor protection and long pulse operations.
- The R_D (ratio of radiated power to conductive heat flux in the SOL, as shown in the equation on the right) based on a simplified model is a useful figure of merit for identifying the divertor state and for detachment/XPR control [Hao Yang et al 2024 Nucl. Fusion 64 106039].
- This work is for the project "Advanced control system development for long pulse tokamak operations" supported by the EUROfusion Engineering Grant 2024.
- Use diagnostics to evaluate R_D in real time, or accelerate the process with machine learning for integration into the feedback control system. Identify system dynamics to refine control system tuning.
- Achieve stable detachment control using optimized control variables and controllers, characterize detachment access and core plasma performance, across different operation conditions in mutli machines: WEST (Improvements to get real-time data of bolometry and TS are needed), TCV and AUG.
- Compare experimental data with SOLEDGE3X-EIRENE simulations in the aspect of real-time dynamics, to develop a simulation workflow for reliable feedback controller design.

Experimental Strategy/Machine Constraints and essential diagnostic

- Detachment control using R_D as the control variable, with the optimized controller adjusting the D gas puff and N seeding rates (reference shot test plus several control tests with iterative controller optimization: 10 pulses in WEST, 10 in TCV, and 10 in AUG).
- Essential diagnostic: Thomson scattering / Helium beam, Bolometry / AXUV / Spectroscopy

$$R_D = \frac{7Rq_{95}^2 P_{rad}}{4ak_{0e}\lambda_q T_{e,sep}^{7/2}},$$

Real-time Bolometry/ AXUV / Spectroscopy (P_{rad})

Real-time TS / Helium beam ($\lambda_q T_{e,sep}^{7/2}$)
$\lambda_q \approx 2/7\, \lambda_T$
Or both estimated by simplified model

- R : Major radius [m]
- a : Minor radius a [m]
- q_{95} : Safety factor (at $\psi_N = 0.95$)
- λ_q : Decay length of heat flux [mm]
- k_{0e} : Electron conductivity coefficient = 2000 (for the plasma in tokamak)
- P_{rad} : Radiation at the downstream of LFS
- $T_{e,sep}$: upstream separatrix electron temperature

Proposed pulses

Device	# Pulses/Session	# Development
AUG	10/1	
MAST-U		
TCV	10/1	
WEST	10/1	

P78: Generalized radiator control via energy balance in the boundary

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- Compare experimental data with SOLEDGE… to develop a simulation workflow for reliab…

- P2-AUG, P1-TCV, P1-WEST
- Aligned with D7

Experimental Strategy/Machine Constraints and essential diagnostic

- Detachment control using R_D as the control variable, with the optimized controller adjusting the D gas puff and N seeding rates (reference shot test plus several control tests with iterative controller optimization: 10 pulses in WEST, 10 in TCV, and 10 in AUG).
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Real-time TS / Helium beam
$\lambda q \approx 2/7\ \lambda_T$
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Proposed pulses

Device	# Pulses/Session	# Development
AUG	10/1	
MAST-U		
TCV	10/1	
WEST	10/1	

P79: Development of model predictive control for power exhaust

Proponents and contact person:
Paulo Figueiredo (P.A.MarinhoFigueiredo@differ.nl), Jorn Veenendaal, Gijs Derks, Thomas Bosman, Matthijs van Berkel

Scientific Background & Objectives: ITER, DEMO and STEP need to operate within save divertor and core operation limits.

Objectives : Develop a two types of Model Predictive Controller (MPC) strategies (linear MPC and SOLPS-based MPC) for the MAST-U & TCV which,

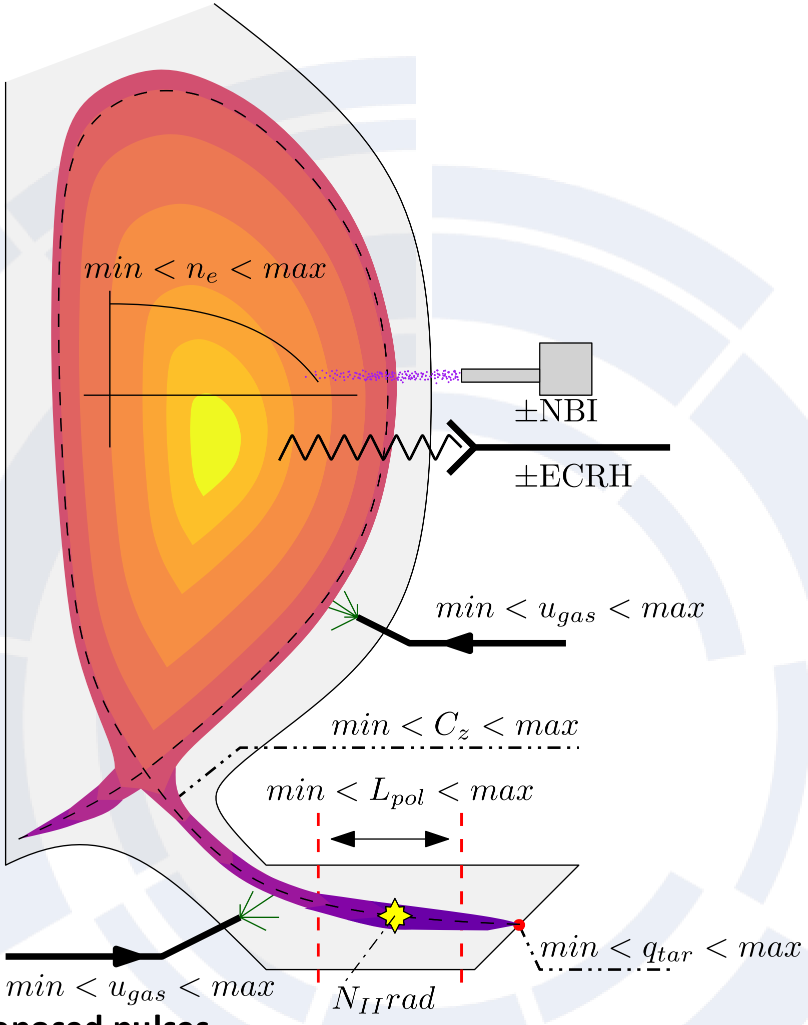
1. Takes divertor operational limits into account,
2. Predicts and counteracts the effect of known transient disturbances on the divertor state,
3. Corrects for unknown transient disturbances using feedback control.

The linear MPC strategy is to show the proof of principle for present day devices with are well diagnosed. The SOLPS-based MPC strategy is aimed towards future reactors which do not feature the same extensive diagnostic coverage.

Experimental strategy:

- **Linear MPC:** Control the Fulcher-band detachment front/NII radiation front, core n_e through direct measurements
- **SOLPS based MPC:** Control the q_{tar} and C_z in the divertor as inferred quantities through a SOLPS-ITER enhanced Kalman observer.
- Compare performance of three controller types: PID based control, linear MPC and SOLPS-based MPC.

