EUROfusion

WPTE GPM 18th November 2024

RT-05: Physics of divertor detachment and its control for ITER, DEMO and HELIAS operation

N. Vianello

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

Research Topic Coordinators

M. Bernert, N. Fedorczak, S. Henderson, H. Reimerdes

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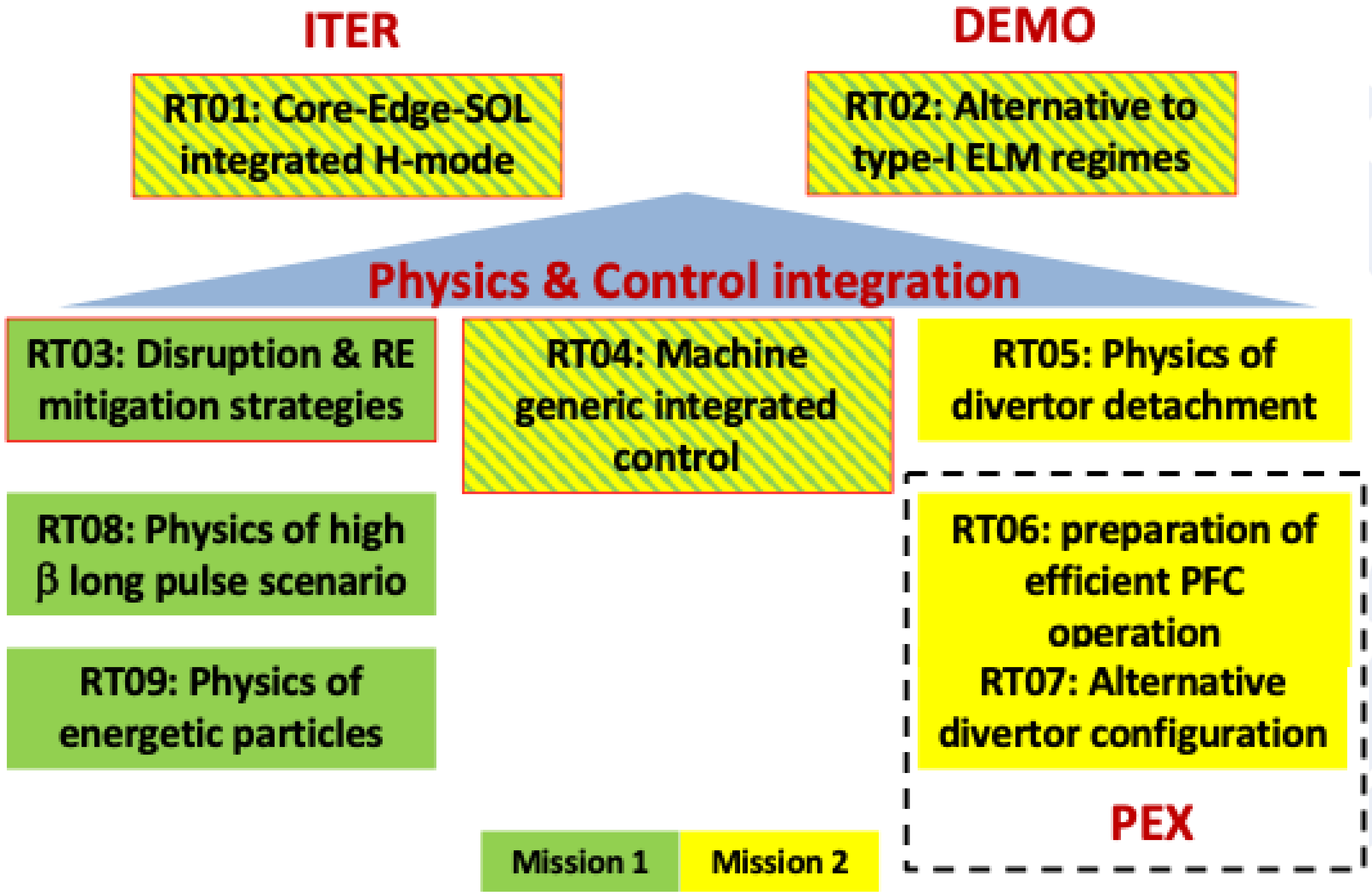
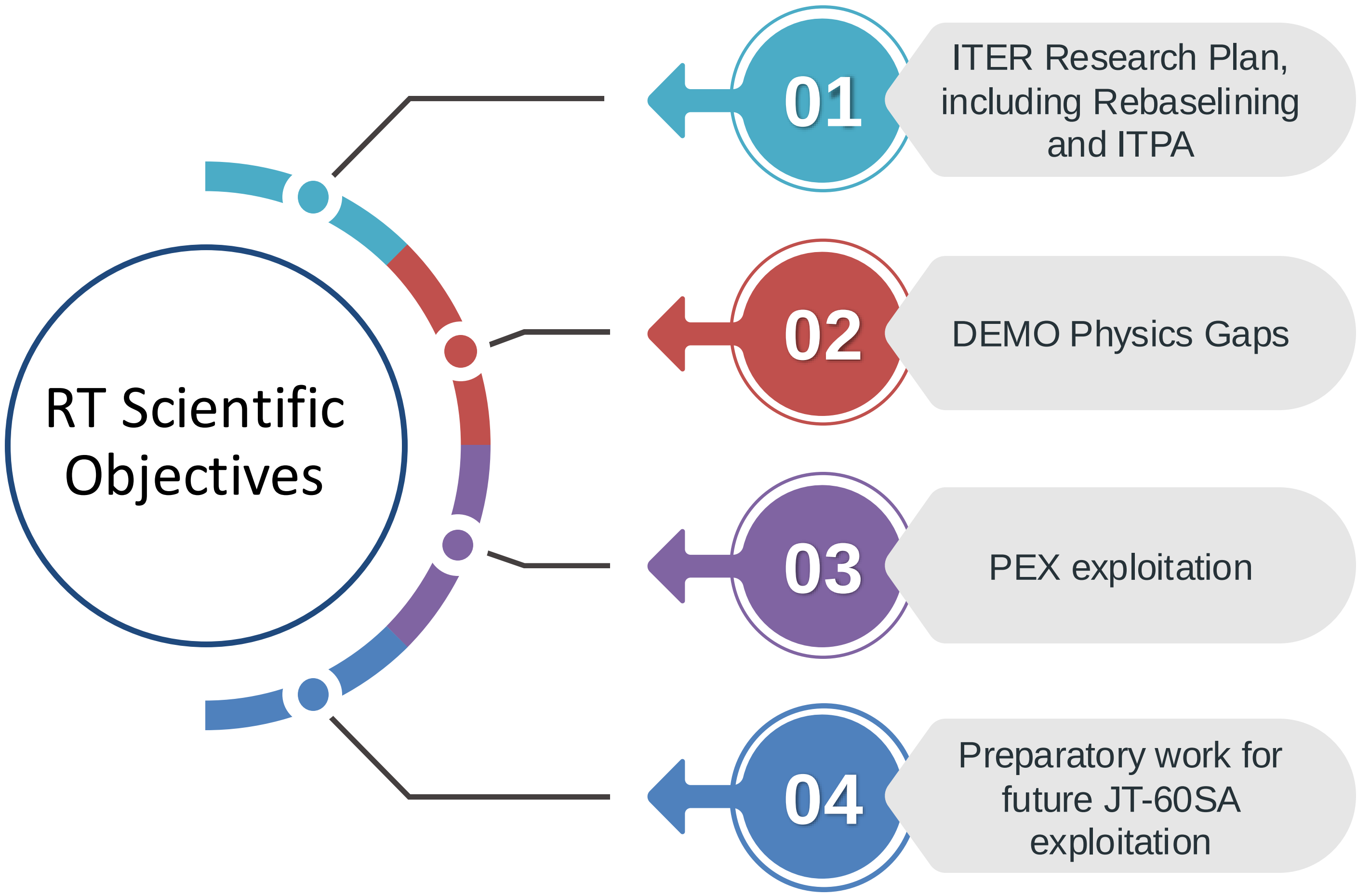
Introduction

RT05 is investigating the detachment physics and possible scenarios at high-radiation fraction in view of DEMO



Prioritization scheme and criteria



Proposal Evaluated according to the criteria:

Adherence to the Scientific Objectives

Team effort

Size and feasibility

All these aspects were considered by the TFLs when setting the priorities – according to the following scheme

P1: experimental priority for 2025

P2: will be done if time allows after Prio 1 experiments are completed/or incorporated in main scenario if feasible

P3: back-up programme

PB: piggy-back experiment/pure analysis proposal

Summary of the proposals

#	Proposal	Main proponents
15	L2H Studies with Impurity seeding	Emilia Solano
92	Development of real time XPR/MARFE observer for the new ASDEX Upgrade upper divertor	Bernhard Sieglin
94	IEDF evolution during detachment onset in WEST divertor	Jernej Kovačič
95	Optimisation of XPR entry and exit in WEST for low disruptivity & high fluence operation	Nicolas Fedorczak
96	High-density ECRH-assisted X-Point Radiators in WEST	Nicolas Rivals
97	Operational density limit for XPR with pellet injection control in WEST	Eleonore Geulin
98	Detachment control based on energy balance and system identification	Hao Yang
99	Development of an integrated reduced model for exhaust	Stuart Henderson
100	Enhancing confinement in ELM suppressed X-point radiator regimes through plasma shaping and density control	Ou Pan
101	Advanced exhaust control on TCV and MAST-U	Gijs Derks
102	Continuation of dynamic measurements and control for the plasma exhaust	Gijs Derks
103	Impulsive detachment experiments in AUG for SOLPS-ITER and JOREK time-dependent validation	Federico Cursi
104	Upstream downstream ion and electron temperatures	Jiri Adamek
105	ELM buffering in conventional divertor configuration including real-time control	Michael Komm
106	Flow characterization in the divertor	Richard Ducker
107	X-point radiator high confinement experiment	Jorge Morales
108	Investigating the impact of plasma-neutral interactions on detachment	Kevin Verhaegh
109	Effect of divertor turbulence on the heat load footprint	Marco Cavedon
110	Investigating the impact of divertor conditions, including impurity seeding, on broadening of the scrape-off-layer power channel	Peter Ryan
111	Investigation of seeding location on impurity distribution, compression and core contamination	Riccardo Morgan
112	Power EXhaust (PEX) databese in H-mode for SOLPS-ITER validation	Elena Tonello
113	Access and radiative capability of the XPR as a function of triangularity in TCV and AUG DivIIo	Tilmann Lunt
114	XPR and CRD in open vs closed divertor – Neutral compression and Helium exhaust	Matthias Bernert
115	Continuous control from attachment to XPR	Matthias Bernert
116	Pellet fueling into XPR & CRD	Matthias Bernert
117	Fluctuation characteristics and transport in the XPR regime	Matthias Bernert
118	Effect of gas baffling on ELM buffering in TCV	Martim Zurita
119	Assessing the effect of impurity seeding on upstream SOL conditions, profiles and fluctuations	Adriano Stagni
120	How replacing gas fuelling by pellet fuelling affects upstream SOL properties, divertor conditions, access to divertor detachment	Christian Perez von Thun
121	Continuation of HDL studies with metallic wall: dependence of maximum sustainable separatrix density in H-mode on impurity seeding (Zeff), plasma shaping (triangularity, closeness to DN) or use of pellets	Christian Perez von Thun
205	Investigating impact of fuelling/seeding location on impurity compression/enrichment	Ryoko Osawa

RT05-Physics of divertor detachment and its control for ITER, DEMO and HELIAS operation

#	
D1	Characterize detachment access and core plasma performance in scenarios using different fuelling schemes, different impurity mixtures
D2	Development of reduced physics model which can be included in radiative detachment control schemes or extrapolations to DEMO/ITER
D3	Quantify edge-SOL particle and heat transport, including the interaction with neutrals, above and below the X-point under detached conditions
D4	Assess the compatibility and stability with X-point radiator regimes with confinement
D5	Quantify the degree of ELM heat load mitigation achievable by impurity seeding, investigating the dependences on relevant machine parameters
D6	Assess the evolution of detachment under slow transients (L-H transitions, sawtooth, loss of impurity seeding)

2025	AUG	TCV	MAST-U	WEST
Tentative allocation	35	150	32	15
Total proposed	246	198	162	228
Scientific/dev.	175/71	165/33	127/35	211/17

#15: L2H Studies with Impurity seeding

- **Proponents and contact person:**
  emilia.solano@ciemat.es,gregor.birkenmeier@ipp.mpg.de,Matthias.Bernert@ipp.mpg.de ,pierre.david@ipp.mpg.de, Costanza.Maggi@ukaea.uk, ephrem.delabie@ukaea.uk, marco.cavedon@unimib.it, pietro.vincenzi@igi.cnr.it, clemente.angioni@ipp.mpg.de, ivo.carvalho@iter.org, ewap@uni.opole.pl, Jorge Morales, etc…

- **Scientific Background & Objectives**
  - future devices plan impurity seeding & detachment. P_{LH} defines device size
  - Some AUG data available in high density branch
  - AUG and JET had lower P_{LH} with metal wall: n_e, P_{sep} or Z_{eff} effect?
  - DIII-D: lower P_{LH} in low density branch In D, not in H, attributed to Z_{eff}
  - Is dominant impact on PLH from dilution, radiation, collisions, $n_{e,sep}$ or profile effects?

- **Experimental Strategy/Machine Constraints and essential diagnostics**
  - Best impurity tbd: **AUG** Ar, **N**, Ne, Kr? **JET** CD_4, **N** or Ne?
  - AUG: 1.2MA/2.3T, JET: V5 or Corner, 1.8T 1.7 MA and 3T 2.5 MA
  - AUG Diags: PNET, CXRS (blibs), HEB, ECE, Li-BES, Thomson scattering, HES, Doppler reflectometer, reflectometry and He beam for fluctuations.
  - JET diags: Bolometry, HRTS, CX, KG10, KG8C, KK3, KK1, …

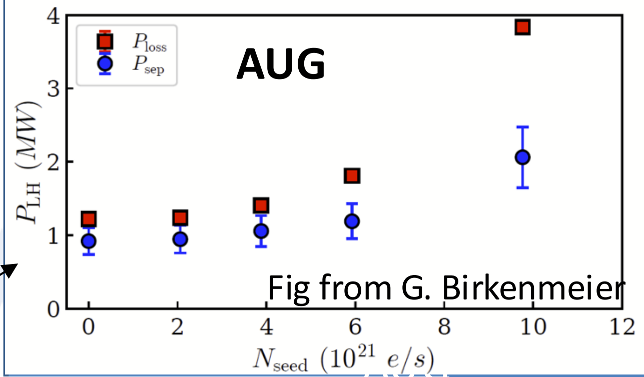


Fig from G. Birkenmeier

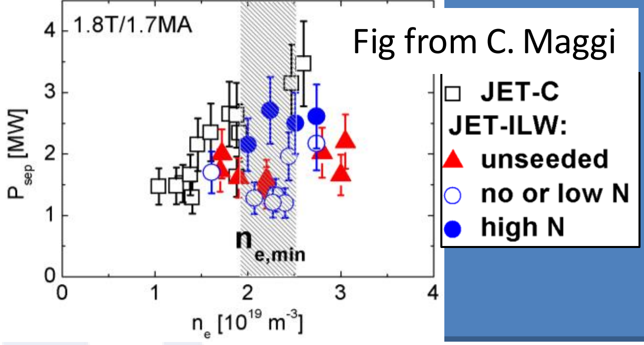


Fig from C. Maggi

Proposed pulses

Device	# Pulses/Session	# Development
AUG	15	5
MAST-U		
TCV		
WEST	related proposal	
JET	20	5

#15: L2H Studies with Impurity seeding

- **Proponents and contact person:**
  emilia.solano@ciemat.es,gregor.birkenmeier@ipp.mpg.de,Matthias.Bernert@ipp.mpg.de ,pierre.david@ipp.mpg.de, Costanza.Maggi@ukaea.uk, ephrem.delabie@ukaea.uk, marco.cavedon@unimib.it, pietro.vincenzi@igi.cnr.it, clemente.angioni@ipp.mpg.de, ivo.carvalho@iter.org, ewap@uni.opole.pl, Jorge Morales, etc…

- **Scientific Background & Objectives**
  - future devices plan impurity seeding & detachment. P_{LH} defines device size
  - Some AUG data available in high density branch
  - AUG and JET had lower P_{LH} with metal wall: n_e, P_{sep} or Z_{eff} effect?
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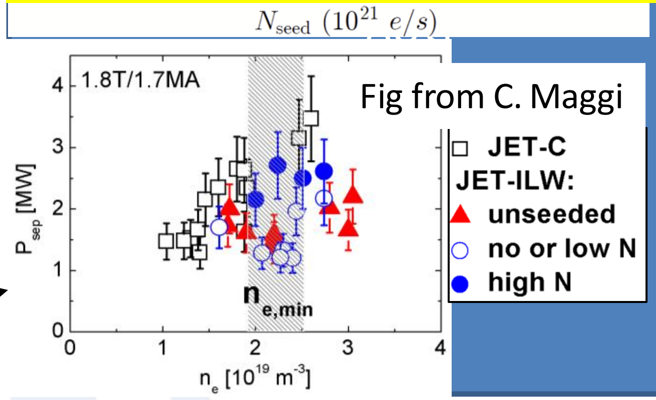
  - AUG Diags: PNET, CXRS (blibs), HEB, ECE, Li-BES, Thomson scattering, HES, Doppler reflectometer, reflectometry and He beam for fluctuations.
  - JET diags: Bolometry, HRTS, CX, KG10, KG8C, KK3, KK1, …

P2: Can have dedicate space eventually on TCV. On AUG to be determined possible piggyback on main proposal (with appropriate slow L-H transition)



Proposed pulses

Device	# Pulses/Session	# Development
AUG	15	5
MAST-U		
TCV		
WEST	related proposal	
JET	20	5

#92: Development of XPR/MARFE real time observer for the upper divertor in ASDEX Upgrade

- **Proponents and contact person:**
  Bernhard Sieglin, Matthias Bernert, Marc Maraschek, Anja Gude, Felix Klossek, Alessandro Pau
- **Scientific Objectives**
  - Implement real time AXUV diode bolometry on ASDEX Upgrade (diagnostic is available, setup needs to be commissioned for real time use for the upper divertor)
  - Implement the additional evaluation process and the corresponding signals into the discharge control system.
  - Implement and commission the signals to be used for feedback control and exception handling.

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

  To achieve the objectives we propose to
  - implement the required real time diagnostics and observers.
  - perform H-Mode density limit discharges in USN to validate the observers.
  - Commission the exception handling capabilities for disruption avoidance.
  - If needed perform system identification for detachment control to obtain feedback control parameters.

- **Scientific Background**

  ASDEX Upgrade is currently being equipped with a new upper divertor. The control capabilities for detachment control and disruption avoidance are currently implemented for the lower divertor. These capabilities will be required for the upper divertor as well. The observation of the XPR/MARFE is desired for both detachment control where continuous control is applied as well as for disruption avoidance using e.g. exception handling. This proposal aims to implement and commission these capabilities for the upper divertor on ASDEX Upgrade.