Essential diagnostics:
TCV: real-time available MANTIS, interferometer, if possible real-time available bolometry
MASTU-U: real-time available, MWI, interferometer



Proposed pulses

Device	# Pulses/Session	# Development
AUG	-	-
MAST-U	14	-
TCV	30	-
WEST	-	-

P79: Development of model predictive control for power exhaust

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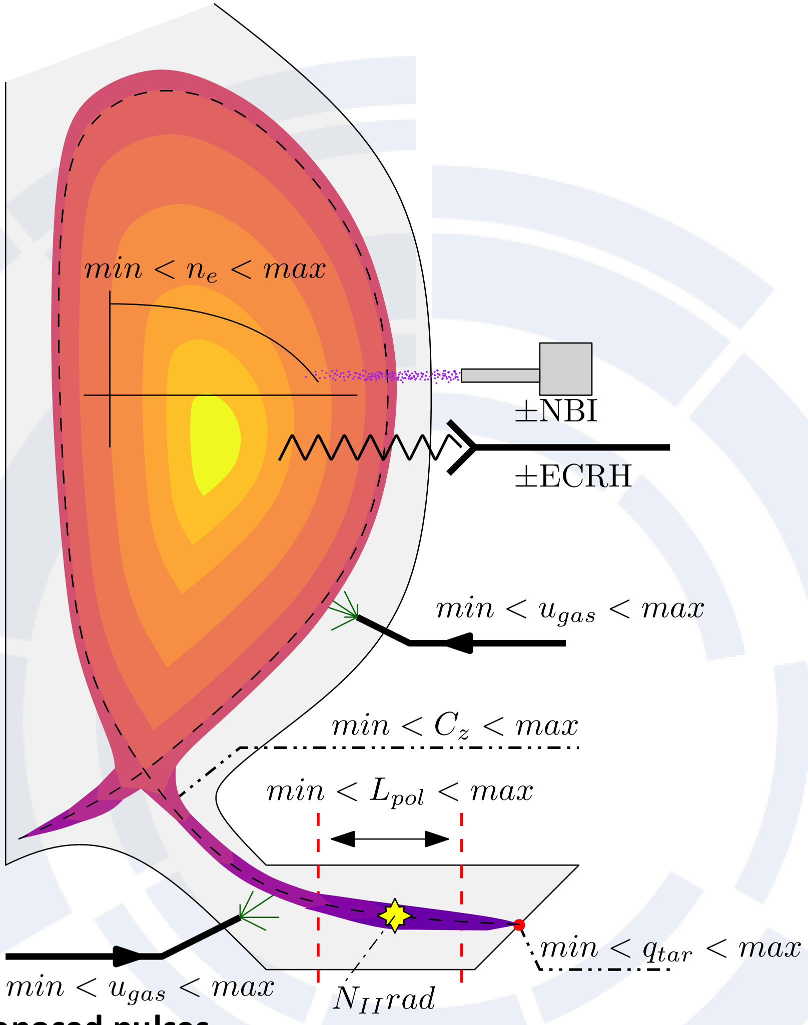
MASTU-U: real-time available, MWI, interferometer



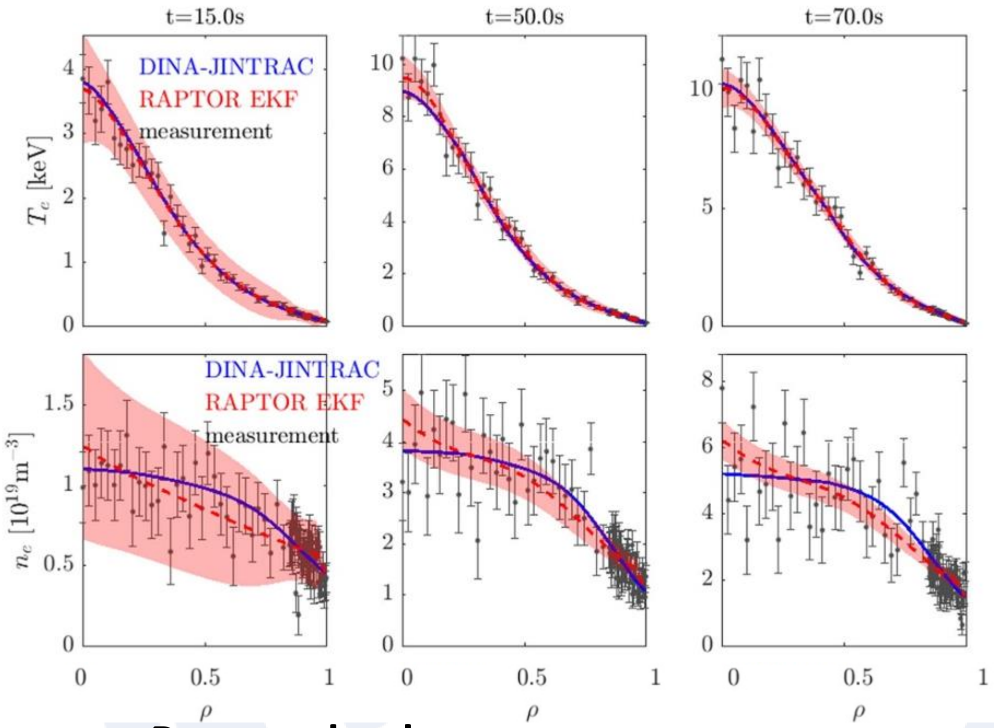
Proposed pulses

Device	# Pulses/Session	# Development
AUG	-	-
MAST-U	14	-
TCV	30	-
WEST	-	-

- P1-TCV,P1-MAST-U
- Aligned with D7

P80: Multi-machine, model-based profile control of kinetic profiles and safety factor

- **Proponents and contact person:**
  simon.vanmulders@epfl.ch et al.
- **Scientific Background:**
  - TCV and AUG have implemented advanced model-based observers providing real-time estimates of internal kinetic and q-profiles — a foundation for active profile control.
  - By integrating Thomson scattering and TORBEAM modeling into RAPTOR, the observer will deliver more accurate q-profiles in ECRH plasmas, enabling precise, model-based profile control.
  - A multi-actuator strategy (gas puffing, pellets, RMPs, and heating systems) will be used to dynamically control the particle density profile, expanding control capability in high-performance scenarios.
  - The coordinated shaping of kinetic and current profiles will be developed to optimize confinement, limit impurity accumulation, and improve exhaust performance—key steps toward reactor-grade operation.
- **Objectives:**
  - **TCV:** Develop and test a q-profile controller based on the RAPTOR linearized model—first in simulation, then experimentally—scanning ECCD deposition to map accessible q-profiles and ITB formation. Apply this controller to regulate $q$min and shape negative-shear or ITB-relevant scenarios.
  - **AUG:** Implement a MIMO controller for simultaneous control of the density peaking factor and edge profile, studying the impact of heating on nene as a disturbance. Integrate these effects into the density observer to support the design of a model predictive controller (MPC).
- **Experimental Strategy/Machine Constraints and essential diagnostic:**
  RT-RAPTOR, RT-CXRS, RT-TS, RT-ECE, ERCH, NBI, ICRH (AUG),PELLETS (AUG)



Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	0
MAST-U	-	-
TCV	15	0
WEST	-	-

P80: Multi-machine, model-based profile control of kinetic profiles and safety factor

- P2-AUG,P1-TCV
- Aligned with D7
- AUG part Joined with P64?

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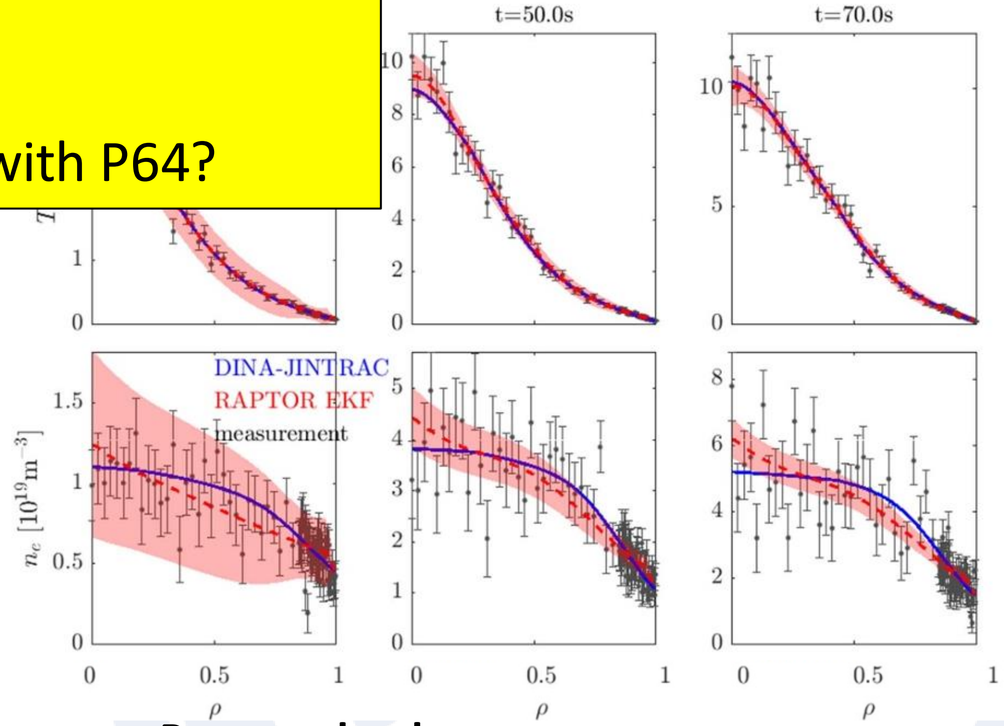
- **Experimental Strategy/Machine Constraints and essential diagnostic:** RT-RAPTOR, RT-CXRS, RT-TS, RT-ECE, ERCH, NBI, ICRH (AUG),PELLETS (AUG)



Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	0
MAST-U	-	-
TCV	15	0
WEST	-	-

P81: First wall temperature estimation and real-time heat flux control

- **Proponents and contact person:**
- Federico Pesamosca (federico.pesamosca@iter.org), Adriano Mele, Martim Zurita, Marta Pedrini

- **Scientific Background & Objectives**

ITER First Wall Heat Load Control (FWHLC) prototype modules were deployed on the TCV tokamak digital control system (SCD) leveraging the shared PCSSP/SCDDS technology and the new plasma shape controller. The natural extension of this work involves developing model-based real-time estimation of the FW surface temperature in the TCV SCD. This will enable advanced FWHL control techniques for ITER to be tested on the TCV tokamak.
Objectives:
  - Deployment of a real-time capable reduced thermal diffusion model for the first wall surface temperature evolution.
  - Validation of real-time estimates of first wall heat flux and temperature against diagnostics data.
  - Development of observers combining control-oriented models and diagnostics measurements for the first wall thermal loads
  - Refinement of FWHL controllers attempting continuous control of plasma thermal loads on plasma-facing components during a discharge.

- **Experimental Strategy/Machine Constraints and essential diagnostic**
- Develop new PCSSP modules for the wall thermal dynamics to deploy in SCD and test their real-time performance.
- Refine the FWHL controllers in dedicated attached LSN diverted shots including plasma movements and ECH power steps triggering FWHLC action.
- Attempt combined kinetic (auxiliary power variation) and magnetic (plasma shape variation) FWHL control.

- Machine constraints: TCV SILO, SISO or NINO (preferred) baffling.
- Essential diagnostics and systems: ECH, IR, LP, RADCAM, TC, SCD

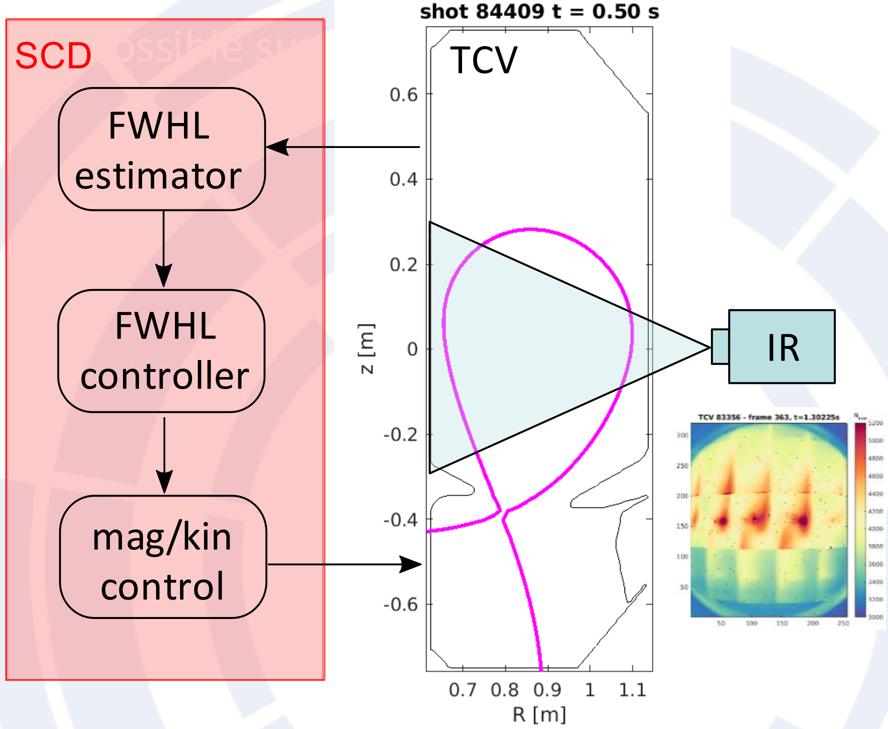


Fig 1: block diagram for FWHLC on TCV.

Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV	15	5
WEST		

P81: First wall temperature estimation and real-time heat flux control

- **Proponents and contact person:**
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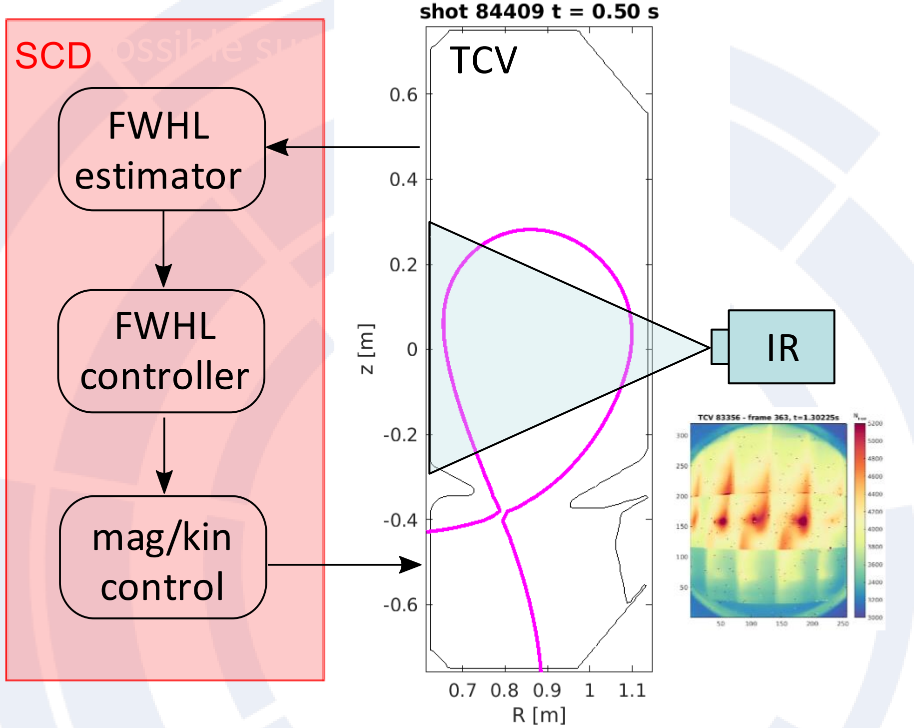

Fig 1: block diagram for FWHLC on TCV.

Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV	15	5
WEST		

- P1-TCV
- Aligned with D6

P82: Reinforcement learning for NTM control

Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV	0	0
WEST		

- **Proponents and contact person:**
- Luca Bonalumi (luca.bonalumi@istp.cnr.it)
- Edoardo Alessi
- Natale Rispoli
- Carlo Sozzi

- **Scientific Background & Objectives**

In the context of (N)TM control with EC injected power, various parameters can impact the stabilization:

- Such parameters are generally inter-dependent.
- Different conditions impact the control strategy, corresponding to different suppression paths.

Aim of the present proposal is to:

- Demonstrate the capability of the RL tool to optimize NTM suppression under multiple objectives.
- Show the robustness of the network w.r.t. equilibrium changes and NTM location inaccuracies

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Develop a dedicated RL tool within a synthetic environment (using CO-MRE, RAPTOR, TORBEAM),
    - Vary the initial conditions
    - Include experimental data in the training loop.
  - Implementation of a real-time controller
  - Open loop test and possibly application in experiments

P82: Reinforcement learning for NTM control

Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV	0	0
WEST		

- **Proponents and contact person:**
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In the context of (N)TM control with EC injected power, various parameters can impact the stabilization:

- Such parameters are generally inter-dependent.
- Different conditions impact the control strategy, corresponding to different suppression paths.

Aim of the present proposal is to:

- Demonstrate the capability of the RL tool to optimize NTM suppression under multiple objectives.
- Show the robustness of the network w.r.t. equilibrium changes and NTM location inaccuracies

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Develop a dedicated RL tool within a synthetic environment (using CO-MRE, RAPTOR, TORBEAM),
    - Vary the initial conditions
    - Include experimental data in the training loop.
  - Implementation of a real-time controller
  - Open loop test and possibly application in experiments

- Parasitic
- Aligned with D6, D9
- Merge with 83

P83: Integrated avoidance and control of NTM

- **Proponents and contact person:**

- francesco.carpanese@epfl.ch antonia.frank@epfl.ch

- **Scientific Background & Objectives**
  - Integrated solution for (N)TM Avoidance/Prevention/Mitigation/Suppression is required to operate high performance tokamaks.
  - A: requires robust estimation of stability boundaries that can be achieved by mixing classical delta prime stability index and data driven model.
  - P,M,S: requires estimation of power and deposition location, where physics based MRE model is now available in RT.
  - A,P,M,S all relies on accurate kinetic and q profiles estimation, now available in RT from state observer such as RAPTOR.
  - Emphasis is to focus on solutions which applies across machines.
- **Objectives:**
  - Developed ML+physics model to predict NTM stability boundary (tearability) from available TCV curated database.
  - Deploy model for safe pre-shot optimization, inter shot analysis, RT NTM avoidance.
  - Test model capabilities for stability boundaries estimation and preemption actuation directions generation (dedicated TCV experiments).
  - Explore solution for transferability to AUG database with few shots adaptation.
  - Reach maturity of operating RT MRE for power allocation estimation during P,M,S (dedicated TCV experiments)
  - Integrated all A,P,M,S onto unique control orchestrator with SAMONE.
- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Low density TCV shots, ECCD.

Proposed pulses

AUG		
MAST-U		
TCV	35	15
WEST		

P83: Integrated avoidance and control of NTM

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- francesco.carpanese@epfl.ch antonia.frank@epfl.ch

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  - A: requires robust estimation of stability boundaries that can be achieved by mixing classical delta prime stability index and data driven model.
  - P,M,S: requires estimation of power and deposition location, where physics based MRE model is now available in RT.
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  - Reach maturity of operating RT MRE for power allocation estimation during P,M,S (dedicated TCV experiments)
  - Integrated all A,P,M,S onto unique control orchestrator with SAMONE.
- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Low density TCV shots, ECCD.

- P2-TCV
- Aligned with D6
- Merge with 83

Proposed pulses

AUG		
MAST-U		
TCV	35	15
WEST		

P84: Data-driven models to enhance real-time plasma state estimation

- **Proponents and contact person:**
  - cristina.venturini@epfl.ch
  - yoeri.poels@epfl.ch
  - olivier.sauter@epfl.ch
  - alessandro.pau@epfl.ch
  - peizheng.zhang@epfl.ch
  - ondrej.kudlacek@ipp.mpg.de
  - rainer.fischer@ipp.mpg.de
  - johannes.illerhaus@ipp.mpg.de
  - simon.vanmulders@epfl.ch
  - francesco.pastore@epfl.ch

Proposed pulses

Device	# Pulses/Session	# Development
AUG	5	
TCV	30	

- **Objectives**
  - Develop models for reconstruction of Ti and vtor profiles on TCV and AUG.
  - Leverage the developed models to guide new experiments.
  - Make the model real-time capable and test the real-time compatible version offline.
  - Inclusion of the model in real-time on TCV and AUG.
  - Real-time control of Ti and/or vtor.
  - Adapt the confinement state classification model to a real-time version and implement it in the TCV control system.
- **Experimental Strategy**
  - Piggy-back activity
    - Use existing validated CXRS data (CXRS for TCV and IDA for AUG) to build the models
    - Validate it with new data from the campaigns and in between shots
    - Use the models to identify under represented operational regimes for which Ti and/or vtor is important
  - Experiments for filling in gaps in the CXRS databases
    - e.g: specific shots to cover holes in CXRS data that are required for Ti estimation for transport/confinement studies
  - Control experiments
    - Demonstrate real-time control of Ti and vtor at a given radial location on TCV and AUG

P84: Data-driven models to enhance real-time plasma state estimation

- **Proponents and contact person:**

  - cristina.venturini@epfl.ch
  - yoeri.poels@epfl.ch
  - olivier.sauter@epfl.ch
  - alessandro.pau@epfl.ch
  - peizheng.zhang@epfl.ch
  - ondrej.kudlacek@ipp.mpg.de
  - rainer.fischer@ipp.mpg.de
  - johannes.illerhaus@ipp.mpg.de
  - simon.vanmulders@epfl.ch
  - francesco.pastore@epfl.ch

Proposed pulses

Device	# Pulses/Session	# Development
AUG	5	
TCV	30	

- P2-AUG, P2-TCV
- Aligned with D7, D9

- **Objectives**
  - Develop models for reconstruction of Ti and vtor profiles on TCV and AUG.
  - Leverage the developed models to guide new experiments.
  - Make the model real-time capable and test the real-time compatible version of
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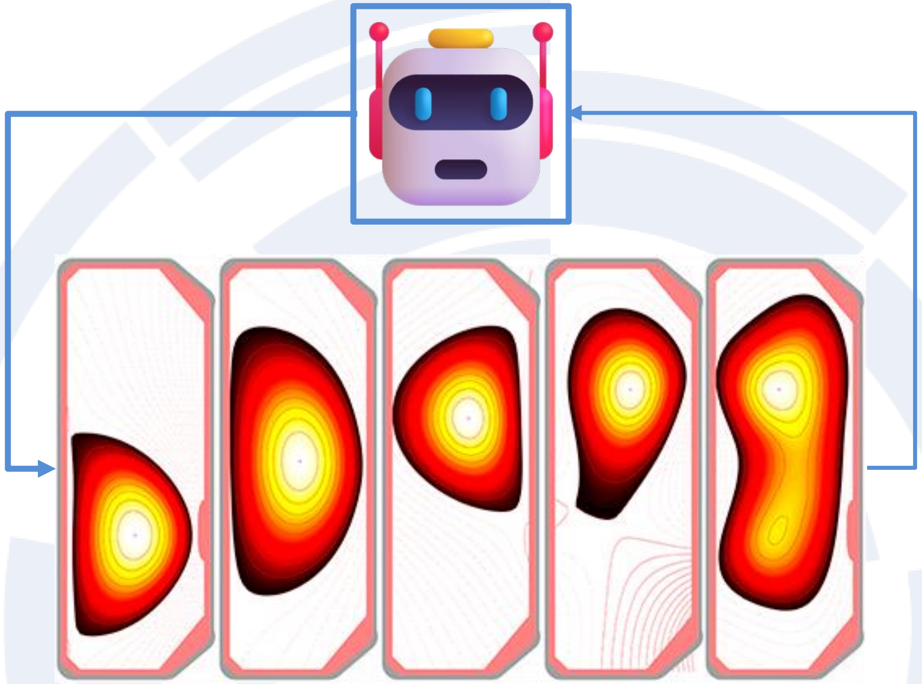
  - Control experiments
    - Demonstrate real-time control of Ti and vtor at a given radial location on TCV and AUG