Proposed pulses

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

#92: Development of XPR/MARFE real time observer for the upper divertor in ASDEX Upgrade

P1: Mandatory work for full exploitation of new Upper Divertor

- **Proponents and contact person:**
  Bernhard Sieglin, Matthias Bernert, Marc Maraschek, Anja Gude, Felix Klossek, Alessandro Pau
- **Scientific Objectives**
  - Implement real time AXUV diode bolometry on ASDEX Upgrade (diagnostic is available, setup needs to be commissioned for real time use for the upper divertor)
  - Implement the additional evaluation process and the corresponding signals into the discharge control system.
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  To achieve the objectives we propose to
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Proposed pulses

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

#94: IEDF evolution during detachment onset in WEST divertor

- **Proponents and contact person:**
- J. Kovacic, jernej.kovacic@fs.uni-lj.si (UNI.LJ); P. Ivanova(IE.BAS), J. Gunn (CEA.FR), M. Dimitrova (IPP.CZ), T. Gyergyek (UNI.LJ)

- **Scientific Background & Objectives**
  - Provide local IEDF (ni, Ti) in time
  - Important quantity in heat flux calculations and atomic physics processes (modelling)
  - Ti important e.g. in gap load calculations

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - L-mode, LSN plasma
  - Transition from attached to detached plasma (density ramp, seeding)
  - Fixed strike point– several RFA insertions around detachment onset
  - Strike point sweeping towards RFA – 2D /time map of detachment
  - Use of RFA + LPs – ion flux comparison, Ti/Te mapping
  - Utilise piggy-backing to get as much RFA data as possible

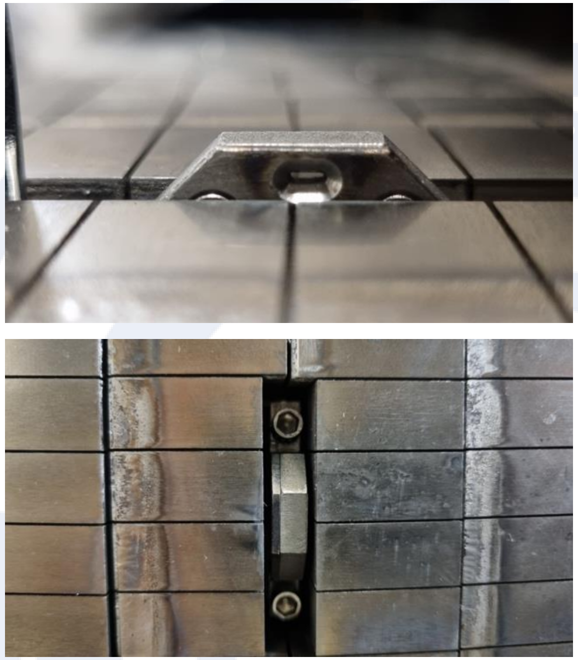

Fig: RFA, MB#28-#29 (WEST divertor)

Proposed pulses

Device	# Pulses/Session	# Development
AUG	-	-
MAST-U	-	-
TCV	-	-
WEST	**10**	**2**

#94: IEDF evolution during detachment onset in

P1/PB: Interesting additional physics. Prioritize piggyback usage of diagnostic (eventually with appropriate settings as SP sweep) w/o dedicated shots

- **Proponents and contact person:**
  - J. Kovacic, jernej.kovacic@fs.uni-lj.si (UNI.LJ); P. Ivanova(IE.BAS), J. Gunn (CEA.FR), M. Dimitrova (IPP.CZ), T. Gyergyek (UNI.LJ)

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  - Provide local IEDF (ni, Ti) in time
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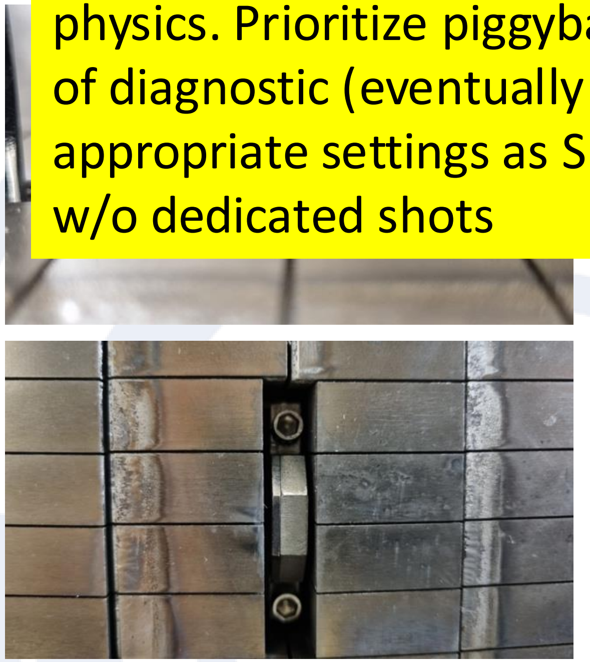


Fig: RFA, MB#28-#29 (WEST divertor)

Proposed pulses

Device	# Pulses/Session	# Development
AUG	-	-
MAST-U	-	-
TCV	-	-
WEST	**10**	**2**

#95 Optimisation of XPR entry and exit in WEST for low disruptivity & high fluence operation

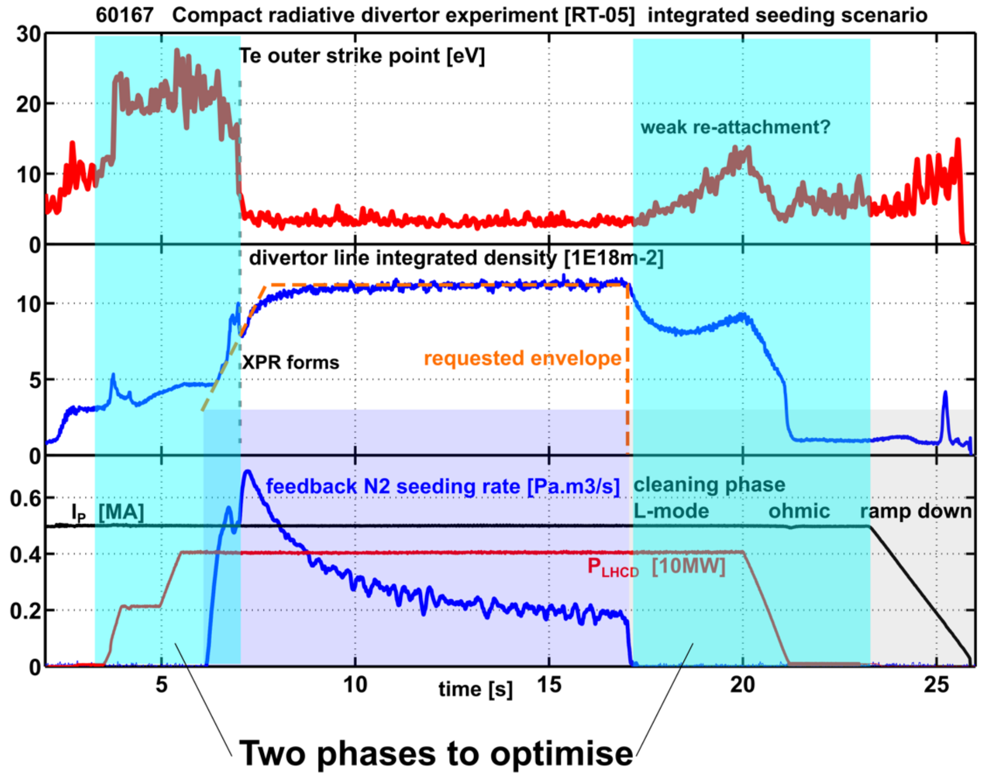
- **Proponents and contact person:**

  N. Fedorczak, J. Gaspar, R. Nouailettas, N. Rivals, E. Geulin…

- **Scientific Background & Objectives**
  - → **Preparation of High fluence campaign in XPR regime**
  - XPR control effective in WEST on ~20s steady-state phases (RT05 results)
  - Needs to be expanded to phases with density & power ramps

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - **Optimise early impurity seeding to trigger XPR in ohmic up through power & density ramp**
    - Nitrogen seeding as reference. Use lid1 as reference observable. Test bolometry observable (under developement)
    - Start from feedforward waveforms, based on static empirical model.
    - Adjust feedforward waveform
    - Apply an optimised realtime waveform of seeding vs power & density ramps
    - Use of ECRH heating (1MW for 1-2s) if needed to ease LHCD ramp up.
  - **Optimise end of pulse with repsect to XPR maintenance, disruptivity & impurity legacy**
    - Adjust seeding ramp down with respect to power ramp down
    - Evaluate the minimum duration of « pure D2 » phase to avoid disruption & stabilize impurity legacy.
  - **Machine requirement:**

    4 to 5MW LHCD, bolometry, lid1, 1MW ECRH (1MW for 1-2s)



Proposed pulses

Device	# Pulses/Session	# Development
AUG	0	0
MAST-U		
TCV		
WEST	40 pulses / 2	

#95 Optimisation of XPR entry and exit in WEST for low disruptivity & high fluence operation

P1/PB: To be combined with #96 in a single session for XPR but at lower priority if ECRH power will be available. Might found space in the optimization of the scenario

- **Proponents and contact person:**

  N. Fedorczak, J. Gaspar, R. Nouailettas, N. Rivals, E. Geulin…

- **Scientific Background & Objectives**
  - → **Preparation of High fluence campaign in XPR regime**
  - XPR control effective in WEST on ~20s steady-state phases (RT05 results)
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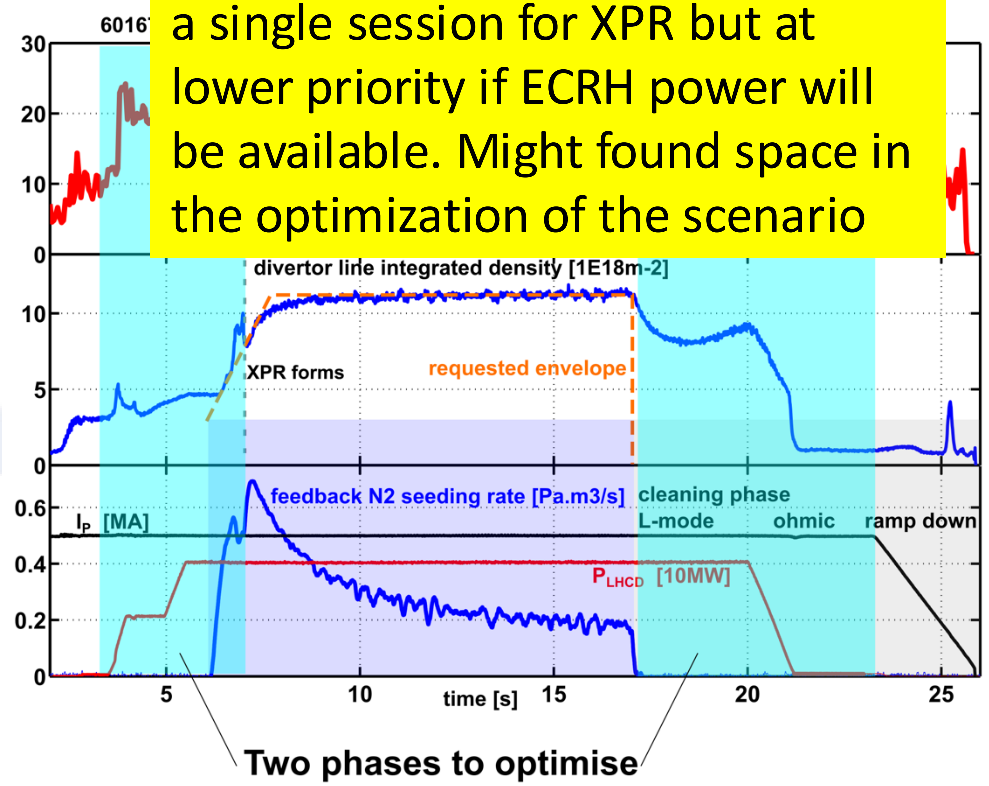

Proposed pulses

Device	# Pulses/Session	# Development
AUG	0	0
MAST-U		
TCV		
WEST	40 pulses / 2	

#96: High-density ECRH-assisted X-Point Radiators in WEST

- **Proponents and contact person:**
    - **Contact: Nicolas RIVALS nicolas.rivals@cea.fr**
    - Nicolas FEDORCZAK nicolas.fedorczak@cea.fr
    - Eléonore GEULIN eleonore.geulin@cea.fr
    - Louis FÈVRE louis.fevre@cea.fr
    - David MOIRAF david.moiraf@cea.fr
    - Matthias BERNERT matthias.bernert@ipp.mpg.de
    - Stuart HENDERSON stuart.Henderson@ukaea.uk
    - Holger REIMERDES holger.reimerdes@epfl.ch
- **Scientific Background & Objectives**
    - Current WEST plasmas are currently **limited in density** due to **lack of central heating** (LHCD is off-centered, too high density lowers central plasma temperature to a region where **W impurities induces a radiative temperature collapse**)
    - **ECRH heating is now installed on WEST**, capable of **central heat deposition**
    - XPR experiments at WEST covered the density operational space up to $n_l = 4.\ 10^{19}\ m^{-2}$, **ECRH should allow access to higher density scenarios**, with the **objective of developing scenarios closer to the expected Greenwald fraction in ITER and future devices**
    - Objectives:
        - Investigate **access to high-density ($n_l >= 5\ 10^{19}\ m^{-2}$) XPR regimes**, in **H-mode if available**, L-mode otherwise
        - Investigate XPR access to **pure-D XPR's** (density-driven detachment), then seeded with **Nitrogen**, **Neon**, and **Argon** impurities
- **Experimental Strategy/Machine Constraints and essential diagnostic**
    - Lower Single Null scenario
    - 4 MW LHCD + 1 MW ECRH, feedback controlled density: density ramp to explore pure-D density limit
    - Seeded scenarios (N, Ne, Ar): start from selected new high density state with ECRH ($n^l >= 5\ 10^{19}\ m^{-2}$) then: 1) FF seeding ramp, then FB at selected X-point line-integrated density value ("lid1", XPR control variable in WEST)
    - Essential diagnostics: Langmuir Probes, DVIS Spectroscopy, lid1 & lid3 Interferometry, Bolometry

Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV		
WEST	40 / 2 sessions	(included in session)

#96: High-density ECRH-assisted X-Point Radiat

P1: Leading proposal for the single session allocated to WEST. Should consider possible inputs from Proposal #95 and #97

- **Proponents and contact person:**

  - **Contact: Nicolas RIVALS nicolas.rivals@cea.fr**
  - Nicolas FEDORCZAK nicolas.fedorczak@cea.fr
  - Eléonore GEULIN eleonore.geulin@cea.fr
  - Louis FÈVRE louis.fevre@cea.fr
  - David MOIRAF david.moiraf@cea.fr
  - Matthias BERNERT matthias.bernert@ipp.mpg.de
  - Stuart HENDERSON stuart.Henderson@ukaea.uk
  - Holger REIMERDES holger.reimerdes@epfl.ch

- **Scientific Background & Objectives**
  - Current WEST plasmas are currently **limited in density** due to **lack of central heating** (LHCD is off-centered, too high density lowers central plasma temperature to a region where **W impurities induces a radiative temperature collapse**)
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    - Investigate XPR access to **pure-D XPR's** (density-driven detachment), then seeded with **Nitrogen**, **Neon**, and **Argon** impurities
- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Lower Single Null scenario
  - 4 MW LHCD + 1 MW ECRH, feedback controlled density: density ramp to explore pure-D density limit
  - Seeded scenarios (N, Ne, Ar): start from selected new high density state with ECRH ($n^l >= 5\ 10^{19}\ m^{-2}$) then: 1) FF seeding ramp, then FB at selected X-point line-integrated density value ("lid1", XPR control variable in WEST)
  - Essential diagnostics: Langmuir Probes, DVIS Spectroscopy, lid1 & lid3 Interferometry, Bolometry

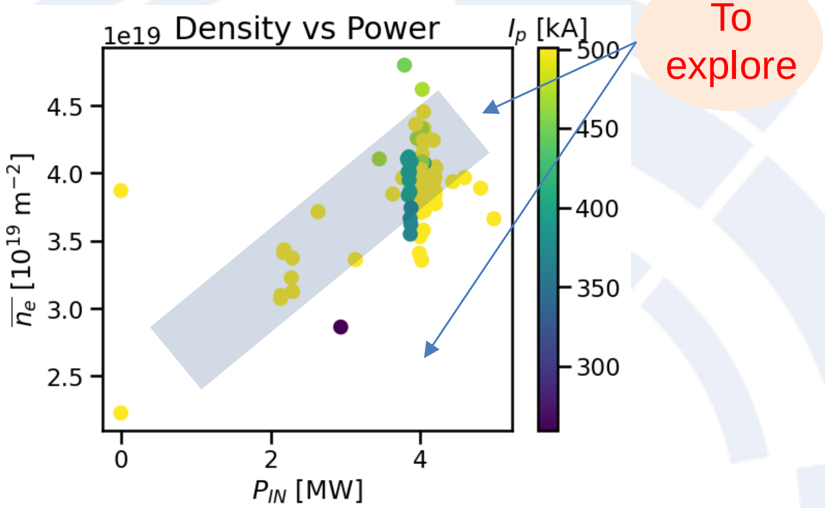
Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV		
WEST	40 / 2 sessions	(included in session)

#97 Operational density limit for XPR with pellet injection control in WEST

- **Proponent(s)**
  - E. Geulin, N. Rivals, N. Fedorczak, J-F Artaud, P. Maget, C. Orrico, J. Javier

- **Scientific Background & Objectives**
  - Operation in XPR regime is attractive for a Fusion Power Plant
    - Reduces thermal fluxes on the wall
    - Enhances plasma confinement
  - **Objective -** Identify achievable operational density domains in WEST during an XPR and assess the impact on :
    - Plasma confinement
    - Thermal fluxes on the divertor
    - Core impurity levels
    - Characterize the physics of the bifurcation
      - Assess the feasibility of achieving high density with low plasma current
      - Assess the feasibility of achieving very high density with high power
    - Validate RAPDENS observer for pulses using pellets
- **Experimental Strategy/Machine constraints and essential diagnostics**
  - Standard L-mode with LHCD and ICRH
    - Density scan controlled by pellet injection:
      - explore maximum density limit for different additional power settings
  - Plasma density & wall temperature, (bolometry, VUV, SXR, Infrared), W sources (visible spectroscopy), Langmuir probes, ECE, reflectometry, high speed camera in front of pellet injection point



Nb of sessions / pulses proposed: 1 session

#97 Operational density limit for XPR with pellet injection

PB: To be considered within #96

- **Proponent(s)**
  - E. Geulin, N. Rivals, N. Fedorczak, J-F Artaud, P. Maget, C. Orrico, J. Javier

- **Scientific Background & Objectives**
  - Operation in XPR regime is attractive for a Fusion Power Plant
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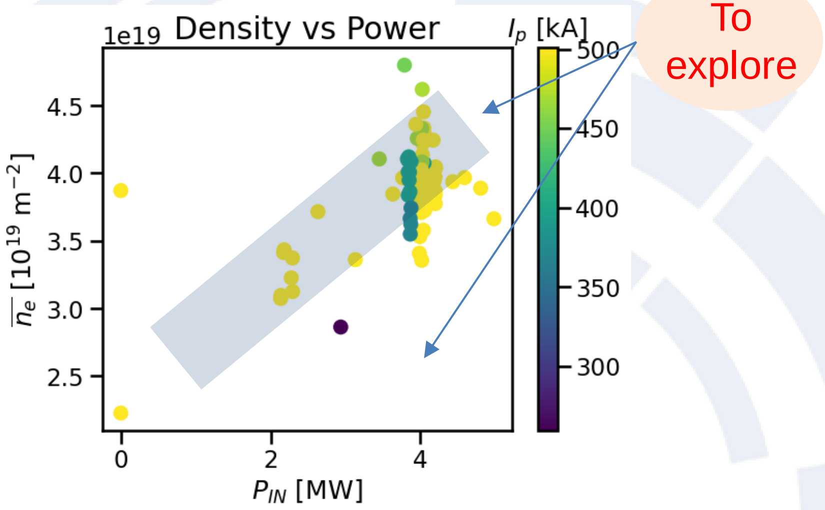
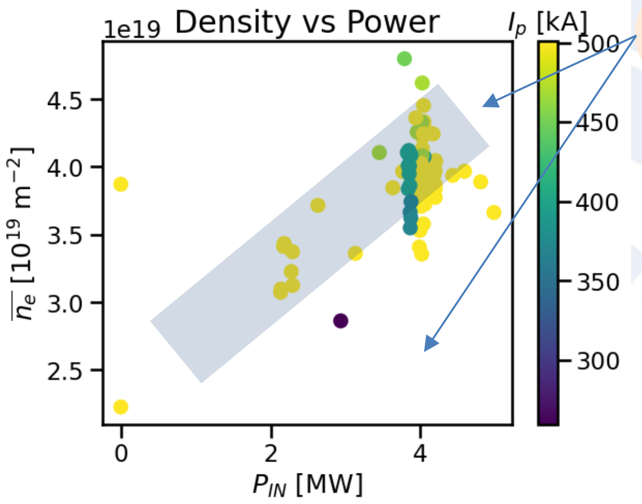


Nb of sessions / pulses proposed: 1 session

#97 Operational density limit for XPR with pellet injection

P1/PB: To be combined with #96 in a single session for XPR

- **Proponent(s)**
  - E. Geulin, N. Rivals, N. Fedorczak, J-F Artaud, P. Maget, C. Orrico, J. Javier
- **Scientific Background & Objectives**
  - Operation in XPR regime is attractive for a Fusion Power Plant
    - Reduces thermal fluxes on the wall
    - Enhances plasma confinement
  - **Objective -** Identify achievable operational density domains in WEST during an XPR and assess the impact on :
    - Plasma confinement
    - Thermal fluxes on the divertor
    - Core impurity levels
    - Characterize the physics of the bifurcation
      - Assess the feasibility of achieving high density with low plasma current
      - Assess the feasibility of achieving very high density with high power
    - Validate RAPDENS observer for pulses using pellets
- **Experimental Strategy/Machine constraints and essential diagnostics**
  - Standard L-mode with LHCD and ICRH
    - Density scan controlled by pellet injection:
      - explore maximum density limit for different additional power settings
  - Plasma density & wall temperature, (bolometry, VUV, SXR, Infrared), W sources (visible spectroscopy), Langmuir probes, ECE, reflectometry, high speed camera in front of pellet injection point



To explore

Nb of sessions / pulses proposed: 1 session

#98: Detachment Control Based on Energy Balance and System Identification

Proponents and contact person:

- Hao YANG (hao.yang@univ-amu.fr), Nicolas Fedorczak, Nicolas Rivals, Eric Serre, Guido Ciraolo, et al.

Scientific Background

- Reliable control of divertor detachment is crucial for divertor protection and long pulse operations.
- R_D (ratio of radiated power to conductive heat flux in SOL, equation on the right) is a useful figure of merit for detachment control [Hao Yang et al 2024 Nucl. Fusion 64 106039].
- The SOLEDGE3X-EIRENE code realistically models dynamic plasma behavior, enabling time-dependent simulations critical for designing reliable feedback controllers.
- This work is for the project "Advanced control system development for long pulse tokamak operations" supported by the EUROfusion Engineering Grant 2024.