P85: Advanced magnetic control

- **Proponents and contact person:**
  - Adriano Mele (adriano.mele@epfl.ch)
  - Francesco Carpanese
  - Cristian Galperti
  - Cosmas Heiss
  - Allen Wang
  - Matteo Grandin
  - Domenico Frattolillo

- **Scientific Background & Objectives**
  - enhance the MPC framework for plasma shape control
  - commission the newly developed Fast MAGnetic controller on use cases of practical relevance
  - design an optimal gain scheduler
  - incorporate machine learning tools to enhance or generalize control performance
  - explore porting to other WPTE devices (e.g. MAST-U) of solutions developed for TCV

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - **Model Predictive Control**
    - further tests of the developed controller on a variety of plasma configurations
    - integration of additional constraints, including coil voltage limits, plasma-wall clearance, and control objectives involving balancing of multiple X-points or drsep
    - exploration of real-time model building or updating for MPC, potentially leveraging machine learning tools, as a step toward nonlinear MPC
    - investigation of alternative MPC paradigms, such as economic or robust MPC
  - **Commissioning of FMag**
    - finalize the validation of the FMag controller on use cases of practical relevance (classic RZIp control, fast shape variations, stabilizing shape control)
    - couple FMag with low-frequency liuqe corrections or a liuqe surrogate model
    - integrate FMag with higher-level controllers such as MPC or CLA-like systems
  - **Machine Learning tools**
    - enhancement of the fbt-nn surrogate with explicit shape feedback
    - incorporation of ML techniques in the MPC framework
    - further development and testing of a (differentiable) liuqe surrogate
  - **Optimal Gain Scheduling**
    - At a fixed desired linear performance metrics, construct a dataset of optimal gain and actuator action from closed loop linear system, given current plasma equilibrium and feedforward target.
    - Train a surrogate model to predict optimal gain given current state.
    - Integrate optimal gain scheduler with the default control system, and test dedicated set of disturbances (deviation from reference scenario) where plasma operation can benefit from improved control.



Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U	0	0
TCV	40	10
WEST		

P85: Advanced magnetic control

- **Proponents and contact person:**
  - Adriano Mele (adriano.mele@epfl.ch)
  - Francesco Carpanese
  - Cristian Galperti
  - Cosmas Heiss
  - Allen Wang
  - Matteo Grandin
  - Domenico Frattolillo

- P1-TCV
- Aligned with D6
- Large proposal.
- Decrease pulses of 40%

- **Scientific Background & Objectives**
  - enhance the MPC framework for plasma shape control
  - commission the newly developed Fast MAGnetic controller on use cases of practical relevance
  - design an optimal gain scheduler
  - incorporate machine learning tools to enhance or generalize control performance
  - explore porting to other WPTE devices (e.g. MAST-U) of solutions developed for TCV

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - **Model Predictive Control**
    - further tests of the developed controller on a variety of plasma configurations
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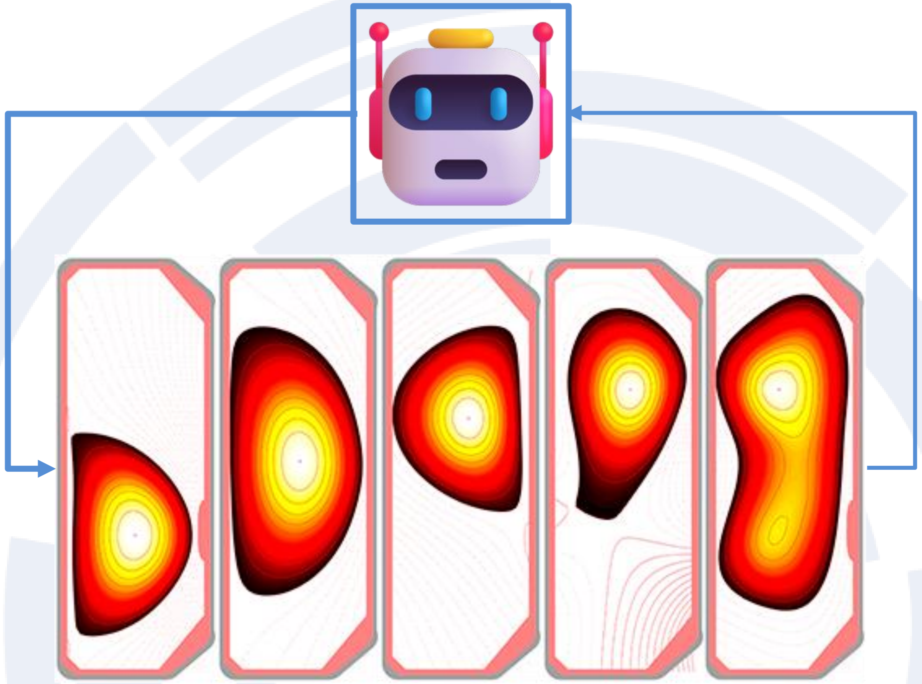


Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U	0	0
TCV	40	10
WEST		

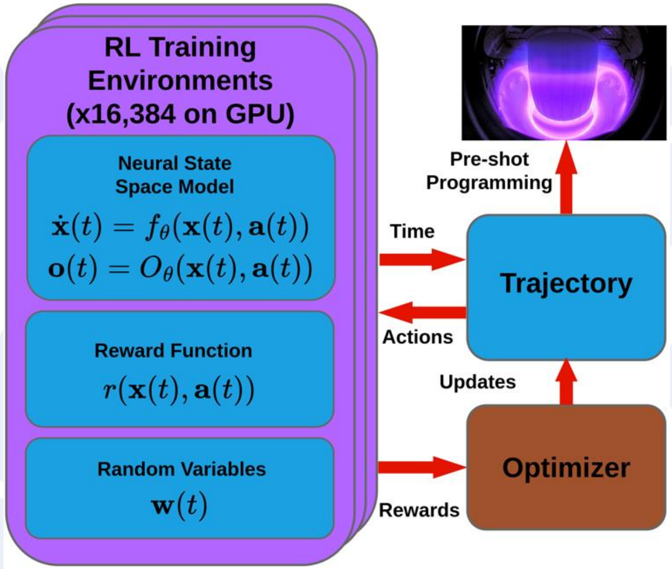
P86:Integrated Control and Plasma Trajectory Optimization

- **Proponents and contact person:**
  alessandro.pau@epfl.ch et al.

- **Scientific Background:**
- Long-Term Goal: Demonstrate reliable high-performance operation in tokamaks by tightly integrating plasma state monitoring & control, off-normal events handling, and machine protection
- The proposal, building upon the high-performance scenario developed in 2024-2025, and aims to bring to maturity integrated control and plasma trajectory optimization tools, integrating NTM, radiation and detachment control.

- **Objectives:**
- Integrate and test Real-Time (RT) observers (e.g., RAPDENS, RAPTOR, RT-MRE, RT-TORBEAM) and proximity monitors within the SAMONE (Supervision and Actuator Manager Off-Normal Events handling) system, focusing on machine-agnostic solutions
- Leverage concurrent work to integrate model- and data-driven models for NTM control (RT-observers for toroidal rotation, pedestal and kinetic profiles and calculation of a tearability proximity monitor).
- Finalize the integration in SAMONE of radiation & detachment control and implement a MARFE observer based on RT
- ◦ Implement adaptive control logic combining confinement state classification models and proximity monitors for MHD/radiative instabilities

- **Experimental Strategy/Machine Constraints and essential diagnostic:**
- RT-RAPTOR, RT-CXRS, RT-TS, co-MRE, RT-BOLOMETRY, ECRH, NBI, SAMONE, SCD



A. Wang, A. Pau et al Nature Comm. (2025)

Proposed pulses

Device	# Pulses/Session	# Development
AUG	-	-
MAST-U	-	-
TCV	35	10
WEST	-	-

P86:Integrated Control and P… …nization

- P1-TCV
- Aligned with D7
- Large proposal
- Include work on data drive models and NTM observers

- **Proponents and contact person:**
  alessandro.pau@epfl.ch et al.

- **Scientific Background:**

- Long-Term Goal: Demonstrate reliable high-performance o… tightly integrating plasma state monitoring & control, off-n… and machine protection
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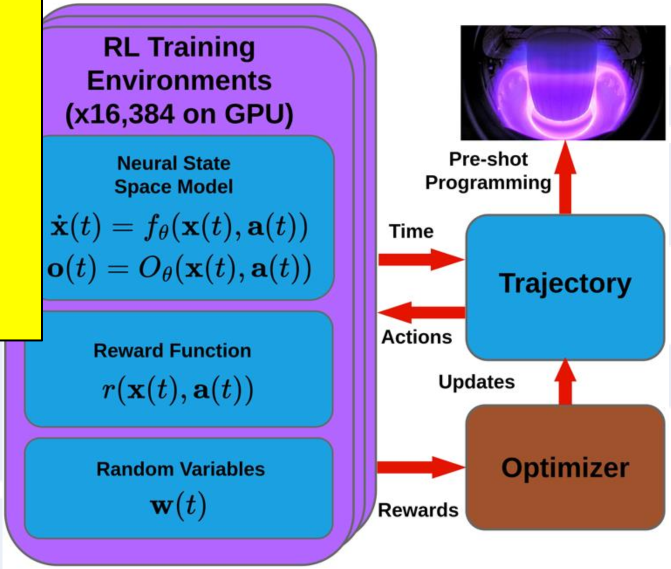
- **Experimental Strategy/Machine Constraints and essential diagnostic:**

- RT-RAPTOR, RT-CXRS, RT-TS, co-MRE, RT-BOLOMETRY, ECRH, NBI, SAMONE, SCD



A. Wang, A. Pau et al Nature Comm. (2025)

Proposed pulses

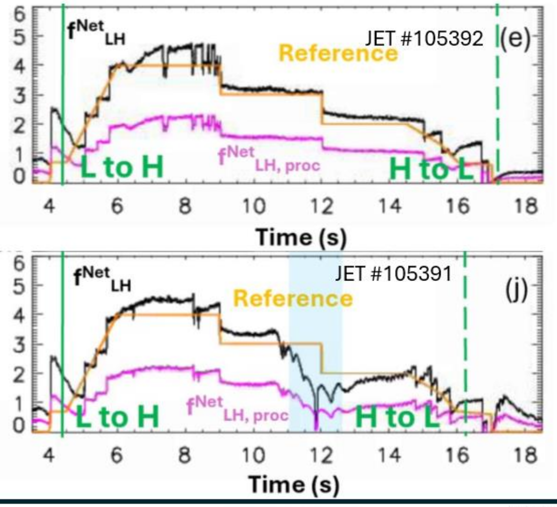
Device	# Pulses/Session	# Development
AUG	-	-
MAST-U	-	-
TCV	35	10
WEST	-	-

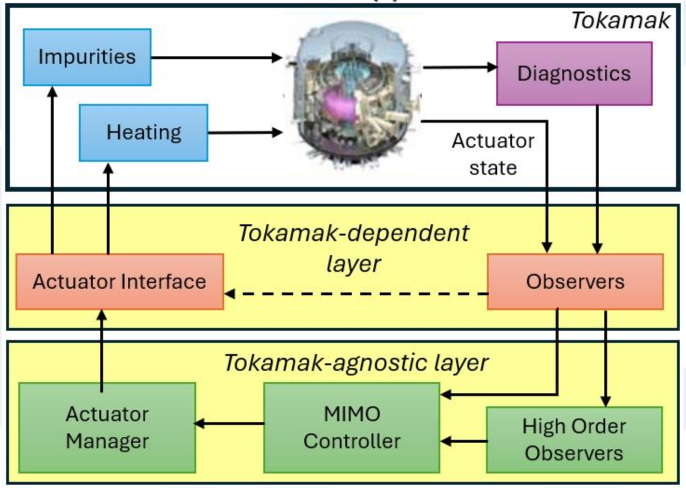
P87: P_{sep}/P_{LH} control using heating power and impurity radiation

- **Proponents and contact person:**
  - saleiferis@mail.ntua.gr, lidia.piron@igi.cnr.it, olivier.sauter@epfl.ch

- **Scientific Background & Objectives**
  - Background: JET Experiments - P_{sep}/P_{LH} controller was used to enter maintain and exit H-mode safely.
  - In this proposal, enhanced active control scheme is proposed, where both P_{heat} and P_{rad} are controlled, using the heating systems and impurity injection as actuators respectively
  - Scientific Objectives:
    - Develop appropriate, data-driven, state observers monitoring the radiated power that goes into the power balance calculation. (D6, D9)
    - Provide P_{sep}/P_{LH} operating range, optimized for ITER-relevant H-mode operation.
    - Quantify the feed-forward effect of impurity injection as an actuator for the radiated power.
    - Using a data-driven (ML-based) system identification, integrate the dynamic response of heating power and impurity injection, in order to develop an optimization strategy for the desired pulse trajectory. (D7, D9)
    - Demonstrate improved control with optimized dual actuator management during normal operation and scripted off-normal events. (D8, D9)
      - For TCV: comparison with SISO P_{rad} and P_{sep}/P_{LH} controllers deployed simultaneously using SAMONE supervisor.

- **Experimental Strategy/Machine Constraints and essential diagnostics**
  - Verify relevant P_{sep}/P_{LH} range and dynamic response to auxiliary power (2 pulses/device).
  - Quantify the feed-forward effect of impurity injection as an actuator for Prad (2-4 pulses/device).
  - Pulses with dual actuator management to demonstrate improved control (6 pulses/device).
  - For TCV: comparison with SISO P_{rad} and P_{sep}/P_{LH} controllers deployed simultaneously using SAMONE supervisor (2 pulses).
  - This experiment can be performed in 1 MA/1.8 T AUG plasmas and standard H-mode TCV plasmas. TCV experiments would benefit from the availability of MANTIS.
  - Essential Diagnostics:
    - Bulk P_{rad} calculation in real-time