Scientific Objectives (D1, D2 and D6 of RT05)

- Use diagnostics to evaluate R_D in real time or speed up the process with machine learning for integration into the feedback control system.
- Identify system dynamics in WEST to refine control system tuning [Collaborate with DIFFER/TUe].
- Compare experimental data with SOLEDGE3X-EIRENE simulations in the aspect of real-time dynamics, to develop a simulation workflow for reliable feedback controller design.
- Achieve stable detachment control using optimized control variables and controllers, characterize detachment access and core plasma performance, across different operation conditions.

Experimental Strategy/Machine Constraints and essential diagnostic

- **Session1:** R_D real-time evaluation and system identification with multisine perturbation, through D gas puff and/or N seeding, with scan of input power and density in SOL (16 pulses).
- **Session2:** Detachment control with R_D as control variable, using the optimized controller by adjusting D gas puff and N seeding rates (16 pulses).
- Essential diagnostic:
  - Langmuir probes, Thomson scattering (edge profiles), Bolometry (divertor), Interferometry (core and X-point), Reflectometer (edge density profile), magnetic field (separatrix position).

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

Real-time diagnostic (P_{rad}, $\lambda_q T_{e,sep}^{7/2}$)

- R : Major radius [m]
- a : Minor radius a [m]
- q_{95} : Safety factor (at ψ_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		
MAST-U		
TCV		
WEST	32 pulse/2	

#98: Detachment Control Based on Energy Balance and System Identification

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- **Session2:** Detachment control with R_D as control variable, using the optimized controller by adjusting D gas puff and N seeding rates (16 pulses).
- Essential diagnostic:
  - Langmuir probes, Thomson scattering (edge profiles), Bolometry (divertor), Interferometry (core and X-point), Reflectometer (edge density profile), magnetic field (separatrix position).

P2: No clear benefit of having this done on WEST (with limited machine time available) w.r.t. what could be done in machine with more generous allocation (e.g. TCV)

ostic

- 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		
MAST-U		
TCV		
WEST	32 pulse/2	

#99: Integrated reduced model for exhaust

- **Proponents and contact person:**

Stuart Henderson Stuart.Henderson@ukaea.uk
M. Bernert, A. Kallenbach, P. David, T. Cortemiglia, D. Silvagni

- **Scientific Background & Objectives**

Multiple reduced models based on engineering parameters exist to predict the steady state and transient SOL conditions

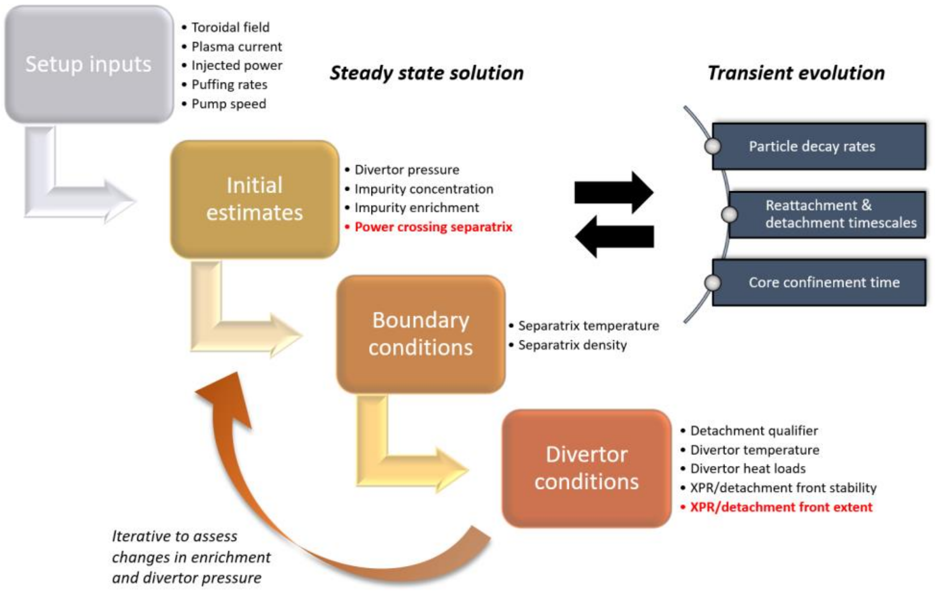
- Assess B_T dependence in detachment qualifier
- Combine existing reduced models and integrate with core model (e.g. IMEP)
- Compare tool against scenarios with continuous detachment control with different impurity mixtures and combinations of Ne/Ar/N

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

Develop detached scenario on AUG at low (~1.5 T) and high (3 T) magnetic field to compare to existing scenarios at 2.5 T and using continuous detachment control vary impurity mixture between Ar+N and Ar+Ne

- Varying B field: 1.5 – 3 T
- AXUV, Psep & Tdiv control with strong seeding

Compare model performance on MAST-U to scenarios with different divertor pressure and levels of detachment



Example exhaust workflow - parameters in red require development

Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	5
MAST-U	10	6
TCV		
WEST		

[1] Kallenbach et al. 2016 PPCF 58 045013 [2] Kallenbach et al. 2019 NME 18 166
[3] Henderson et al. 2023 NF 63 086024

#99: Integrated reduced model for exhaust

P1:
- Validation of reduced model considered of high priority
- Number of shot requested too high w.r.t. available budget and possible combination with other experiment (e.g. on MAST-U)

- **Proponents and contact person:**

Stuart Henderson Stuart.Henderson@ukaea.uk
M. Bernert, A. Kallenbach, P. David, T. Cortemiglia, D. Silvagni

- **Scientific Background & Objectives**

Multiple reduced models based on engineering parameters exist to predict the steady state and transient SOL conditions

- ➢ Assess B_T dependence in detachment qualifier
- ➢ Combine existing reduced models and integrate with core model (e.g. IMEP)
- ➢ Compare tool against scenarios with continuous detachment control with different impurity mixtures and combinations of Ne/Ar/N

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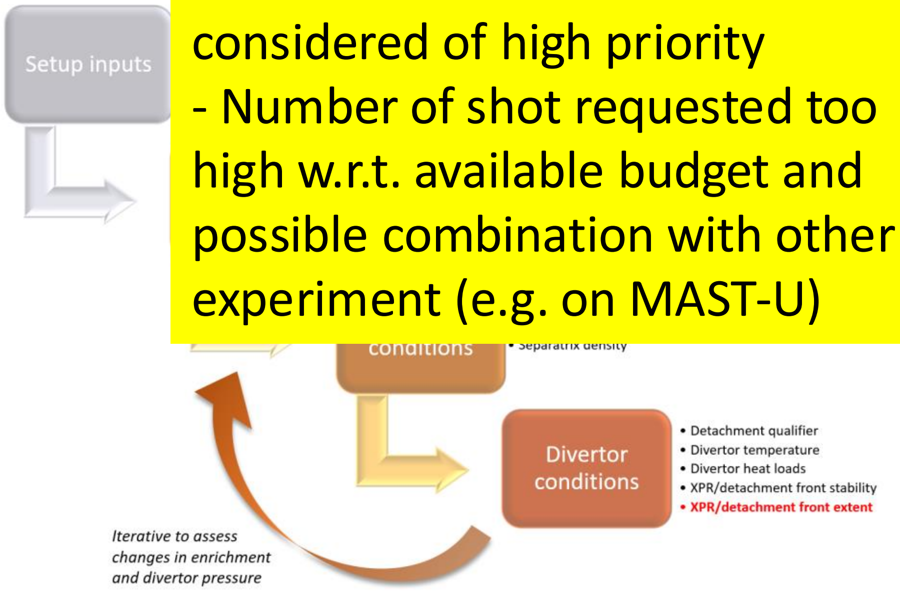
Develop detached scenario on AUG at low (~1.5 T) and high (3 T) magnetic field to compare to existing scenarios at 2.5 T and using continuous detachment control vary impurity mixture between Ar+N and Ar+Ne

- ➢ Varying B field: 1.5 – 3 T
- ➢ AXUV, Psep & Tdiv control with strong seeding

Compare model performance on MAST-U to scenarios with different divertor pressure and levels of detachment



Example exhaust workflow - parameters in red require development

Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	5
MAST-U	10	6
TCV		
WEST		

[1] Kallenbach et al. 2016 PPCF 58 045013 [2] Kallenbach et al. 2019 NME 18 166
[3] Henderson et al. 2023 NF 63 086024

#100: Enhancing confinement in ELM suppressed XPR regimes through plasma shaping and density control

• Proponents and contact person:

- Ou Pan (ou.pan@ipp.mpg.de), Matthias Bernert, Tilmann Lunt, Ulrich Stroth, Michael Dunne, Michael Faitsch

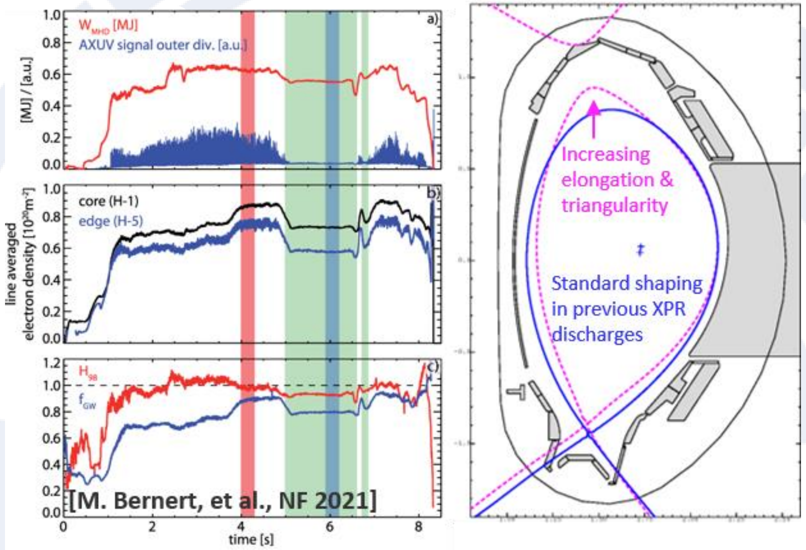
• Scientific Background & Objectives

- X-point radiator (XPR) is a promising approach for managing power exhaust in future fusion devices like EU-DEMO.
- In AUG, ELM mitigation can be achieved in the XPR regime when the radiator penetrates deeply enough into the confined region. However, this is typically accompanied by a 10-20% degradation in confinement.
- It has been demonstrated in other scenarios that plasma shaping (such as elongation and triangularity) or a lower separatrix density can improve confinement. In previous XPR experiments, however, simple plasma shaping and high gas-puffing were usually used to better control and access the XPR regime.
- In this work, we aim to explore the possibility of enhancing confinement during the ELM suppressed XPR phase by adjusting the plasma shape and gas fueling.

• Experimental Strategy/Machine Constraints and essential diagnostic

- Strategy: once the ELM suppressed XPR regime is achieved, implement the following strategies and observe the resulting changes in confinement: 1. increase plasma elongation; 2. increase triangularity; 3. decrease gas-puffing; 4. adjust beta or the toroidal magnetic field. Test combinations of the most promising strategies and repeat the experiments at different heating power levels.

- Essential diagnostics: bolometry, AXUV, reflectometry, ECE, CXRS, Thomson scattering, Lithium beam, Helium beam, magnetic coils, LPs



[M. Bernert, et al., NF 2021]

Proposed pulses

Device	# Pulses/Session	# Development
AUG	8	2
MAST-U		
TCV		
WEST		

#100: Enhancing confinement in ELM suppressed XPR regimes through plasma shaping and density control

P1:
- Reduced number of shots and check feasibility of modification in single shot to optimized machine usage

- **Proponents and contact person:**
  - Ou Pan (ou.pan@ipp.mpg.de), Matthias Bernert, Tilmann Lunt, Ulrich Stroth, Michael Dunne, Michael Faitsch

- **Scientific Background & Objectives**
  - X-point radiator (XPR) is a promising approach for managing power exhaust in future fusion devices like EU-DEMO.
  - In AUG, ELM mitigation can be achieved in the XPR regime when the radiator penetrates deeply enough into the confined region. However, this is typically accompanied by a 10-20% degradation in confinement.
  - It has been demonstrated in other scenarios that plasma shaping (such as elongation and triangularity) or a lower separatrix density can improve confinement. In previous XPR experiments, however, simple plasma shaping and high gas-puffing were usually used to better control and access the XPR regime.
  - In this work, we aim to explore the possibility of enhancing confinement during the ELM suppressed XPR phase by adjusting the plasma shape and gas fueling.

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Strategy: once the ELM suppressed XPR regime is achieved, implement the following strategies and observe the resulting changes in confinement: 1. increase plasma elongation; 2. increase triangularity; 3. decrease gas-puffing; 4. adjust beta or the toroidal magnetic field. Test combinations of the most promising strategies and repeat the experiments at different heating power levels.
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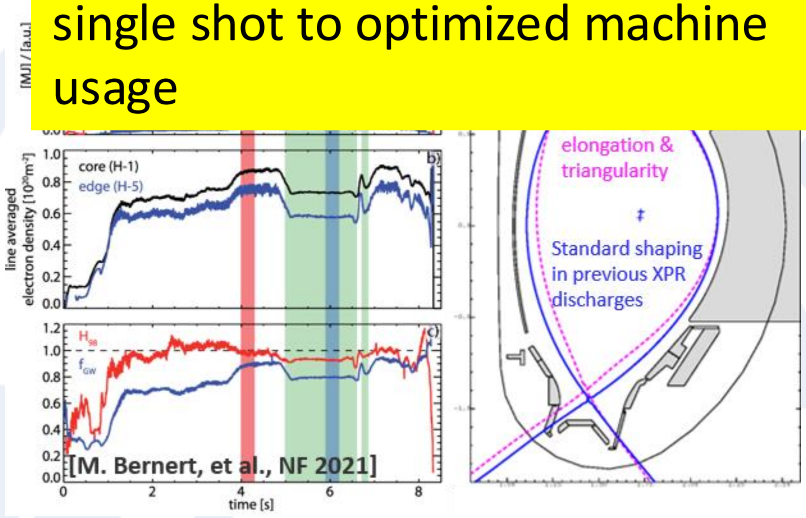


Proposed pulses

Device	# Pulses/Session	# Development
AUG	8	2
MAST-U		
TCV		
WEST		

#101: Advanced Exhaust Control on TCV and MAST-U

Proponents and contact person:

Gijs Derks (g.l.derks@differ.nl) Matthijs van Berkel (m.vanberkel@differ.nl), Artur Perek, Bob Kool, Tijs Wijkamp

Scientific Background & Objectives

This is a continuation of ENR 11 on control of radiative loss processes in the divertor using machine-learning accelerated multi-spectral image processing.

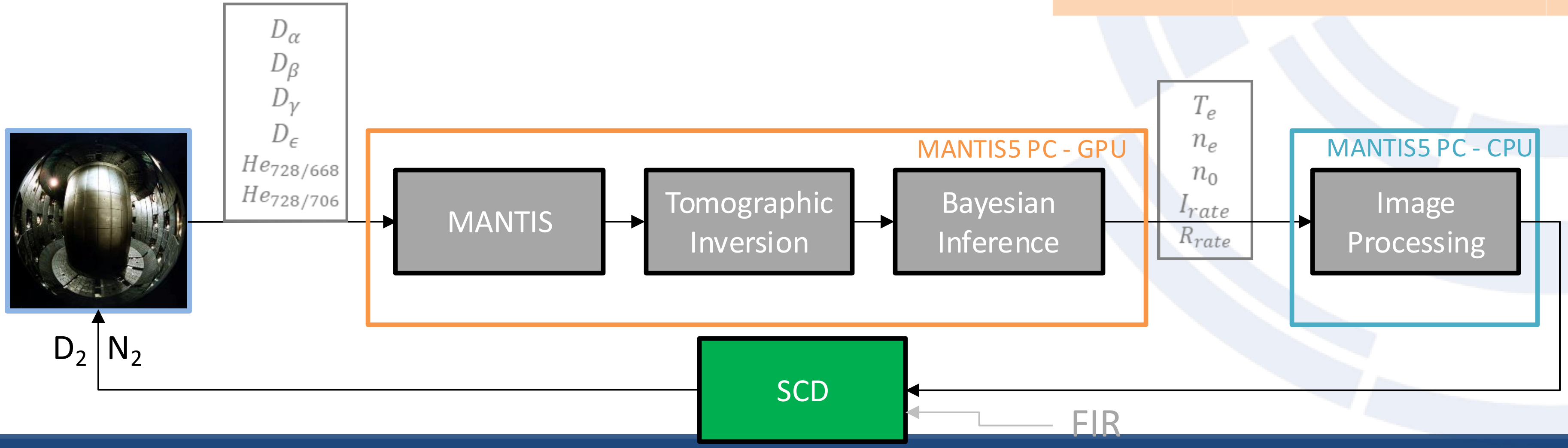
Experimental Strategy/Machine Constraints and essential diagnostic

TCV: Design and test Ionization front controller with ML in the loop (2 shots), Design and test combined HeII, Ionisation, MARFE controller (1 shot), Multivariable control, including FIR measurement for core (1 shot)

MAST-U: Design and test Ionization front controller with ML in the loop (2 shots)

Proposed pulses

Device	# Pulses/Session	# Development
AUG	0	-
MAST-U	4	0
TCV	4	0
WEST	0	0



#101: Advanced Exhaust Control on TCV and MAST-U

Proponents and contact person:

Gijs Derks (g.l.derks@differ.nl) Matthijs van Berkel (m.vanberkel@differ.nl), Artur Perek, Bob Kool, Tijs Wijkamp

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Experimental Strategy/Machine Constraints and essential diagnostic

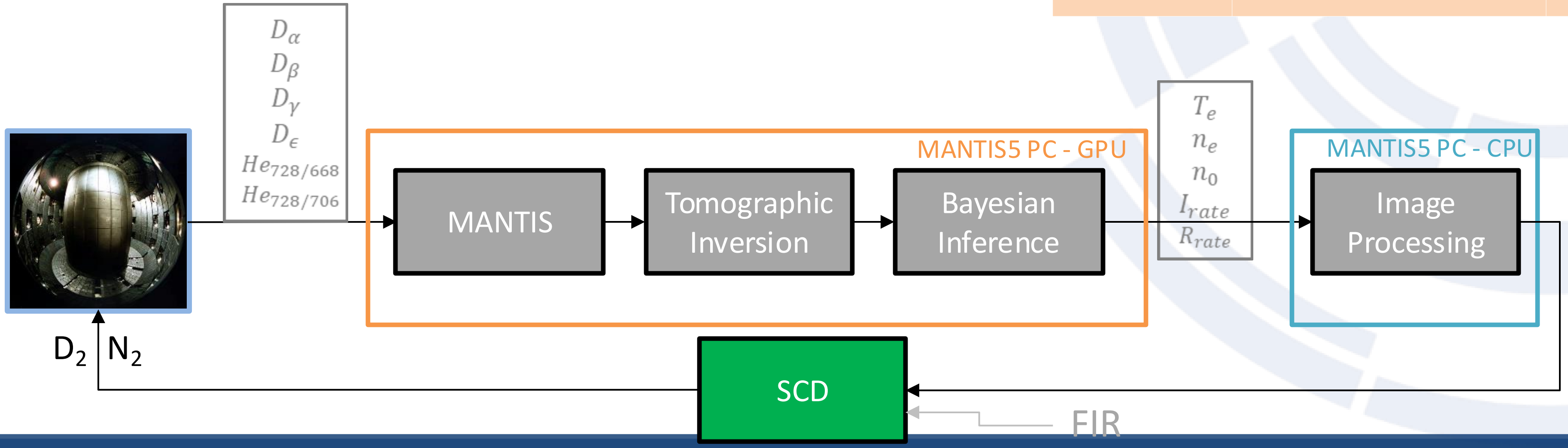
TCV: Design and test Ionization front controller with ML in the loop (2 shots), Design and test combined HeII, Ionisation, MARFE controller (1 shot), Multivariable control, including FIR measurement for core (1 shot)

MAST-U: Design and test Ionization front controller with ML in the loop (2 shots)

P1 (TCV)/ P2 (MAST-U):

Proposed pulses

Device	# Pulses/Session	# Development
AUG	0	-
MAST-U	4	0
TCV	4	0
WEST	0	0



#102: Continuation of dynamic characterization and control of the plasma exhaust

- **Proponents and contact person:**
  Gijs Derks (g.l.derks@differ.nl), Bob Kool, Thomas Bosman, Lennard Ceelen, Matthijs van Berkel, Chris Orrico, Loes Jansen, Juan Javier, Nicola Lonigro, Timo Ravensbergen
- **Scientific Background & Objectives**

Continue with the characterization of exhaust dynamics across devices such that the control-oriented models which are crucial to achieve exhaust control in future devices can be developed.

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

Strategy/goals:

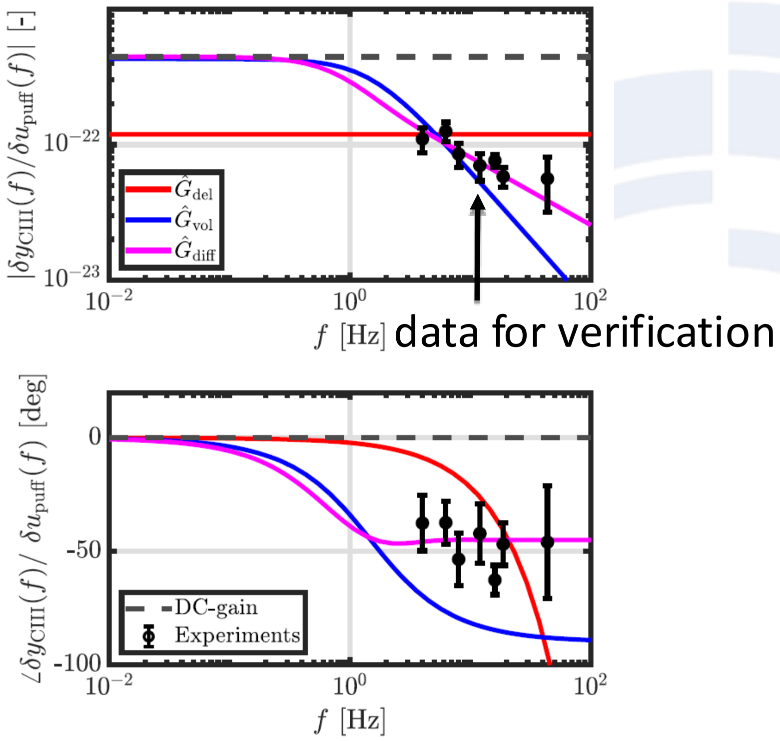
MAST-U: detachment +MIMO control with divertor/mid valve, SYSID with N_2 seeding, PFR valve, and in H-mode (ported from 2024)

TCV: System identification with N_2 seeding and midplane D2 in high-power baffled H-mode (MANTIS, APG,FIR)

AUG: upper XPR system-identification + control, L-mode D2 system-identification in support of benchmark JOREK and SOLPS, (pressure gauges, AXUV, FIR)

WEST: Identify W-wall outgassing dynamics and demonstrate long-pulse exhaust control (ported from 2024) (IR thermography, visible spectroscopy)

In general: fast (>400 Hz) core and edge diagnostics to measure the plasma response to perturbations.



*Adapted from Koenders et al 2022 Nucl. Fusion **62** 066025*

Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	-
MAST-U	31	-
TCV	6	-
WEST	14	-

#102: Continuation of dynamic characterization and control of the plasma exhaust

- **Proponents and contact person:**
  Gijs Derks (g.l.derks@differ.nl), Bob Kool, Thomas Bosman, Lennard Ceelen, Matthijs van Berkel, Chris Orrico, Loes Jansen, Juan Javier, Nicola Lonigro, Timo Ravensbergen
- **Scientific Background & Objectives**

Continue with the characterization of exhaust dynamics across devices such that the control-oriented models which are crucial to achieve exhaust control in future devices can be developed.

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

Strategy/goals:

MAST-U: detachment +MIMO control with divertor/mid valve, SYSID with N_2 seeding, PFR valve, and in H-mode (ported from 2024)

TCV: System identification with N_2 seeding and midplane D2 in high-power baffled H-mode (MANTIS, APG,FIR)

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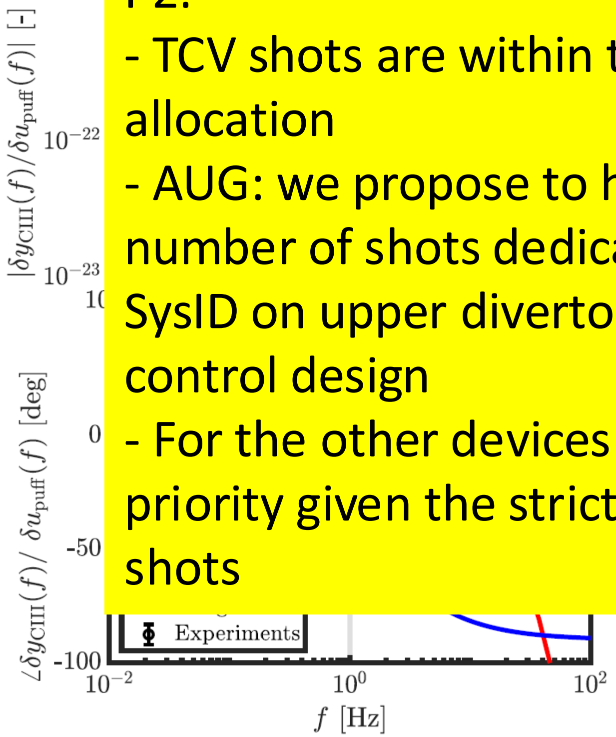

Adapted from Koenders et al 2022 Nucl. Fusion **62** 066025

P2:
- TCV shots are within the allocation
- AUG: we propose to have lower number of shots dedicated to SysID on upper divertor to help control design
- For the other devices lower priority given the strict number of shots

Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	-
MAST-U	31	-
TCV	6	-
WEST	14	-

#103: Impulsive Detachment Experiments in AUG for SOLPS-ITER and JOREK time-dependent validation

Proponents and contact person

Federico.Cursi@kuleuven.be, D.Maris@student.tue.nl, Timo.Ravensbergen@iter.org, Javier.Artola@iter.org, Xavier.Bonnin@iter.org, Richard.Pitts@iter.org, Matthias.Bernert@ipp.mpg.de, Wouter.Dekeyser@kuleuven.be, Martine.Baelmans@kuleuven.be

Scientific Background

- Timescales of detachment/reattachment transients are essential for detachment control design
- Shared effort of 2 PhDs to simulate time-dependent detachment/reattachment with SOLPS-ITER (F. Cursi, KU Leuven) and JOREK (D. Maris, DIFFER/TUe) to inform ITER detachment control
- First rigorous experimental validation of these time-dependent simulations → simple environment for modelling and extensive diagnostic coverage

Scientific Objectives

- Validate SOLPS-ITER and JOREK in time-dependent mode for transient detachment and reattachment simulations (and code comparison)
- After validation, time-dependent simulations of ITER scenarios will identify timescales of interest for detachment control design → objectives D2 and D6 of RT05

Experimental Strategy/Machine Constraints and essential diagnostic

- Impulsive **detachment** with divertor D puffs in L-mode D-only discharges (3-5 + 2-3 shots)
- Impulsive **reattachment** during N-seeded H-mode discharges with impurity gas cuts (3-5 shots)
- Extensive diagnostic coverage needed for validation:
  Langmuir probes, IR cameras, Thomson scattering (div & main chamber), Li-beams, ECE, He-beam, baratrons/ionization gauges (divertor neutral pressure), AXUV-diode bolometry, bolometry, CXRS, Divertor spectroscopy, …

Proposed pulses

Device	# Pulses/Session	# Development
AUG	6-10	2-3

#103: Impulsive Detachment Experiments in AUG for SOLPS-ITER and JOREK time-dependent validation

P2:
- Proper data mining needed before dedicated machine time
- Properly discuss feasibility of impulsive detachment in L-mode with gas only
- Focus on L-mode with reduced number of shots.

Proponents and contact person

Federico.Cursi@kuleuven.be, D.Maris@student.tue.nl, Timo.Ravensbergen@iter.org,
Richard.Pitts@iter.org, Matthias.Bernert@ipp.mpg.de, Wouter.Dekeyser@kuleuven.b

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  Langmuir probes, IR cameras, Thomson scattering (div & main chamber), Li-beams, ECE, He-beam, baratrons/ionization gauges (divertor neutral pressure), AXUV-diode bolometry, bolometry, CXRS, Divertor spectroscopy, …

Proposed pulses

Device	# Pulses/Session	# Development
AUG	6-10	2-3

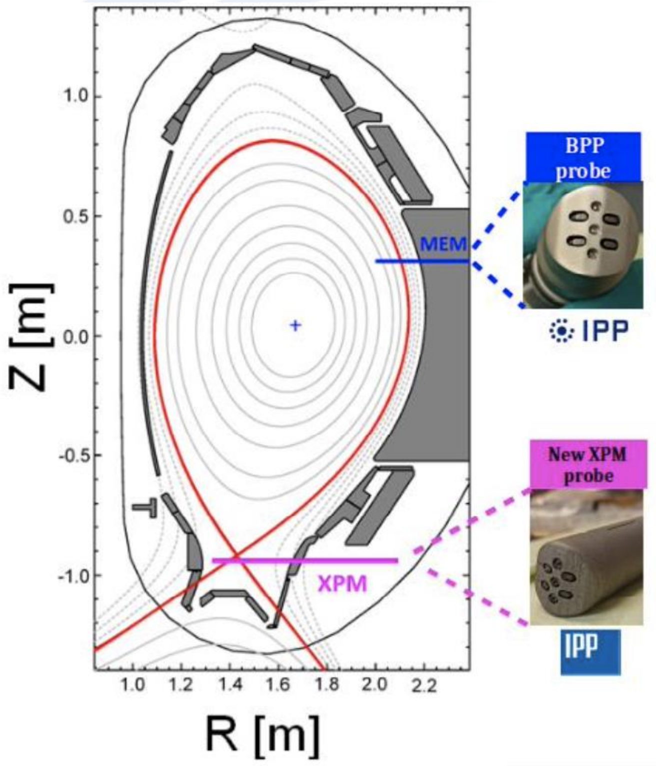
#104: Comparison of the upstream and downstream SOL ion and electron temperatures during detachment

Proponents and contact person:
J. Adamek (adamek@ipp.cas.cz), G. Grenfell,
J. Cavalier, D. Brida, A. Redl

Scientific Background:
Knowledge of Ti/Te important for calculation of heat flux to PFC. A simple assumption Ti =Te is commonly used for all plasma conditions.

Objectives:
- provide experimental results on the Ti/Te ratio with density scan up to the detachment condition at upstream and downstream locations.
- investigate the Ti evolution during ELMs within H-mode/QCE using conditionally averaged technique as well.

Experimental Strategy/Machine Constraints and essential diagnostic
- achieve L and H mode detachment regimes in AUG
- perform measurements with dedicated probe heads (see figure) at midplane and X-point locations



Proposed pulses

Device	# Pulses/Session	# Development
AUG	6	3
MAST-U	0	0
TCV	0	0
WEST	0	0

#104: Comparison of the upstream and downstream SOL ion and electron temperatures during detachment

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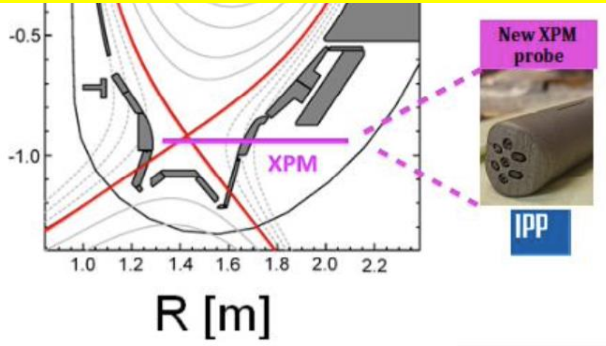
Experimental Strategy/Machine Constraints and essential diagnostic
- achieve L and H mode detachment regimes in AUG
- perform measurements with dedicated probe heads (see figure) at midplane and X-point locations

P2:
- Midplane MEM analysis should be done as PB w.r.t. general investigation of far SOL in H-Mode detachment (also XPR).
- Reduced number of shots at lower power to have both MEM and XP probe operational



Proposed pulses

Device	# Pulses/Session	# Development
AUG	6	3
MAST-U	0	0
TCV	0	0
WEST	0	0

#105: ELM buffering in conventional divertor configuration including real-time control

[Komm NF 2023]

- **Proponents and contact person:**

Michael Komm (komm@ipp.cas.cz), Stuart Henderson, Michael Faitsch Davide Silvagni , Matthias Bernert, Ondrej Kudlacek, Miguel Astrain

- **Scientific Background & Objectives**

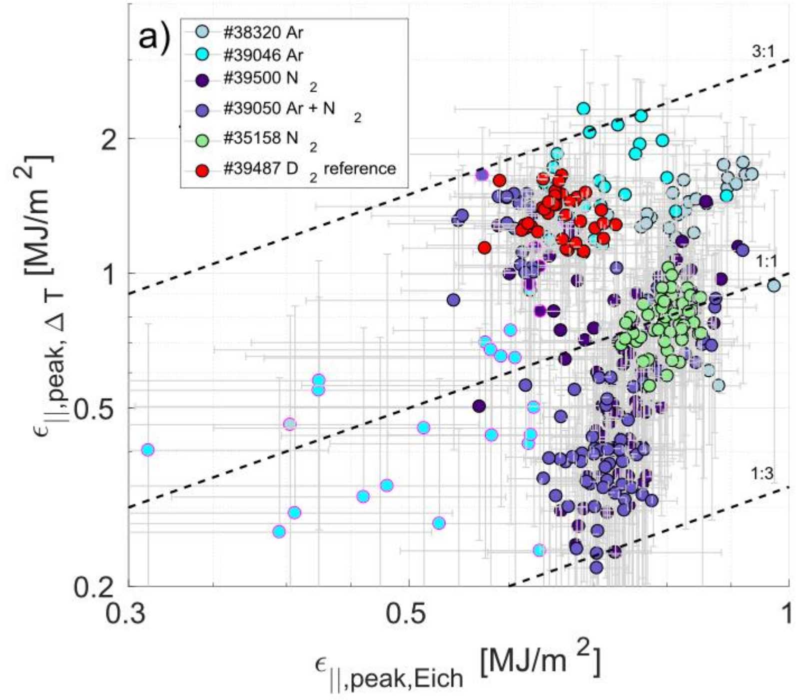
Directly linked to RT05-22: D5

- **Objectives at AUG**

1. Simultaneous observation ELM impact on both divertor targets by IR camera (at the top divertor)
2. Measurements of Te in ELM filaments by recipr. manipulators
3. Effect of divertor closure - comparison between ELM buffering in the bottom closed divertor and open upper divertor
4. Optimisation of the impurity mixture for simultaneous high ELM buffering and good confinement
5. **Development of a real-time controller for the ELM impacting energy/fluence using shunt current measurements**
6. Effect of seeding termination on the duration of ELM buffering **Objectives at MAST-U**
7. Develop an ELM buffering scenario both for the conventional and long divertor leg

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

- Type I ELMy plasma with the AUG lowe rand upper divertor
- Divertor IR thermography
- Stable H-mode scenario with impurity seeding at MAST-U



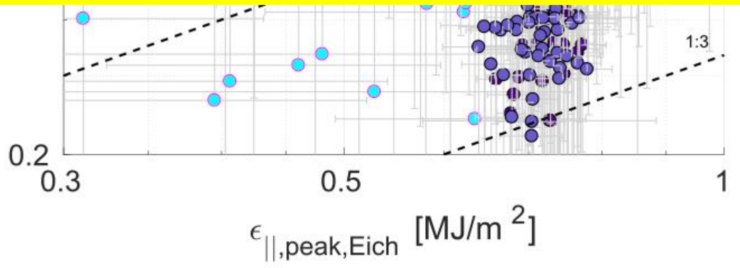
Proposed pulses

Device	# Pulses/Session	# Development
AUG	13 pulses	9 pulses
MAST-U	5 pulses	10 pulses
TCV		
WEST		

#105: ELM buffering in conventional divertor configuration including real-time control

[Komm NF 2023]

P1 (AUG)/P2(MAST-U):
- Required for fulfillment of one of the TE Enhancement project on AUG
- Schedule shots according to the progress of the hardware and programming on AUG
- Minimize the shot consumption



- **Proponents and contact person:**

Michael Komm (komm@ipp.cas.cz), Stuart Henderson, Michael Faitsch Davide Silvagni , Matthias Bernert, Ondrej Kudlacek, Miguel Astrain

- **Scientific Background & Objectives**

Directly linked to RT05-22: D5

- **Objectives at AUG**

1. Simultaneous observation ELM impact on both divertor targets by IR camera (at the top divertor)
2. Measurements of Te in ELM filaments by recipr. manipulators
3. Effect of divertor closure - comparison between ELM buffering in the bottom closed divertor and open upper divertor
4. Optimisation of the impurity mixture for simultaneous high ELM buffering and good confinement
5. **Development of a real-time controller for the ELM impacting energy/fluence using shunt current measurements**
6. Effect of seeding termination on the duration of ELM buffering **Objectives at MAST-U**
7. Develop an ELM buffering scenario both for the conventional and long divertor leg

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

- Type I ELMy plasma with the AUG lowe rand upper divertor
- Divertor IR thermography
- Stable H-mode scenario with impurity seeding at MAST-U

Proposed pulses

Device	# Pulses/Session	# Development
AUG	13 pulses	9 pulses
MAST-U	5 pulses	10 pulses
TCV		
WEST		

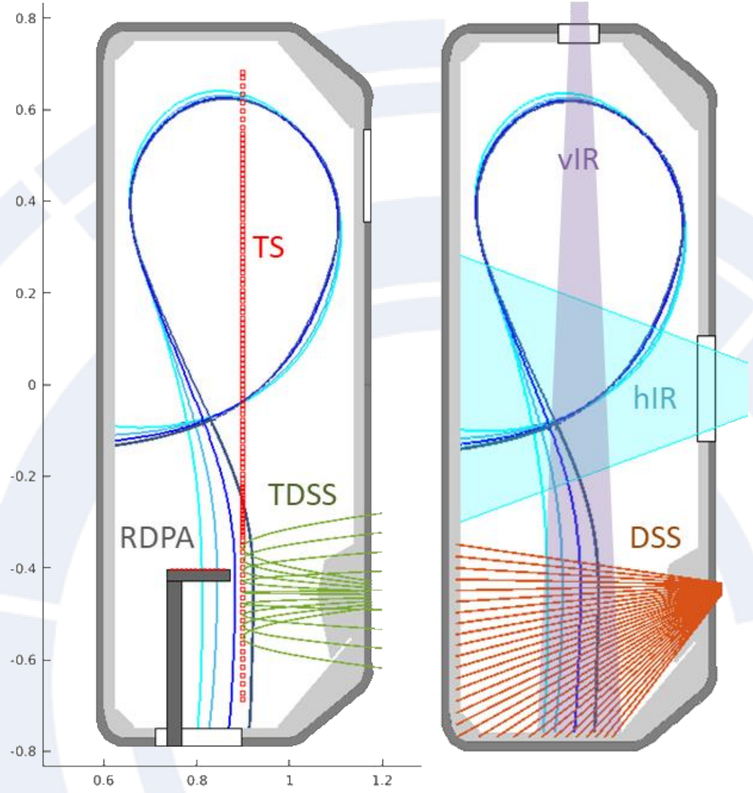
#106: Flow characterization in the divertor

- **Proponents and contact person:**
  massimo.carpita@epfl.ch
  richard.ducker@epfl.ch
  m.j.h.cornelissen@tue.nl

- **Scientific Background & Objectives**
  - Perform multi-device (TCV, MAST-U, AUG*) characterization of the parallel plasma flows along the divertor in L-mode and H-mode.
  - Evaluate the influence on parallel flows in the divertor with respect to
    - ❖ field direction (drifts)
    - ❖ divertor regime (attached / detached), closure & pumping
    - ❖ detachment strategy: seeded impurity and fuelling location

- **Experimental Strategy and essential diagnostics**
  - [TCV] L-mode for best diagnosed scenario to develop in-depth understanding of the physics and testbed for diagnostics:
    - ❖ TDSS – including new LoS arrangement
    - ❖ CIS – benchmark new diagnostic for 2D flows
    - ❖ RDPA – 2D Langmuir probe measurements
    - ❖ MANTIS & TS – 2D plasma quantities

  - H-mode to characterize divertor flows for reactor-relevant scenarios.