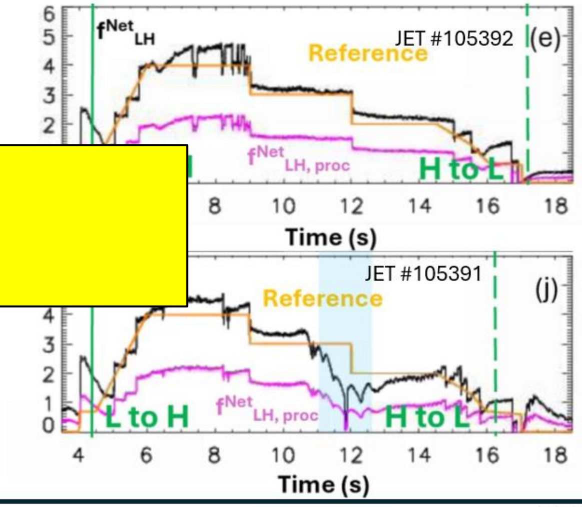


Proposed pulses

Device	# Pulses/Session	# Development
AUG	12	
TCV	12	

P87: P_{sep}/P_{LH} control using heating power and impurity radiation

- P2-AUG, P1-TCV
- Aligned with D7



- **Proponents and contact person:**
  - saleiferis@mail.ntua.gr, lidia.piron@igi.cnr.it, olivier.sauter@epfl.ch

- **Scientific Background & Objectives**
  - Background: JET Experiments - P_{sep}/P_{LH} controller was used to enter maintain and exit H-mode safely.
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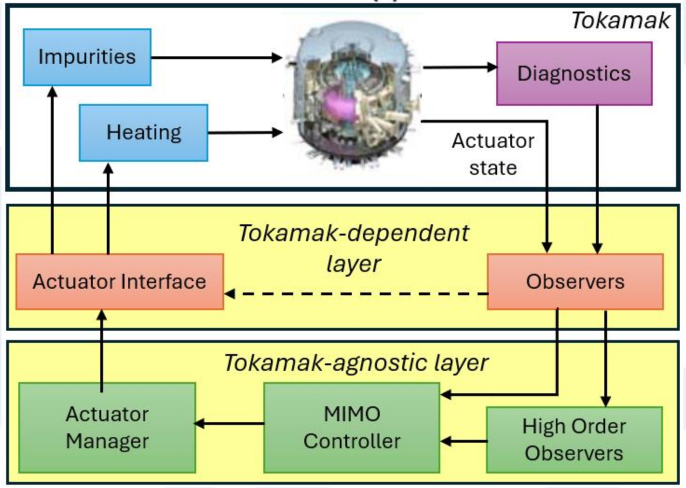
      - For TCV: comparison with SISO P_{rad} and P_{sep}/P_{LH} controllers deployed simultaneously using SAMONE supervisor.



- **Experimental Strategy/Machine Constraints and essential diagnostics**
  - Verify relevant P_{sep}/P_{LH} range and dynamic response to auxiliary power (2 pulses/device).
  - Quantify the feed-forward effect of impurity injection as an actuator for Prad (2-4 pulses/device).
  - Pulses with dual actuator management to demonstrate improved control (6 pulses/device).
  - For TCV: comparison with SISO P_{rad} and P_{sep}/P_{LH} controllers deployed simultaneously using SAMONE supervisor (2 pulses).
  - This experiment can be performed in 1 MA/1.8 T AUG plasmas and standard H-mode TCV plasmas. TCV experiments would benefit from the availability of MANTIS.
  - Essential Diagnostics:
    - Bulk P_{rad} calculation in real-time

Proposed pulses

Device	# Pulses/Session	# Development
AUG	12	
TCV	12	

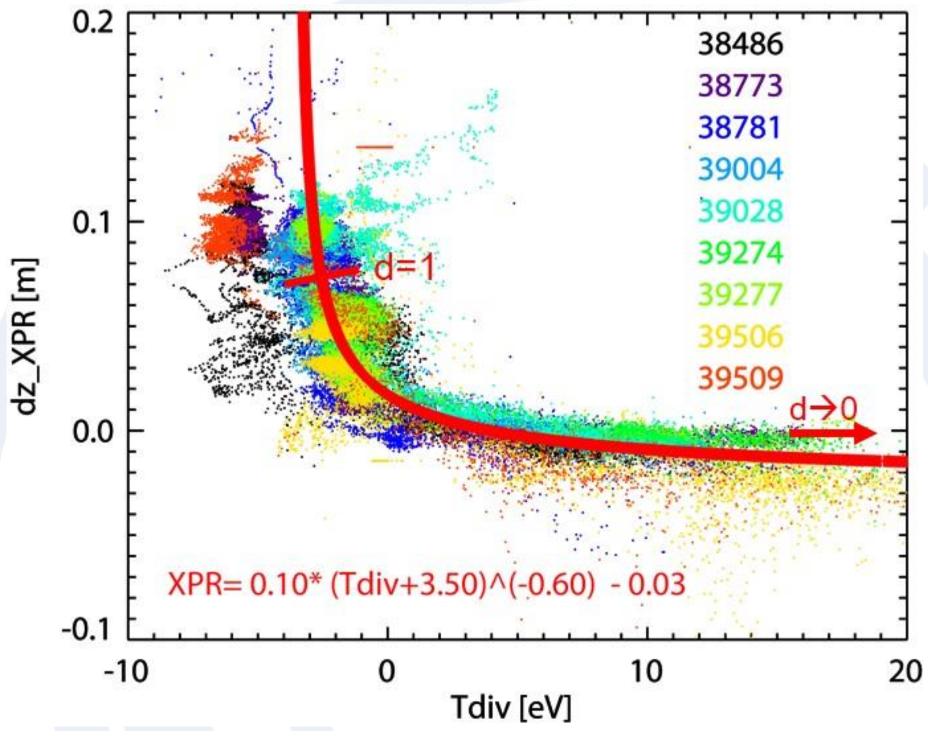
P93: Continuous control from attachment to XPR

- **Proponents and contact person:**
  - Pierre.David@ipp.mpg.de
  - Matthias.Bernert@ipp.mpg.de
  - Bernard.Sieglin@ipp.mpg.de

- **Scientific Background & Objectives**
  - Tdiv control is only valid up to partial detachment, while XPR control requires an XPR present (~full detachment). The aim is to couple both controllers, providing a continuous control from attached to fully detached

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Strong nitrogen seeding
  - AXUV & Tdiv control

  - Strategy:
    – Couple both controller via a new detachment parameter d
    – Develop controller gains to match Tdiv & XPR control at both extremes
    – Demonstrate continuous control for attached to fully detached plasmas [4#]



Proposed pulses

Device	# Pulses/Session	# Development
AUG	1	3
MAST-U		
TCV		
WEST		

P93: Continuous control from attachment to XPR

- **Proponents and contact person:**
  - Pierre.David@ipp.mpg.de
  - Matthias.Bernert@ipp.mpg.de
  - Bernard.Sieglin@ipp.mpg.de