Proposed pulses

Device	# Pulses/Session	# Development
AUG	5*	
MAST-U	10	
TCV	20	
WEST		

#106: Flow characterization in the divertor

- **Proponents and contact person:**

massimo.carpita@epfl.ch
richard.ducker@epfl.ch
m.j.h.cornelissen@tue.nl

- **Scientific Background & Objectives**
  - Perform multi-device (TCV, MAST-U, AUG*) characterization of the parallel plasma flows along the divertor in L-mode and H-mode.
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    - ❖ MANTIS & TS – 2D plasma quantities
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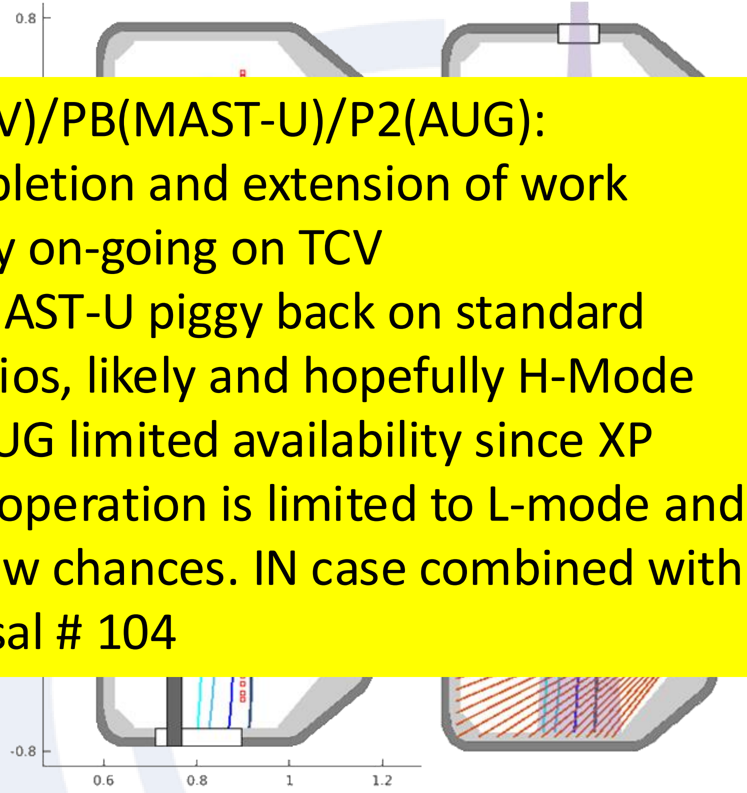


P1 (TCV)/PB(MAST-U)/P2(AUG):
- Completion and extension of work already on-going on TCV
- for MAST-U piggy back on standard scenarios, likely and hopefully H-Mode
- for AUG limited availability since XP probe operation is limited to L-mode and very low chances. IN case combined with proposal # 104

Proposed pulses

Device	# Pulses/Session	# Development
AUG	5*	
MAST-U	10	
TCV	20	
WEST		

#107: X-point radiator high confinement experiment

- **Proponents and contact person:**

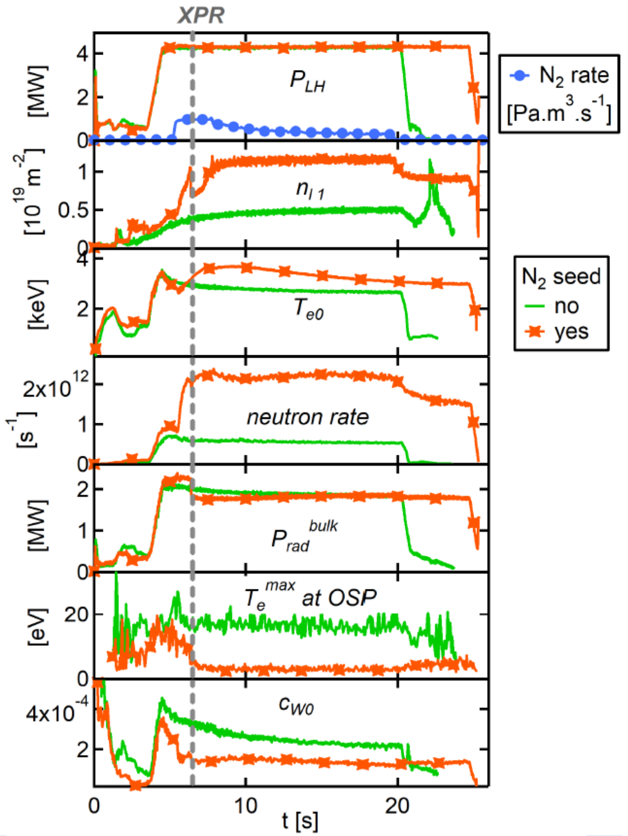
Jorge Morales (jorge.morales2@cea.fr), Patrick Maget, Gregor Birkenmeier, Nicolas Rivals, Eléonore Geulin, Jean Cazabonne, Theo Fonghetti, Pierre Manas, Rémi Dumont, Annika Ekedahl, Léna Delpech, Julien Hillairet, Laure Vermare, Loïc Schiesko, Samuele Mazzi, Nicolas Fedorczak, Alexandre Fil, Jamie Gunn, Laurent Colas, Jean-François Artaud, Philippe Moreau, Xavier Litaudon, Sascha Rienacker, Pascale Hennequin

- **Scientific Background & Objectives**
- **Background**: Study of light impurities effect on L-H transition (and back transition) is important for ITER. XPR plasmas have been studied in several machines as ASDEX and TCV **[Bernert, NF, 2020 and NME, 2023]**. Also in WEST, several studies of L-mode XPR plasmas, in different magnetic configurations (LSN and DN), have been carried out **[Rivals, NME, 2024]**. More studies are needed to confirm and expand previous findings in order to derisk ITER baseline.
- **Questions addressed**:
    - What is the impact of light impurities on L-H, H-L transitions in an attached plasma interacting with a full tungsten wall?
    - Starting with a plasma in X-point radiator (XPR) regime, how L-H, H-L transitions and H-mode vary?
    - Is it possible to keep a XPR plasma from L to H-mode using, the already developed, WEST real-time XPR control scheme?
- **Experimental Strategy/Machine Constraints and essential diagnostic**

1. Scan in nitrogen impurity seeding in order to increase Z_{eff}, but without entering XPR regime. Also perform power scan, characterize L-H transition and H-mode.
2. Enter XPR state. Then, increase power to trigger L-H transition, evaluate the changes on L-H transition dynamics and divertor behavior.
3. With WEST real-time XPR control strategy, keep XPR from L to fully developed H-mode.

- Main diagnostics: X-point interferometry, Langmuir probes, Thomson scattering (edge and core), Z_{eff} from bremsstrahlung, bolometry and Doppler reflectometry.

Fig. measurements for pulses with (#58089) and without (#58072) nitrogen seeding. The transition time to the XPR regime is indicated with a vertical dashed line (notice that neutron rate and T_{e0} increase before entering XPR, only with Z_{eff} change effect).



Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV		
WEST	40/2	10

#107: X-point radiator high confinement experiment

- **Proponents and contact person:**

Jorge Morales (jorge.morales2@cea.fr), Patrick Maget, Gregor Birkenmeier, Nicolas Rivals, Eléonore Geulin, Jean Cazabonne, Theo Fonghetti, Pierre Manas, Rémi Dumont, Annika Ekedahl, Léna Delpech, Julien Hillairet, Laure Vermare, Loïc Schiesko, Samuele Mazzi, Nicolas Fedorczak, Alexandre Fil, Jamie Gunn, Laurent Colas, Jean-François Artaud, Philippe Moreau, Xavier Litaudon, Sascha Rienacker, Pascale Hennequin

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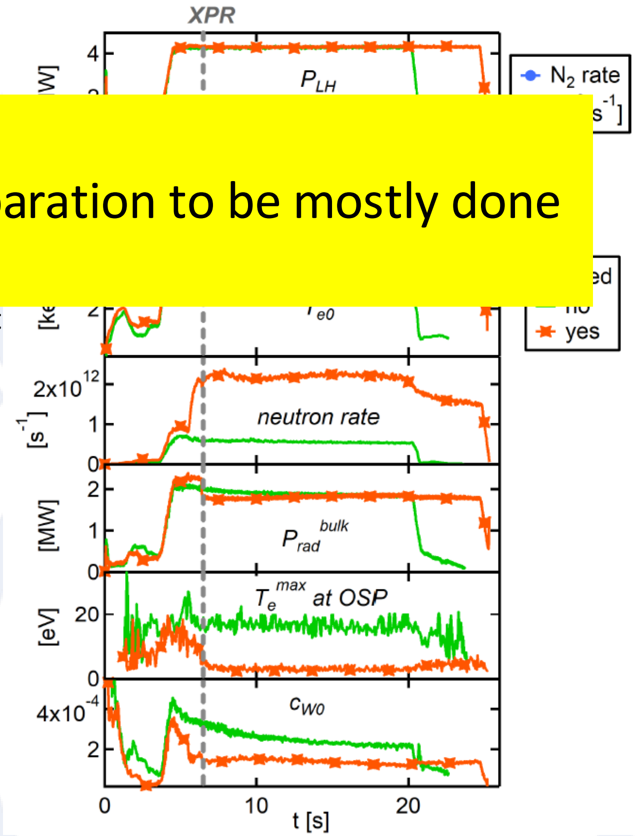
- **Experimental Strategy/Machine Constraints and essential diagnostic**

1. Scan in nitrogen impurity seeding in order to increase Z_{eff}, but without entering XPR regime. Also perform power scan, characterize L-H transition and H-mode.
2. Enter XPR state. Then, increase power to trigger L-H transition, evaluate the changes on L-H transition dynamics and divertor behavior.
3. With WEST real-time XPR control strategy, keep XPR from L to fully developed H-mode.

- Main diagnostics: X-point interferometry, Langmuir probes, Thomson scattering (edge and core), Z_{eff} from bremsstrahlung, bolometry and Doppler reflectometry.

P2:
- Scenario preparation to be mostly done internally

(#58089) and without (#58072) nitrogen seeding. The transition time to the XPR regime is indicated with a vertical dashed line (notice that neutron rate and T_{e0} increase before entering XPR, only with Z_{eff} change effect).



Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV		
WEST	40/2	10

#108: Investigating the physics of divertor plasma-neutral interactions

- **Proponents and contact person:**

Kevin Verhaegh, et al. (kevin.verhaegh@ukaea.uk)

- **Scientific Background & Objectives**

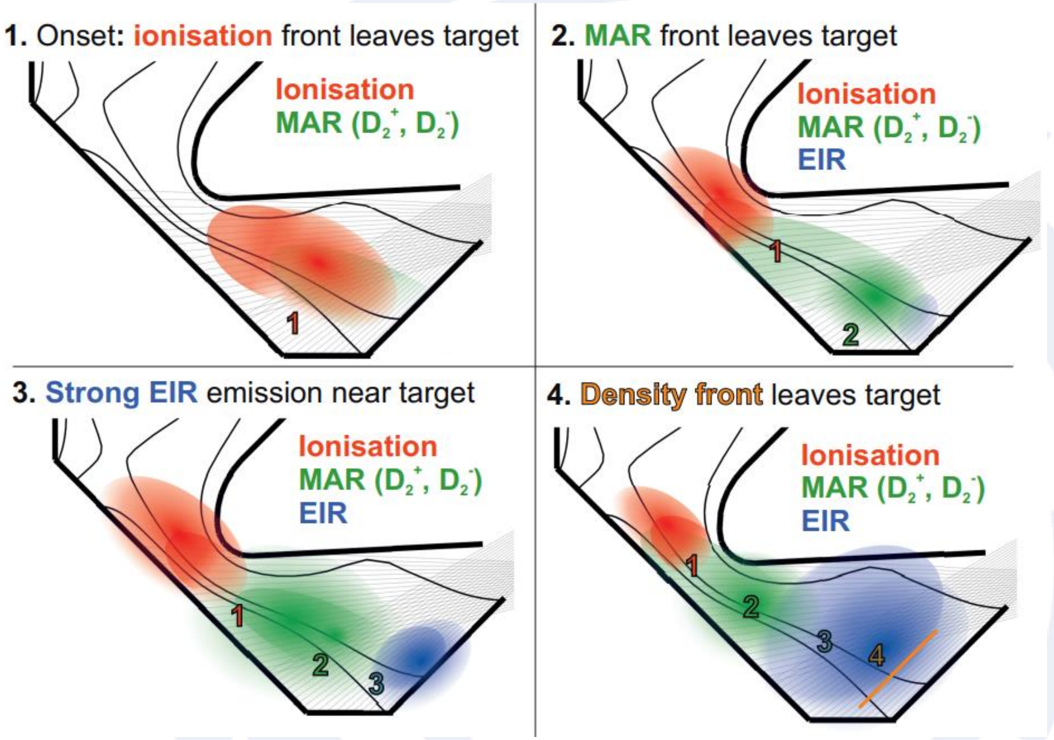
- Plasma-neutral interactions key to detachment, however not properly treated in simulations
- Recent studies show importance of plasma-molecular interactions on TCV, MAST-U and JET

Goals:

1. Develop common strategies to diagnose plasma-neutral (atom & molecular) interactions.
2. Develop understanding of impact plasma-neutral interactions as function of: 2.1) divertor shape; 2.2) target material; 2.3) molecular transport; 2.4) neutral trapping / baffling
3. Perform analysis on multiple devices (TCV, MAST-U, WEST, AUG (start with historical data))

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

- Finalise ongoing work if required (TCV/MAST-U) and start WEST investigations
- New: investigate plasma-neutral interactions in H-mode
- New: investigate plasma-neutral interactions during extrinsic seeding



Proposed pulses

Device	# Pulses/Session	# Development
AUG	?	?
MAST-U	20	6
TCV	20	3
WEST	15	5

#108: Investigating the physics of divertor plasma-neutral interactions

- **Proponents and contact person:**

  Kevin Verhaegh, et al. (kevin.verhaegh@ukaea.uk)

- **Scientific Background & Objectives**

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- Recent studies show importance of plasma-molecular interactions on TCV, MAST-U and JET

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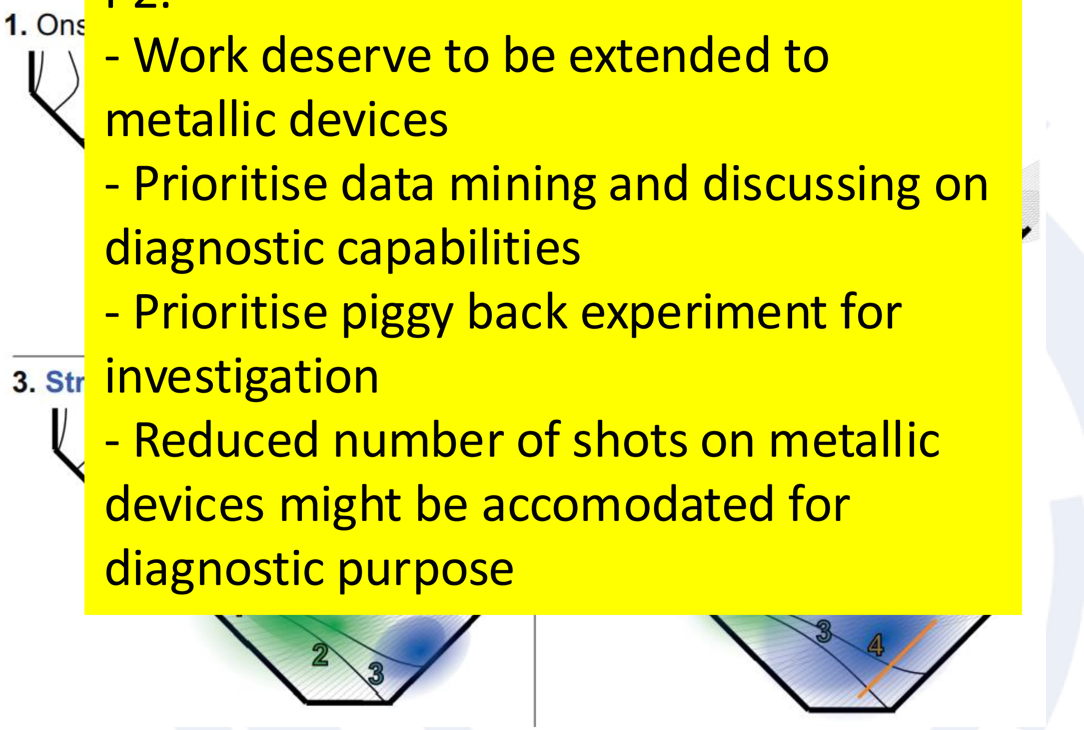


P2:
- Work deserve to be extended to metallic devices
- Prioritise data mining and discussing on diagnostic capabilities
- Prioritise piggy back experiment for investigation
- Reduced number of shots on metallic devices might be accomodated for diagnostic purpose

Proposed pulses

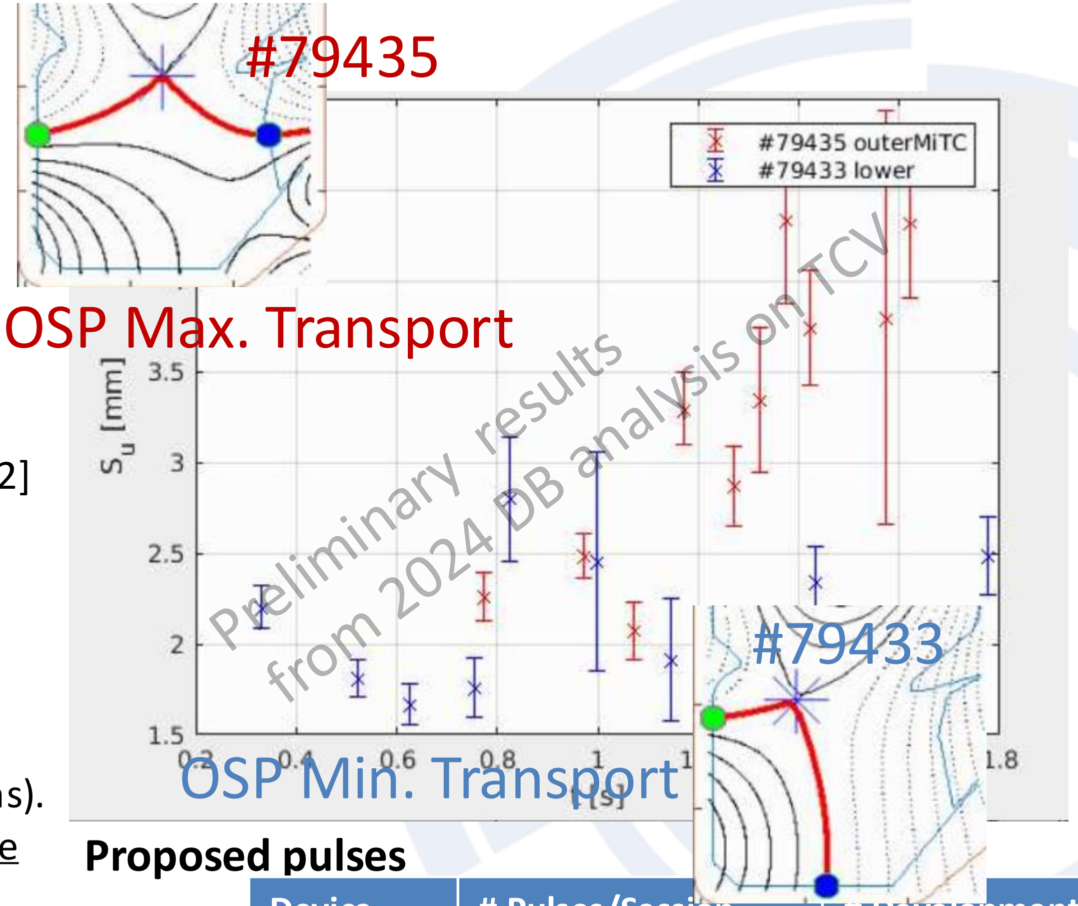
Device	# Pulses/Session	# Development
AUG	?	?
MAST-U	20	6
TCV	20	3
WEST	15	5

#109: Effect of divertor turbulence on the heat load footprint

- **Proponents and contact person:**
  - Marco.Cavedon@unimib.it
  - Dominik.Brida@ipp.mpg.de
  - Michael.Faitsch@ipp.mpg.de

- **Scientific Background & Objectives:**
  - Understand Heat Load Spreading dependencies turbulent transport: relative alignment of ∇p and κ on TCV [Walden, 2022]
  - E x B drifts and flux expansion thanks to the new AUG upper divertor and improved diagnostics

- **Experimental Strategy/Machine Constraints and essential diagnostic:**
  - TCV: Inner strike scans in L-mode density ramp (shot repetitions). <u>Preliminary encouraging results from the outer leg analysis (see figure, 2024 db analysis)!</u>
  - AUG: L-mode density ramp towards detach. from "welding torch" to X-div + change of Bt/Ip
  - AUG: same scans as in L-mode but N-seeding with constant density



Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	2
MAST-U		
TCV	4	2
WEST		

#109: Effect of divertor turbulence on the heat load footprint

- **Proponents and contact person:**
  - Marco.Cavedon@unimib.it
  - Dominik.Brida@ipp.mpg.de
  - Michael.Faitsch@ipp.mpg.de

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- **Experimental Strategy/Machine Constraints and essential diagnostic:**
  - TCV: Inner strike scans in L-mode density ramp (shot repetitions). Preliminary encouraging results from the outer leg analysis (see figure, 2024 db analysis)!
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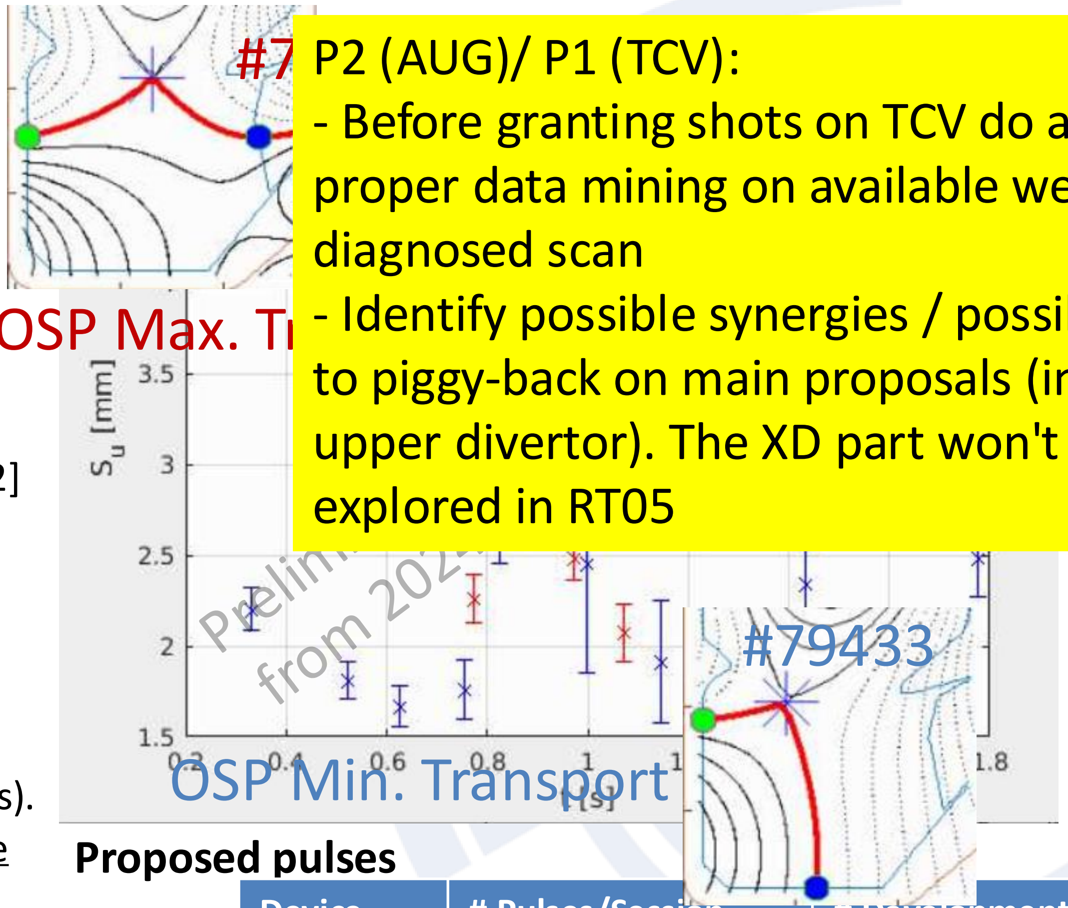


P2 (AUG)/ P1 (TCV):
- Before granting shots on TCV do a proper data mining on available well diagnosed scan
- Identify possible synergies / possibility to piggy-back on main proposals (in the upper divertor). The XD part won't be explored in RT05

Proposed pulses

Device	# Pulses/Session	# Development
AUG	10	2
MAST-U		
TCV	4	2
WEST		

#110: Investigating the impact of divertor conditions, including impurity seeding, on broadening of the scrape-off-layer power channel

- **Proponents and contact person:**

peter.ryan@ukaea.uk, k.h.a.verhaegh@tue.nl, stuart.henderson@ukaea.uk, david.moulton@ukaea.uk

See proposal for the full list

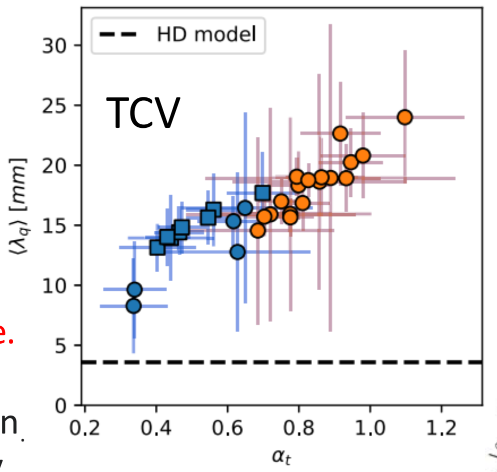
- **Scientific Background & Objectives**

- A broad SOL power channel is favourable for reducing the peak heat flux entering the divertor(s), but it could be detrimental for the first wall lifetime.
- Perform an α_t (normalised midplane collisionality) scan on MAST-U and investigate the impact on near-SOL λ_T and λ_n, and density shoulder formation.
- In particular, test the Z_{eff} dependence in α_t through a multimachine impurity seeding.
- Correlate broadening of near-SOL λ_T and λ_n with turbulence measurements.

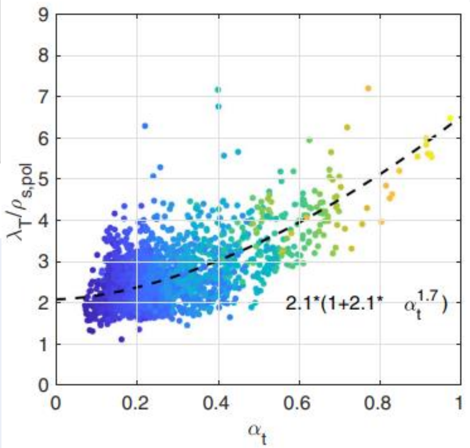
- **Experimental Strategy/Machine Constraints and essential diagnostic**

- MAST-U: CD double-null, scan of α_t using midplane fuelling, divertor pressure scan, impurity seeding scan; H-mode if scenarios developed otherwise L-mode.
- AUG: H-mode CD single-null, impurity seeding scan.
- TCV: H-mode CD single-null; scan of α_t without baffles; impurity seeding scan with SILO baffles.
- High resolution midplane TS, target IR thermography, far-SOL midplane reciprocating probe.

A. Stagni *et al* 2022 *Nucl. Fusion* **62** 096031



T. Eich *et al* 2020 *Nucl. Fusion* **60** 056016



Proposed pulses

Device	# Pulses/Session	# Development
AUG	5	0
MAST-U	15	5
TCV	10	0
WEST		

#110: Investigating the impact of divertor conditions, including impurity seeding, on broadening of the scrape-off-layer power channel

- **Proponents and contact person:**

peter.ryan@ukaea.uk, k.h.a.verhaegh@tue.nl, stuart.henderson@ukaea.uk, david.moulton@ukaea.uk

See proposal for the full list

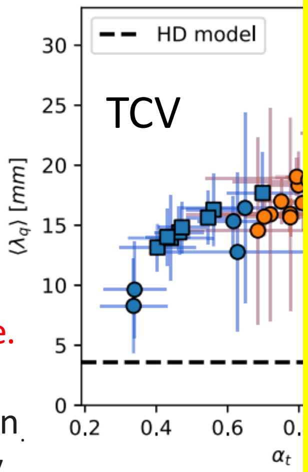
- **Scientific Background & Objectives**

➢ A broad SOL power channel is favourable for reducing the peak heat flux entering the divertor(s), but it could be detrimental for the first wall lifetime.
➢ Perform an α_t (normalised midplane collisionality) scan on MAST-U and investigate the impact on near-SOL λ_T and λ_n, and density shoulder formation.
➢ In particular, test the Z_{eff} dependence in α_t through a multimachine impurity seeding.
➢ Correlate broadening of near-SOL λ_T and λ_n with turbulence measurements.

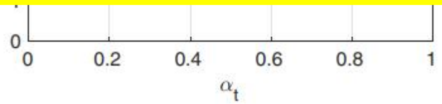
- **Experimental Strategy/Machine Constraints and essential diagnostic**

➢ MAST-U: CD double-null, scan of α_t using midplane fuelling, divertor pressure scan, impurity seeding scan; H-mode if scenarios developed otherwise L-mode.
➢ AUG: H-mode CD single-null, impurity seeding scan.
➢ TCV: H-mode CD single-null; scan of α_t without baffles; impurity seeding scan with SILO baffles.
➢ High resolution midplane TS, target IR thermography, far-SOL midplane reciprocating probe.

A. Stagni *et al* 2022 *Nucl.*



PB:
- Proper data mining needed particularly on TCV where baffle/unbaffled and divertor shapes data are already available
- If any specific scan well tailored needed accommodation of shots on TCV
- on AUG mainly piggyback/combined with Proposal #119
- on MAST-U piggyback



Proposed pulses

Device	# Pulses/Session	# Development
AUG	5	0
MAST-U	15	5
TCV	10	0
WEST		

#111: Investigation of seeding location on impurity distribution, compression and core contamination

- **Proponents and contact person:**
  Riccardo.morgan@epfl.ch et al.

- **Scientific Background & Objectives**
  - SOLPS simulations predicting very different behavior in impurity distribution for different poloidal seeding locations
  - Experimental indications of toroidal asymmetries caused by non axisymmetric (localized) impurity seeding

  - Investigate the role of seeding location on impurity distribution/compression, access to detachment and core contamination
  - Compare experimental measurements, including the 2D emission distribution, to SOLPS predictions

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

- Repeat same LSN, L-mode shot while changing poloidal location of seeding valve: HFS main chamber, HFS divertor, HFS inclined tile, LFS inclined tile, LFS divertor (5 shots + 2 for reproducibility). Investigation with NINO and SILO baffling (14 shots total).

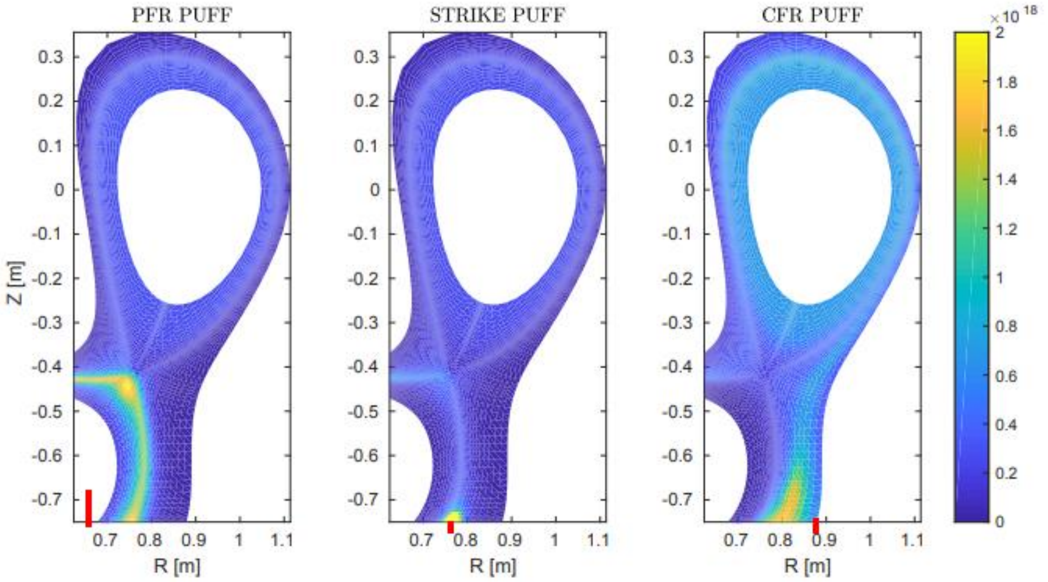
  - Compare nitrogen emission with MANTIS, bolometry, DSS

  - Compare effects on heat fluxes with LPs, IR camera

- Repeat same LSN, L-mode shot while changing toroidal location of seeding valve: toroidal angles 48, 111, 214, 310 (4 shots + 1 for reproducibility)

  - Compare diagnostics signal with changing seeding location

- Compare the shots with new and/or existing SOLPS-ITER simulations



Proposed pulses

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

#111: Investigation of seeding location on impurity distribution, compression and core contamination

- **Proponents and contact person:**
  Riccardo.morgan@epfl.ch et al.

- **Scientific Background & Objectives**
  - SOLPS simulations predicting very different behavior in impurity distribution for different poloidal seeding locations
  - Experimental indications of toroidal asymmetries caused by non axisymmetric (localized) impurity seeding
  - Investigate the role of seeding location on impurity distribution/compression, access to detachment and core contamination
  - Compare experimental measurements, including the 2D emission distribution, to SOLPS predictions

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- Repeat same LSN, L-mode shot while changing poloidal location of seeding valve: HFS main chamber, HFS divertor, HFS inclined tile, LFS inclined tile, LFS divertor (5 shots + 2 for reproducibility). Investigation with NINO and SILO baffling (14 shots total).

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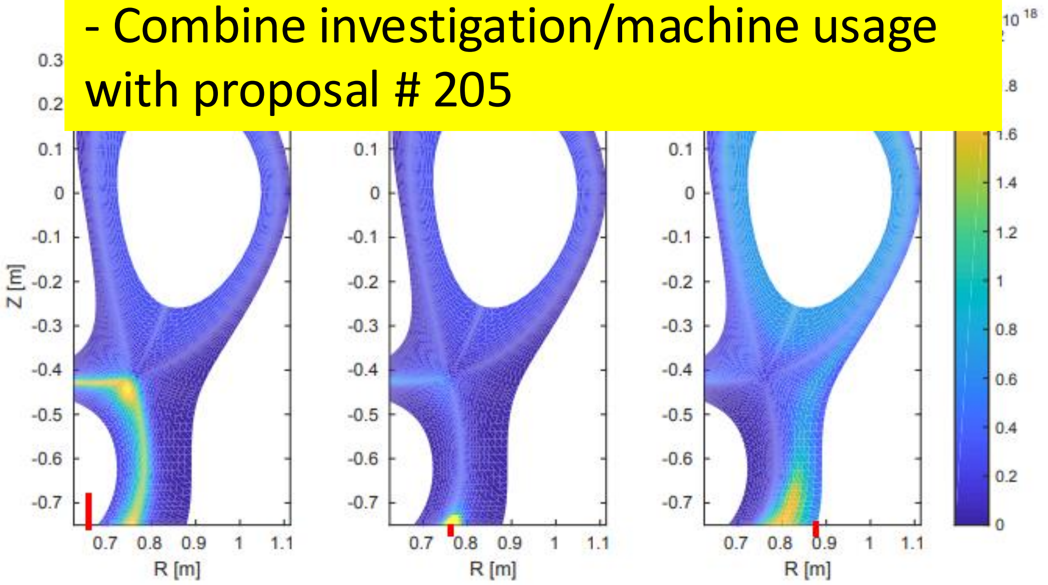
  - Compare diagnostics signal with changing seeding location

- Compare the shots with new and/or existing SOLPS-ITER simulations

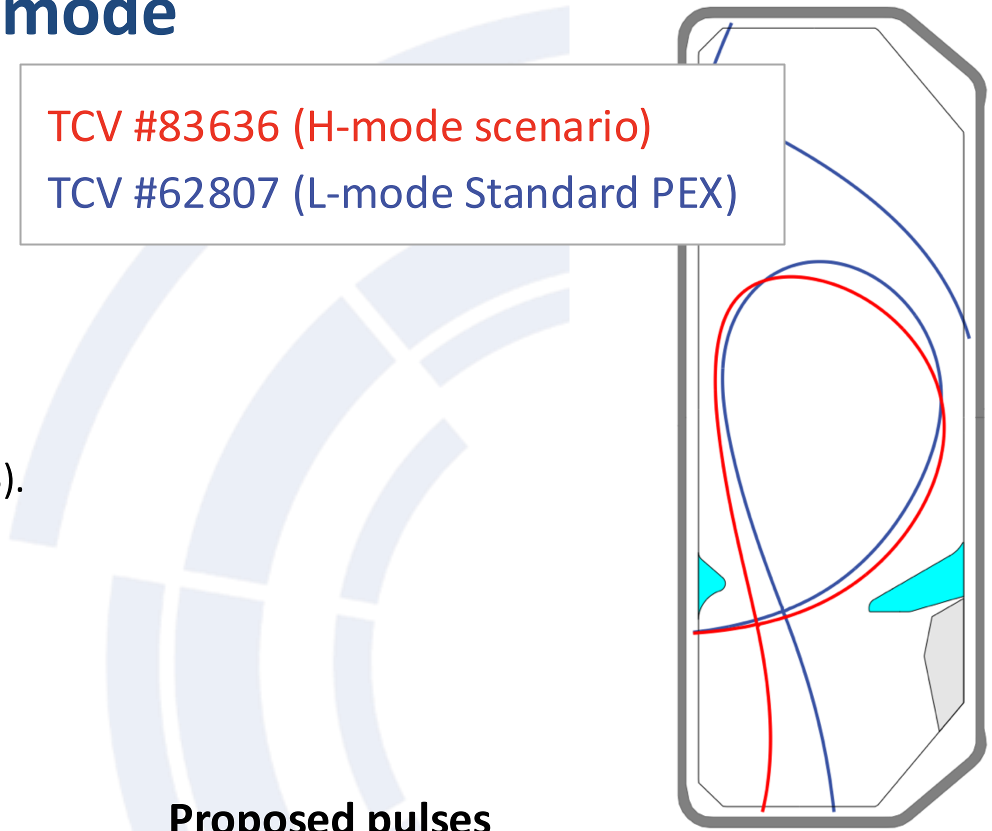
P1:
- Combine investigation/machine usage with proposal # 205



Proposed pulses

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

#112: Power EXhaust (PEX) database in H-mode for SOLPS-ITER validation



Proponents and contact person:

- Elena Tonello, elena.tonello@epfl.ch
- Holger Reimerdes, holger.reimerdes@epfl.ch

Scientific Background & Objectives

TCV and its PEX upgrade as testbed for numerical edge-plasma codes (SOLPS). Previous work has generated extensive experimental and simulation data for L-mode scenarios with all baffle configurations.

- Characterise power exhaust under reactor-relevant plasma conditions and high-performance scenarios (D1).
- Direct comparison of L-mode and H-mode power exhaust properties.
- Systematic comparison of experiments with SOLPS-ITER modelling to quantify edge-SOL particles, heat transport, interaction with neutrals and impurities (D3).

Experimental Strategy/Machine Constraints and essential diagnostic

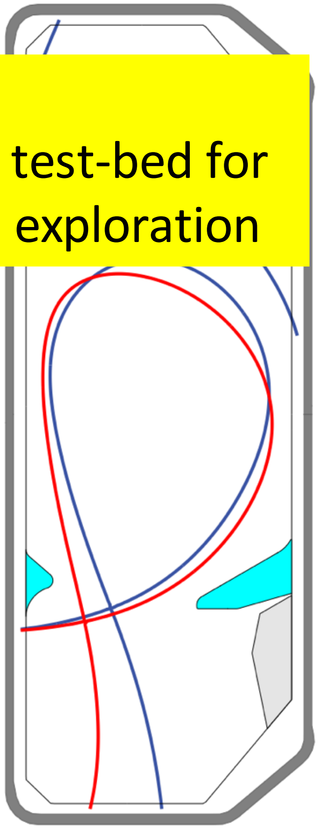
- Develop a robust H-mode scenario comparable with all baffle sets, minimizing inner baffle and main chamber plasma-wall interaction compared to the existing H-mode scenarios in TCV.
- Heating power: X2 ECH and NBI-1
- Standard PEX diagnostics (LPs, IR cameras, MANTIS, BOLO…)

Proposed pulses

AUG		
MAST-U		
TCV	20	10
WEST		

#112: Power EXhaust (PEX) database in H-mode for SOLPS-ITER validation

P1:
- Scenario will represent the test-bed for code validation and H-mode exploration



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- Systematic comparison of experiments with SOLPS-ITER modelling to quantify edge-SOL particles, heat transport, interaction with neutrals and impurities (D3).

Experimental Strategy/Machine Constraints and essential diagnostic

- Develop a robust H-mode scenario comparable with all baffle sets, minimizing inner baffle and main chamber plasma-wall interaction compared to the existing H-mode scenarios in TCV.
- Heating power: X2 ECH and NBI-1
- Standard PEX diagnostics (LPs, IR cameras, MANTIS, BOLO…)

Proposed pulses

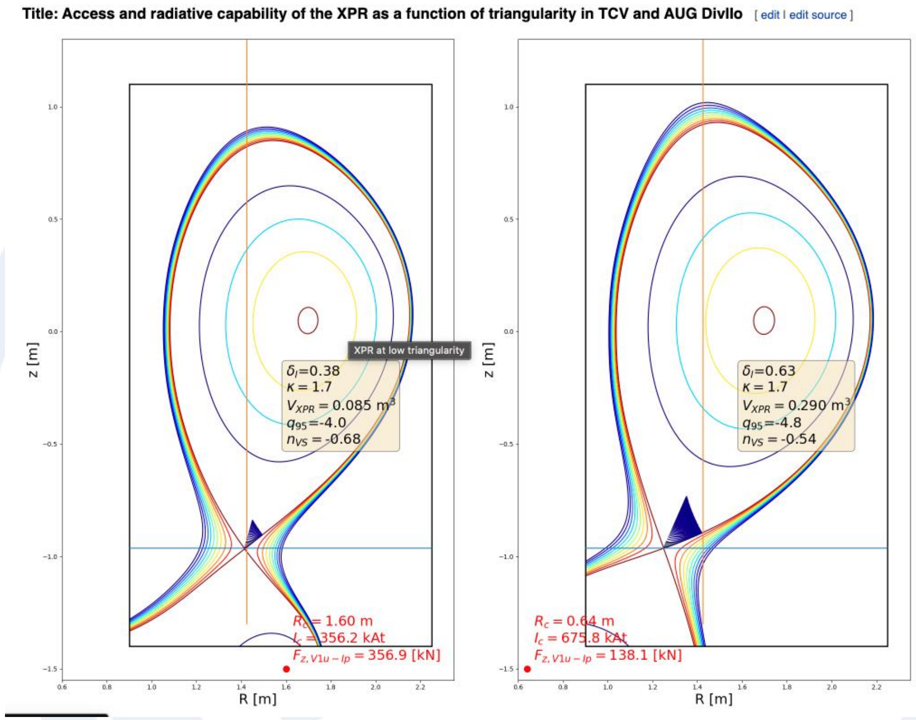
AUG		
MAST-U		
TCV	20	10
WEST		

#113: Access and radiative capability of the XPR as a function of triangularity in TCV and AUG DivIIo

- **Proponents and contact person:**

  T. Lunt et al.

- **Scientific Background & Objectives**
  - According to simple analytic considerations based on the XPR model developed by U.Stroth the accessibility as well as the radiative capability of the XRP should strongly depend on triangularity.
- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Scan the impurity seeding rate / density at different triangularities in TCV
  - Scan the impurity seeding rate / density at different triangularities in AUG
  - The following numerical and analytical tools are at our hand to analyze the experimental results
    - XPR model by U.Stroth
    - SOLPS-ITER
    - EMC3-EIRENE



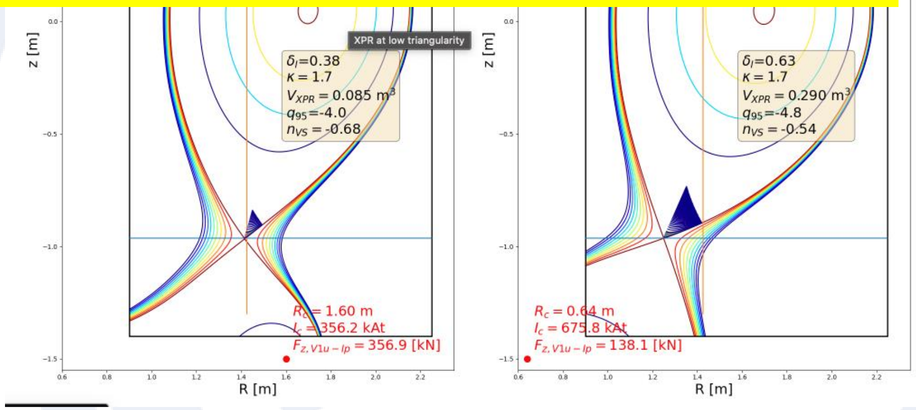
AUG	5	
MAST-U		
TCV	5	
WEST		

#113: Access and radiative capability of the XPR as a function of triangularity in TCV and AUG DivIIo

P1 (TCV)/P2(AUG):
- Look for combination with proposal #99
- Limit the scan of triangularity to bare minimum for AUG

- **Proponents and contact person:**
  T. Lunt et al.