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  - Strategy:
    - Couple both controller via a new detachment parameter d
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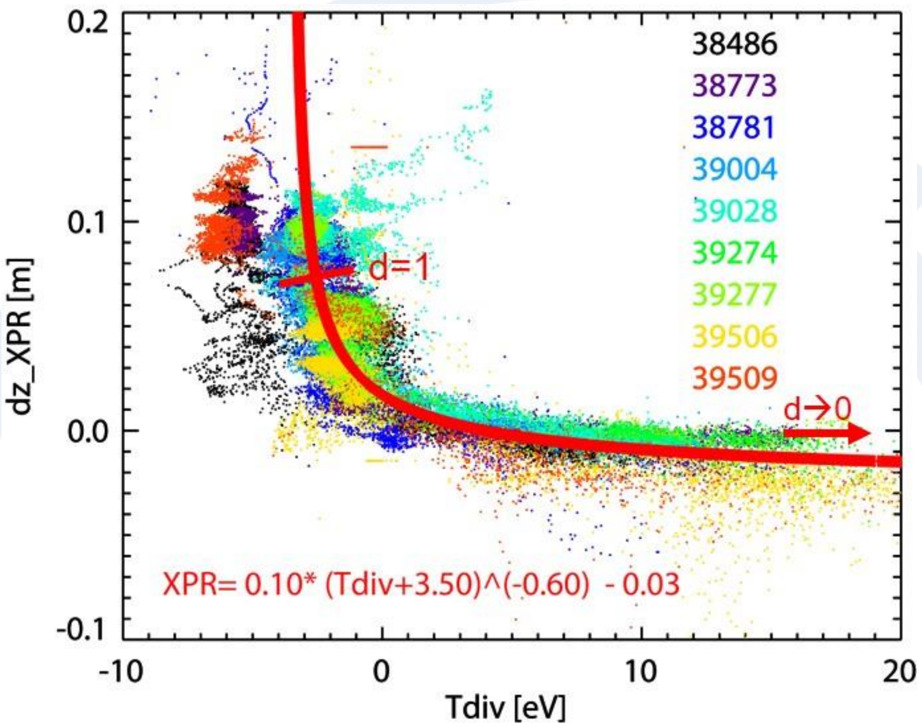
    - Demonstrate continuous control for attached to fully detached plasmas [4#]

- P1-AUG 2026
- Aligned with D7



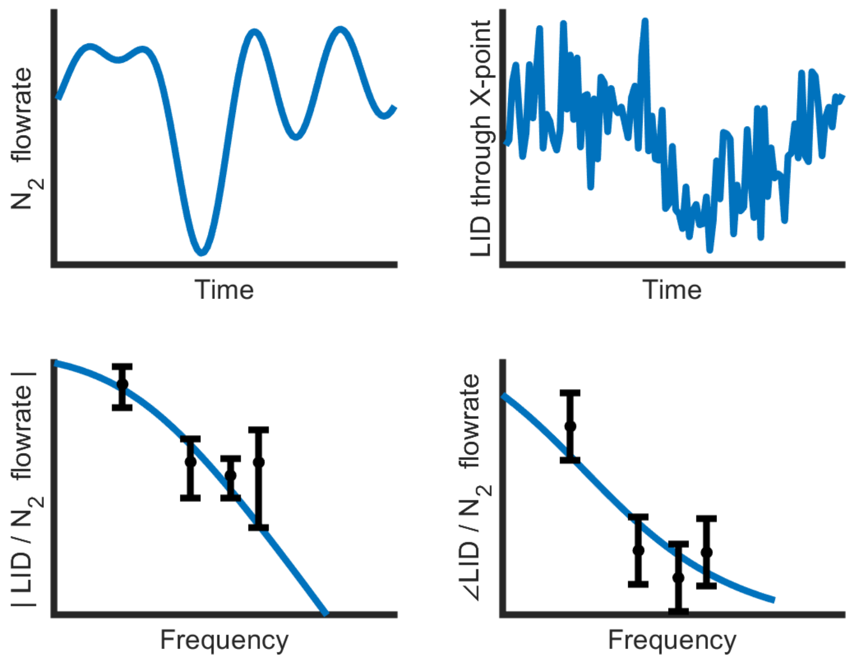
Proposed pulses

Device	# Pulses/Session	# Development
AUG	1	3
MAST-U		
TCV		
WEST		

P109: System identification of exhaust plasma using nitrogen and deuterium gas puffing in XPR-regime

- **Proponents and contact person:**
  - Juan Javier Palacios Roman (palacios@differ.nl), Paulo Marinho Figuerdo, Matthijs van Berkel, Gijs Derks, Sven Wiesen, Stuart Henderson, Nicolas Fedorczak, Nicolas Rivals, Hao Yang.
- **Scientific Background & Objectives**

  System identification experiments in the XPR-regime of WEST and MAST-U are yet to be conducted. With data derived from system identification experiments, we can develop low complexity dynamic models to:
  - Improve physics understanding of the time-scales in XPR-regimes at various devices necessary for time-dependent exhaust modelling;
  - Evaluate performance and stability of and design fueling/seeding schemes in the XPR-regime (RT05 D1, D2, D4);
  - Compare to the obtained models of other devices, e.g., AUG and JET, to extrapolate to future devices (RT05 D2).
- **Experimental Strategy & Essential Diagnostics**
  - Perturb N_2 gas flowrate with sinewaves and measure the response in various diagnostics interferometry, bolometry, spectroscopy and visible light (top figures). Repeat experiment for D_2.
  - Fit low complexity dynamic models (frequency response function) to data (bottom figures).
  - Validate predictive nature of dynamic model by testing new fueling/ seeding schemes in both simulations and experiments.



Device	# Pulses/Session	# Development
AUG	-	-
MAST-U	5/1	0
TCV	-	-
WEST	5/1	0

P109: System identification of exhaust plasma using nitrogen and deuterium gas puffing in XPR-regime

- **Proponents and contact person:**
  - Juan Javier Palacios Roman (palacios@differ.nl), Paulo Marinho Figuerdo, Matthijs van Berkel, Gijs Derks, Sven Wiesen, Stuart Henderson, Nicolas Fedorczak, Nicolas Rivals, Hao Yang.
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  - Improve physics understanding of the time-scales in XPR-regimes at various devices necessary for time-dependent exhaust modelling;
  - Evaluate performance and stability of and design schemes in the XPR-regime (RT05 D1, D2, D4);
  - Compare to the obtained models of other device JET, to extrapolate to future devices (RT05 D2).
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  - Perturb N_2 gas flowrate with sinewaves and meas in various diagnostics interferometry, bolometry, spectroscopy and visible light (top figures). Repeat experiment for D_2.
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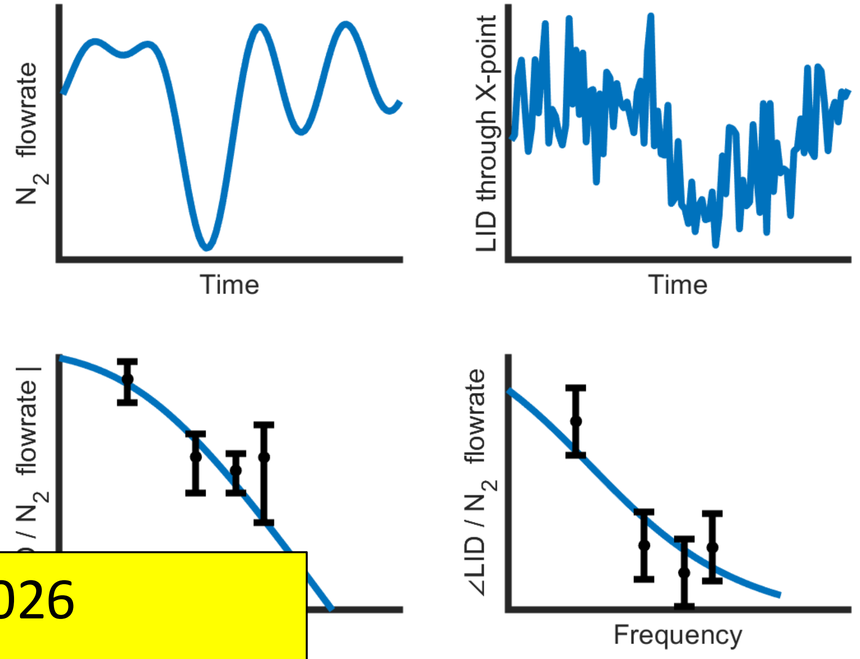

- P2-MAST-U-2026
- P2-WEST
- Aligned with D6
- Is data already available?

[illegible]	Pulses/Session	# Development
[illegible]	[illegible]	-
MAST-U	5/1	0
TCV	-	-
WEST	5/1	0