- **Scientific Background & Objectives**
  - According to simple analytic considerations based on the XPR model developed by U.Stroth the accessibility as well as the radiative capability of the XRP should strongly depend on triangularity.
- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Scan the impurity seeding rate / density at different triangularities in TCV
  - Scan the impurity seeding rate / density at different triangularities in AUG
  - The following numerical and analytical tools are at our hand to analyze the experimental results
    - XPR model by U.Stroth
    - SOLPS-ITER
    - EMC3-EIRENE



AUG	5	
MAST-U		
TCV	5	
WEST		

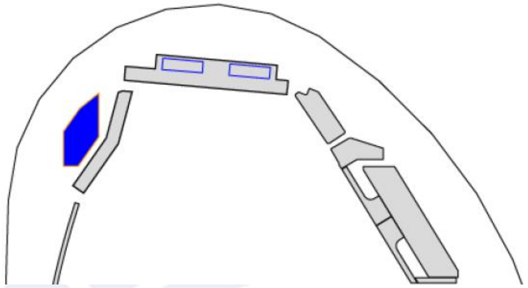
#114: XPR and CRD in open vs closed divertor – Neutral compression and Helium pumping

- **Proponents and contact person:**

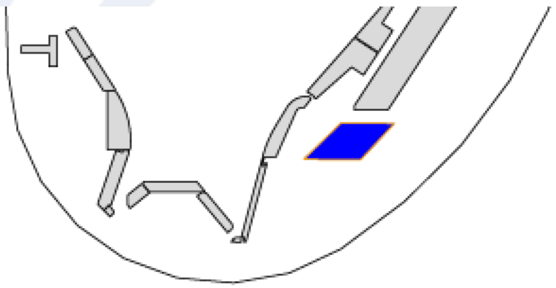
  M. Bernert, T. Lunt, A. Zito, A. Kappatou, D. Brida, H. Reimerdes, M. Griener, O. Pan, M. Faitsch, A. Kallenbach, U. Stroth, S. Henderson

- **Scientific Background & Objectives**
  - The new AUG divertor offers to compare open (USN) and closed (LSN) divertor geometries. With the XPR and notably the CRD, the neutral compression could be maintained despite full detachment. Therefore the neutral compression and He exhaust has to be further understood in these scenarios.
  - A stable XPR regime has not yet been developed on MAST-U, although initial attempts were made during the previous campaign. Given MAST-U’s ability to operate with both open and closed divertor geometries, we plan to continue developing the XPR scenario in both configurations, enabling comparison with AUG results

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Experiments in USN and LSN with XPR and CRD (both in standard SN divertor configuration) with and without cryo pumps and with He puffs
  - The CRD distance to the target should be varied to identify the optimum for neutral compression and potentially He exhaust
  - Open divertor configuration needs to be developed on MAST-U, and XPR existence will be gauged using IRVB poloidal reconstructions



Upper open vs lower closed divertor w/ cryo pumps



Proposed pulses

Device	# Pulses/Session	# Development
AUG	13	9
MAST-U	12	12
TCV		
WEST		

#114: XPR and CRD in open vs closed divertor – Neutral compression and Helium pumping

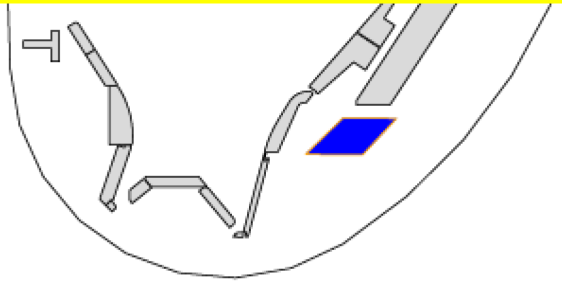
- **Proponents and contact person:**

  M. Bernert, T. Lunt, A. Zito, A. Kappatou, D. Brida, H. Reimerdes, M. Griener, O. Pan, M. Faitsch, A. Kallenbach, U. Stroth, S. Henderson

- **Scientific Background & Objectives**
  - The new AUG divertor offers to compare open (USN) and closed (LSN) divertor geometries. With the XPR and notably the CRD, the neutral compression could be maintained despite full detachment. Therefore the neutral compression and He exhaust has to be further understood in these scenarios.
  - A stable XPR regime has not yet been developed on MAST-U, although initial attempts were made during the previous campaign. Given MAST-U's ability to operate with both open and closed divertor geometries, we plan to continue developing the XPR scenario in both configurations, enabling comparison with AUG results

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Experiments in USN and LSN with XPR and CRD (both in standard SN divertor configuration) with and without cryo pumps and with He puffs
  - The CRD distance to the target should be varied to identify the optimum for neutral compression and potentially He exhaust
  - Open divertor configuration needs to be developed on MAST-U, and XPR existence will be gauged using IRVB poloidal reconstructions

P1 (AUG)/P2(MAST-U):
- Important proposal for XPR/CRD with high priority for the He compression
- MAST-U need to check for possible compatibility with seeded H-mode scenario



Proposed pulses

Device	# Pulses/Session	# Development
AUG	13	9
MAST-U	12	12
TCV		
WEST		

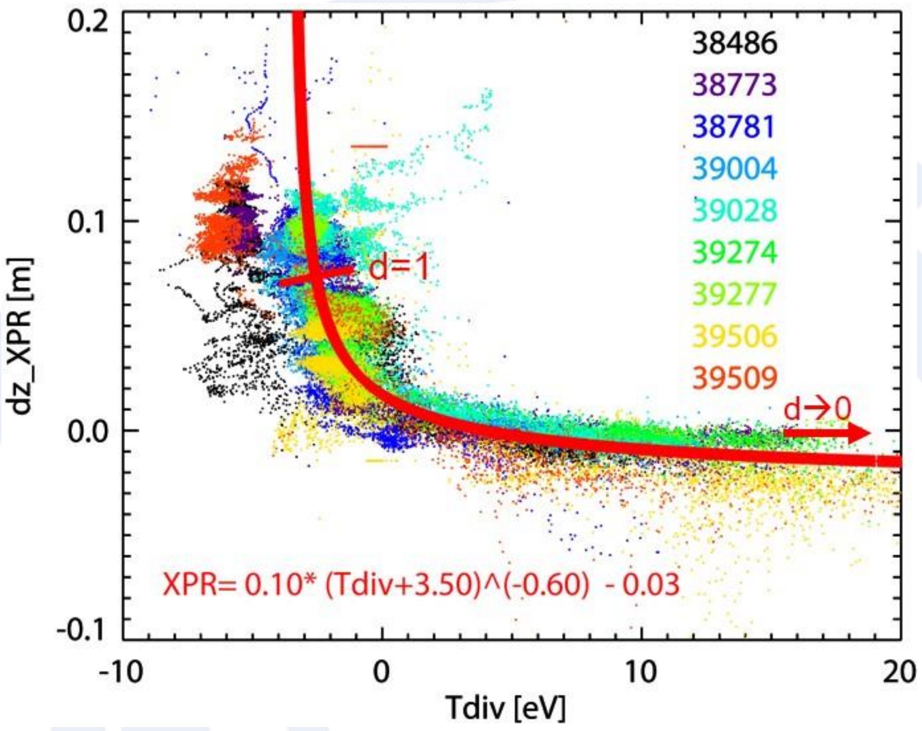
#115: Continuous control from attachment to XPR

- **Proponents and contact person:**

  M.Bernert, B. Sieglin, P.David

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

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

#115: Continuous control from attachment to XPR

PB on scenario development on #114

- **Proponents and contact person:**

  M.Bernert, B. Sieglin, P.David

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

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Heavy nitrogen seeding
  - AXUV & Tdiv control
  - Strategy:
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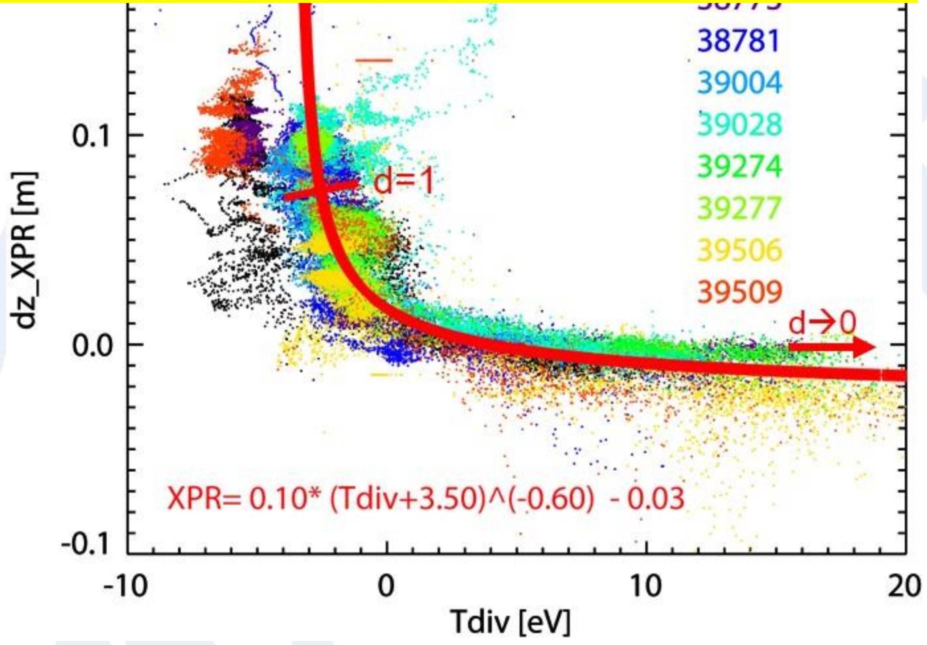
    - Demonstrate continuous control for attached to fully detached plasmas [4#]



Proposed pulses

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

#116: Pellet fueling into XPR & CRD

- **Proponents and contact person:**

  M.Bernert, P. Lang, B. Sieglin, P.David, S. Henderson

- **Scientific Background & Objectives**
  - Pellets lead to transient perturbations of density, temperature and power flux to the XPR region. All parameters might have strong influence onto the XPR behaviour and stability. This is to be tested in standard configuration and the CRD.
  - First tests at JET showed that the scenario is stable, but did not yet apply full pellet fueling

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Heavy nitrogen seeding
  - AXUV real time system
  - Pellets
  - Strategy:

    Shoot single pellets and pellet trains:

    - first test with small pellets [1#]

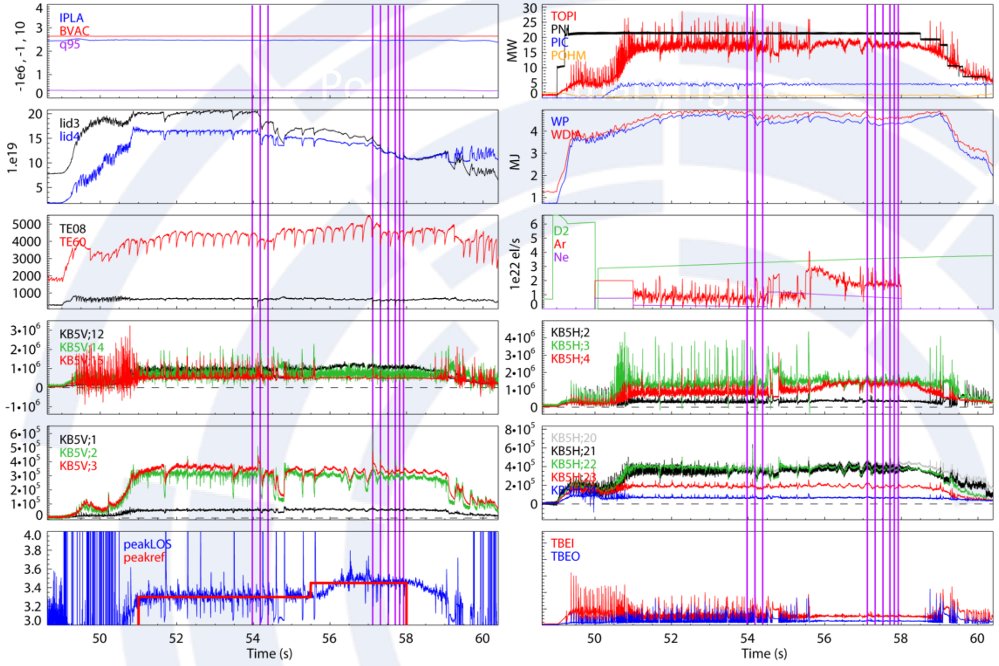
    - active controlled XPR vs constant FF seeding [2#]

    - pellet fueling on top or replacing D2 puff [2#]

    - a CRD scenario with active XPR control [2#]

    - use Kr doped pellets in the active XPR control [2#]

Pellet Fueling in XPR at JET (JPN 105555)



Proposed pulses

Device	# Pulses/Session	# Development
AUG	9	0
MAST-U		
TCV		
WEST		

#116: Pellet fueling into XPR & CRD

- **Proponents and contact person:**

  M.Bernert, P. Lang, B. Sieglin, P.David, S. Henderson

- **Scientific Background & Objectives**
  - Pellets lead to transient perturbations of density, temperature and power flux to the XPR region. All parameters might have strong influence onto the XPR behaviour and stability. This is to be tested in standard configuration and the CRD.
  - First tests at JET showed that the scenario is stable, but did not yet apply full pellet fueling

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Heavy nitrogen seeding
  - AXUV real time system
  - Pellets
  - Strategy:

    Shoot single pellets and pellet trains:

    - first test with small pellets [1#]

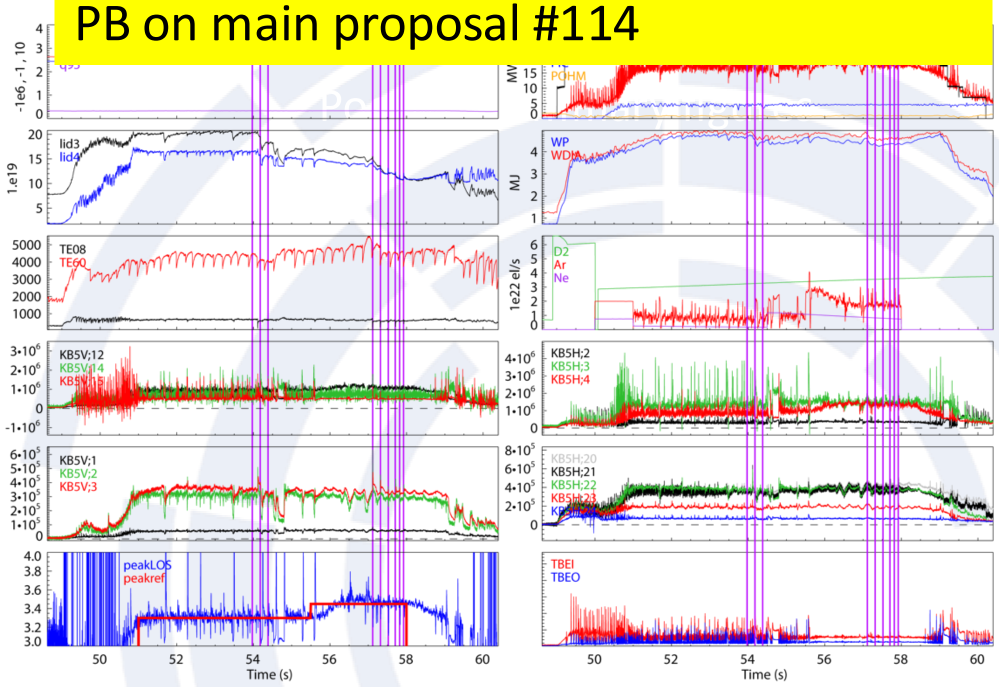
    - active controlled XPR vs constant FF seeding [2#]

    - pellet fueling on top or replacing D2 puff [2#]

    - a CRD scenario with active XPR control [2#]

    - use Kr doped pellets in the active XPR control [2#]

PB on main proposal #114



Proposed pulses

Device	# Pulses/Session	# Development
AUG	9	0
MAST-U		
TCV		
WEST		

#117: Fluctuation characteristics and transport in the XPR regime

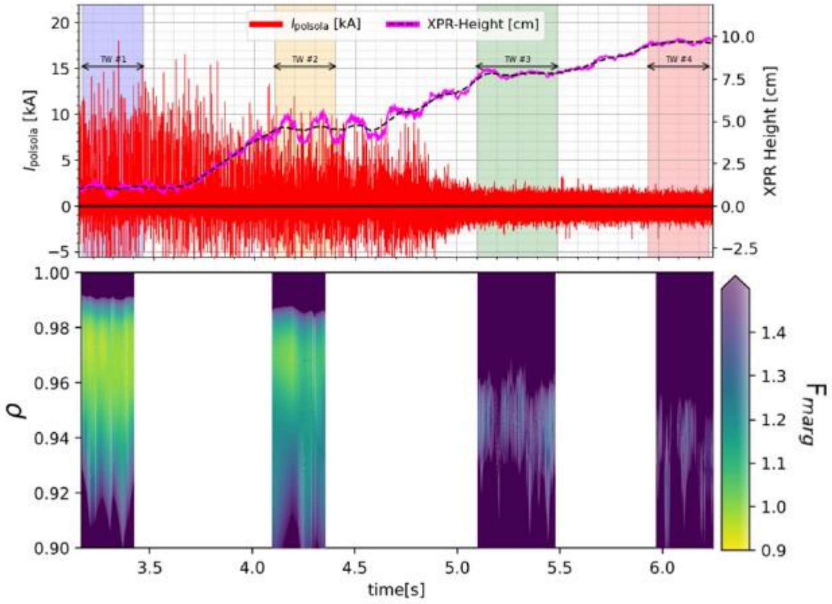
- **Proponents and contact person:**

  Y.-C. Liang (PhD start Jan.), M. Griener, M. Bernert, O. Pan, R.Reimerdes, S.Henderson, M. Herschel, G. Grenfell, J. Stobbs, E. Wolfrum, T. Gleiter, A. Kappatou, R. McDermott U. Stroth, T. Happel

- **Scientific Background & Objectives**
  - XPR ELM suppression is correlated to fluctuating signals in the divertor
  - An additional transport channel is most likely causing the relaxation of the pedestal profiles and, thus, the ELM suppression
  - Impurity transport might also be changed and the charge state distribution of N needs to be measured and analysed in detail, investigating deviations from neoclassical transport, e.g. due to the presence of neutrals in the XPR.
  - Detailed measurement and a comparison to TCV should help to understand the underlying physics

  – Measure filament characteristics in the pedestal and SOL in the XPR regime with and without ELMs
  – Document the impact on the pedestal & SOL profiles (λq, λ_n)
  – MEM measurements of the SOL and first wall fluxes
  – Measure the N charge state distribution and quantify the impact of neutrals
  – Correlate measurements in the midplane SOL to divertor measurement of fluctuations
  – Compare to the XPR SF- ELM suppression at TCV

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Discharges in LSN and USN (latter in fwd and rev. Bt) optimized for filament measurements (He beam, GPI, reflectom.)
  - Two (and four) different height of the XPR to measure characteristics before and after ELM suppression
  - Repetitions for spectroscopy diagnostics and MEM positioning



Proposed pulses

Device	# Pulses/Session	# Development
AUG	13	3
MAST-U		
TCV		
WEST		

#117: Fluctuation characteristics and transport in the XPR regime

PB on scenario development on #114 whenever run in LSN. Possible dedicated shots to complete characterization if needed. To be combined with proposal #119

- **Proponents and contact person:**

  Y.-C. Liang (PhD start Jan.), M. Griener, M. Bernert, O. Pan, R.Reimerdes, S.Henderson, M. Herschel, G. Grenfell, J. Stobbs, E. Wolfrum, T. Gleiter, A. Kappatou, R. McDermott U. Stroth, T. Happel

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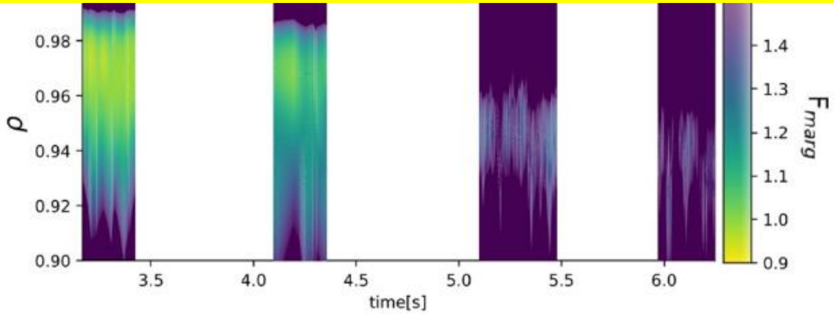
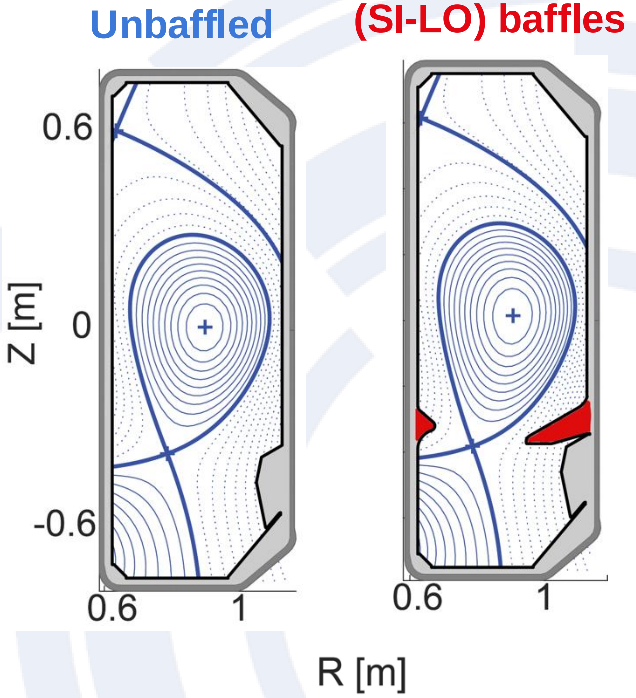


Proposed pulses

Device	# Pulses/Session	# Development
AUG	13	3
MAST-U		
TCV		
WEST		

#118: Effect of gas baffling on ELM buffering in TCV

- **Proponents and contact person**
  - M. Zurita (martim.zurita@epfl.ch), H. Reimerdes, O. Février, M. Carpita, A. Stagni, C. Theiler, E. Tonello, R. Ducker
- **Scientific Background**
  - Gas baffles increase divertor neutral pressure, facilitating detachment and decreasing core degradation by impurities
  - ELM buffering is fundamental to decrease target heat loads
- **Objectives**
  - Demonstrate ELM buffering in TCV
  - Evaluate most effective impurity for ELM buffering in TCV (N, Ar, Ne)
  - Can baffles boost the seeded impurities' effect to mitigate ELMs?
- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Low collisionality, Type-I ELM, SN plasmas w/ ECH+NBH
  - Impurity seeding ramps and constant rate with N, Ar, Ne
  - IR thermography to evaluate ELM fluence and buffering fraction
  - Compare two TCV campaigns: unbaffled and SI-LO baffled



Proposed pulses

Device	# Pulses	# Develop.
AUG		
MAST-U		
TCV	14	6
WEST		

#118: Effect of gas baffling on ELM buffering in TCV

short-inner

P1:
- Speaks directly to one of the scientific objectives
- Nice companion paper (apart from RT) with proposal # 105

- **Proponents and contact person**
  - M. Zurita (martim.zurita@epfl.ch), H. Reimerdes, O. Février, M. Carpit... A. Stagni, C. Theiler, E. Tonello, R. Ducker
- **Scientific Background**
  - Gas baffles increase divertor neutral pressure, facilitating detachment and decreasing core degradation by impurities
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  - Impurity seeding ramps and constant rate with N, Ar, Ne
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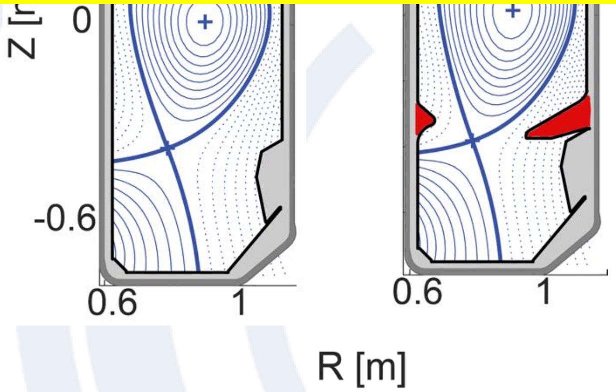
  - Compare two TCV campaigns: unbaffled and SI-LO baffled



Proposed pulses

Device	# Pulses	# Develop.
AUG		
MAST-U		
TCV	14	6
WEST		

#118: Assessing the effect of impurity seeding on upstream SOL conditions, profiles and fluctuations

- **Proponents and contact person:**

A. Stagni, H. Reimerdes, M. Zurita, C. Theiler, R. Morgan, B. Labit, O. Février, N. Vianello, M. Bernert, D. Brida, G. Grenfell, M. Agostini, M. La Matina, M. Ugoletti, Y. Wang, P. Hennequin, P. Ryan

- **Scientific Background & Objectives**

– Successful exploitation of the α_t on AUG and TCV to describe the changes in SOL dynamics with respect to separatrix density and plasma shape

– Not yet clear picture of the effect of impurities in seeded scenarios, with regards to changes in edge impurity content and Z_{eff} near the separatrix
  - Extend the α_t framework to impurity-seeded plasmas
  - Measure the impact of a seeding-induced α_t modification on upstream SOL profiles and radial electric field E_r
  - Assess the role of E_r within the α_t framework
  - Correlate the properties of upstream edge and SOL properties with those of upstream turbulence and fluctuations

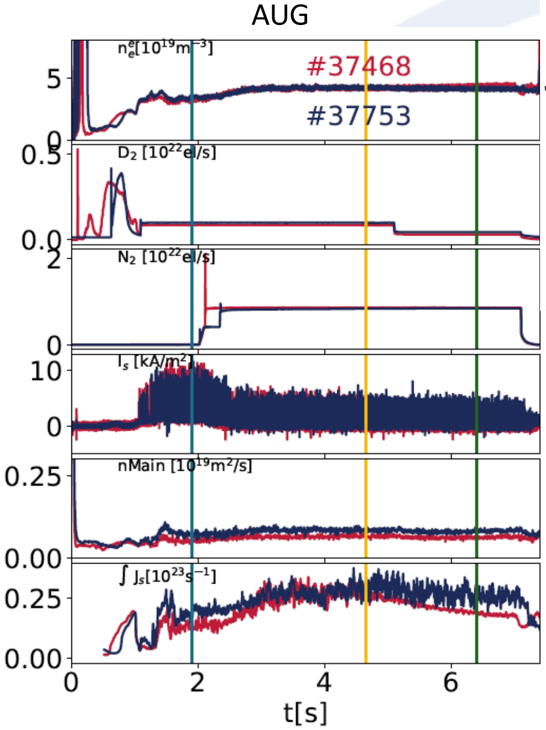
- **Experimental Strategy/Machine Constraints and essential diagnostic**

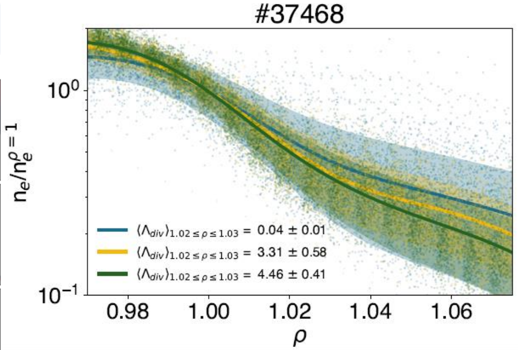
– Plasma discharges in conventional LSN divertor, both high and low delta

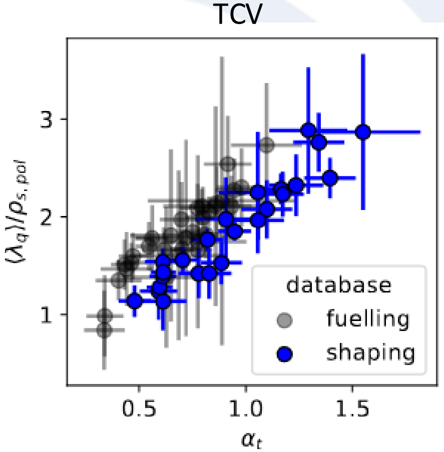
– Use different levels of main gas rate and seeding rate, scan the response of the midplane and divertor collisionalities

– Probe response of α_t against different gas fueling and seeding rates

– Diagnostics: all available upstream and divertor systems for edge profiles (incl. E_r), fluctuations and neutrals







Proposed pulses

Device	# Pulses/Session	# Development
AUG	10[a]	
MAST-U		
TCV	10[b]	10[b]
WEST		

[a] Can be reduced with data mining and/or piggyback

[b] Pending the outcome of 2024 experiments

#118: Assessing the effect of impurity seeding on upstream SOL conditions, profiles and fluctuations

- **Proponents and contact person:**

A. Stagni, H. Reimerdes, M. Zurita, C. Theiler, R. Morgan, B. Labit, O. Février, N. Vianello, M. Bernert, D. Brida, G. Grenfell, M. Agostini, M. La Matina, M. Ugoletti, Y. Wang, P. Hennequin, P. Ryan

- **Scientific Background & Objectives**

– Successful exploitation of the α_t on AUG and TCV to describe the changes in SOL dynamics with respect to separatrix density and plasma shape

– Not yet clear picture of the effect of impurities in seeded scenarios, with regards to changes in edge impurity content and Z_{eff} near the separatrix

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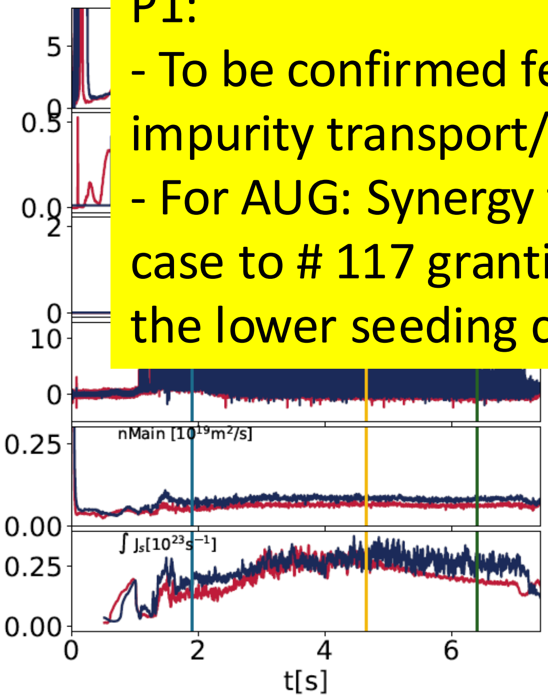
- **Experimental Strategy/Machine Constraints and essential diagnostic**

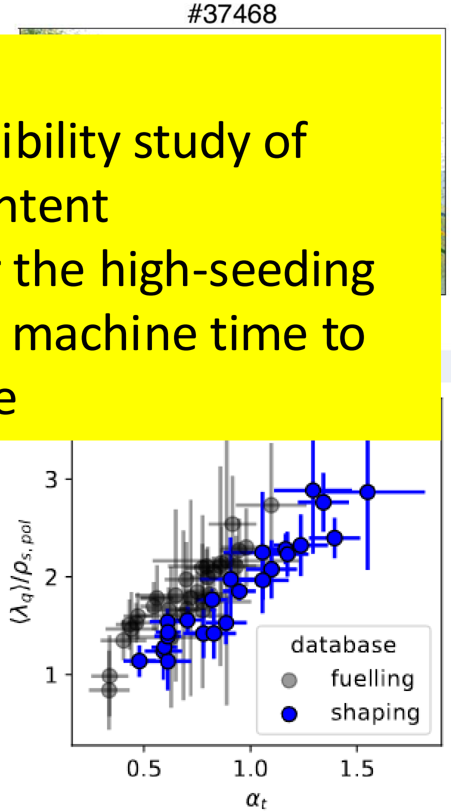
– Plasma discharges in conventional LSN divertor, both high and low delta

– Use different levels of main gas rate and seeding rate, scan the response of the midplane and divertor collisionalities

– Probe response of α_t against different gas fueling and seeding rates

– Diagnostics: all available upstream and divertor systems for edge profiles (incl. E_r), fluctuations and neutrals





P1:
- To be confirmed feasibility study of impurity transport/content
- For AUG: Synergy for the high-seeding case to # 117 granting machine time to the lower seeding case

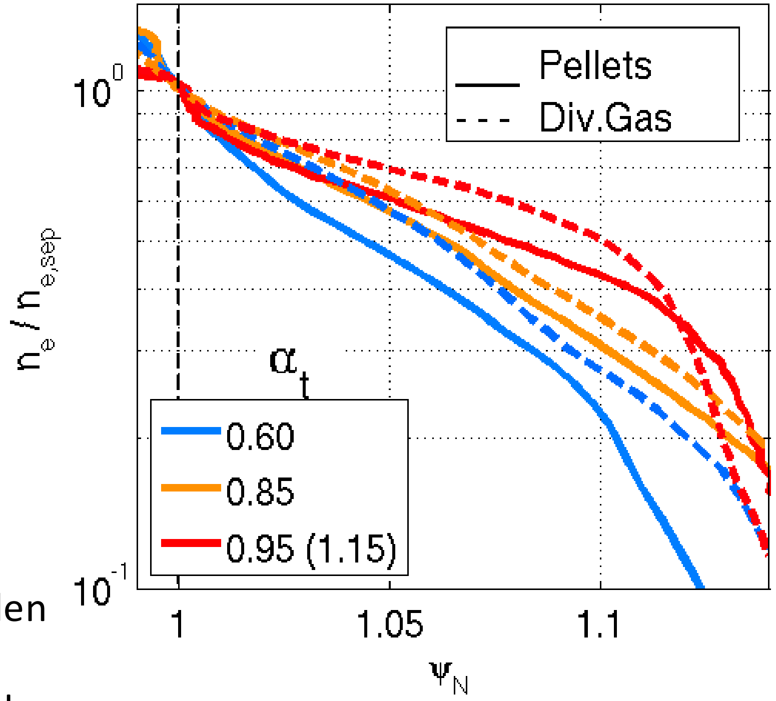
Proposed pulses

Device	# Pulses/Session	# Development
AUG	10[a]	
MAST-U		
TCV	10[b]	10[b]
WEST		

[a] Can be reduced with data mining and/or piggyback

[b] Pending the outcome of 2024 experiments

#120: How replacing gas fuelling by pellet fuelling affects SOL, divertor, detachment/XPR access



- **Proponents and contact person:**
- christian.perez.von.thun@ifpilm.pl, matthias.bernert@ipp.mpg.de

Scientific Background

- ITER full performance pulses have to rely on pellets to fuel the plasma (high SOL opacity)
- Latest JET gas pellet comparisons have shown differences in SOL upstream profiles including shoulder formation with pellets, nesep vs Te @OSP or nesep vs divertor neutral pressure.

Objectives

- Extend (with relatively low investment) pellet gas SOL assessment done on JET to AUG to widen physics basis
- XPR access with pellets covered by separate proposal by M. Bernert. Extra information could be obtained with 3 additional pulses with 'fuelling ramp' technique (to complement XPR dataset).

Experimental Strategy

- Complementary to HDL proposal: Choose one of the scenarios successively used in HDL proposal (say, fuelling scheme 'A') and repeat fuelling ramps but with the two other fuelling schemes ('B','C') where ABC are pellets vs MC gas puff vs Divertor gas puff (2 pulses)
- For XPR access option: use same XPR scenario as in by M. Bernert with fixed (constant) level of impurity seeding, and do fuelling ramp to access XPR either with pellets (1 pulse), main chamber gas puff(1 pulse), divertor gas puff (1 pulse). Compare conditions at which
- XPR onset during the ramp occurs for each fuelling scheme (nesep, subdivertor neutrals etc)

Proposed pulses

Device	# Pulses/Session	# Development
AUG	2 (+3 for XPR)	0
MAST-U		
TCV	>= 6 for δ (TBD)	?
WEST		

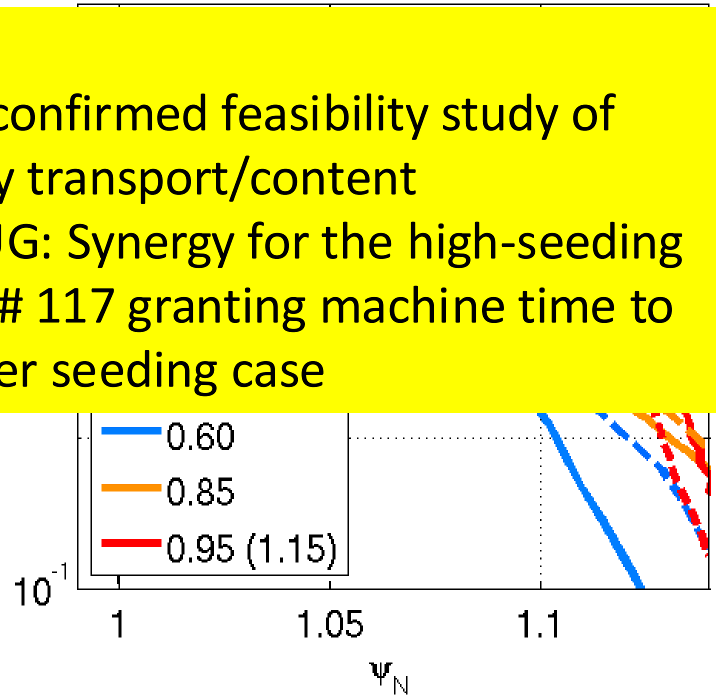
#120: How replacing gas fuelling by pellet fuelling affects SOL, divertor, detachment/XPR access

- **Proponents and contact person:**
- christian.perez.von.thun@ifpilm.pl, matthias.bernert@ipp.mpg.de

P1:
- To be confirmed feasibility study of impurity transport/content
- For AUG: Synergy for the high-seeding case to # 117 granting machine time to the lower seeding case

Scientific Background

- ITER full performance pulses have to rely on pellets to fuel the plasma (high SC opacity)
- Latest JET gas pellet comparisons have shown differences in SOL upstream profiles including shoulder formation with pellets, nesep vs Te @OSP or nesep vs divertor neutral pressure.



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- XPR onset during the ramp occurs for each fuelling scheme (nesep, subdivertor neutrals etc)

Proposed pulses

Device	# Pulses/Session	# Development
AUG	2 (+3 for XPR)	0
MAST-U		
TCV	>= 6 for δ (TBD)	?
WEST		

#121: Continuation of HDL studies with metallic wall: max nesep dependence on seeding (Zeff) & δ

- **Proponents and contact person:** christian.perez.von.thun@ifpilm.pl

Scientific Background

- In tokamak reactors will require both high nesep & seeding for exhaust. ITER has high δ ~ 0.5.
- Max. sustainable nesep in H-mode set by HDL but some HDL dependencies not well
- understood (or not sufficiently explored).
- E.g. on recent JET expts: modest δ increase 0.27 --> 0.36 allowed 20% increase of nesep
- w/o triggering HDL, while on AUG no obvious increase seen yet
- (Bernert PPCF2015, Huber NME2017, Sieglin PPCF 2024).
- Seeding modifications to HDL (Zeff) not explored yet (to my knowledge) but clearly important

Objectives

- Assess how seeding modifies max. sustainable nesep in H-mode (AUG)
- Expand HDL triangularity assessment on AUG to higher δ>0.4 (plus on TCV despite C-wall?)

Proposed pulses

Device	# Pulses/Session	# Development
AUG	>=7 for Z_{eff} >=4 for δ	? ?
MAST-U		
TCV	>= 10 for δ (TBD)	?
WEST		

Experimental Strategy

- Traditional 'fuelling ramp' approach until H-L backtr.
- To overcome 'fuelling limit' on AUG (Bernert 2015, Huber NME2017) consider preferential use of pellets?
- Zeff scan: Use established seeding scenario (eg. from XPR studies). Fixed fuelling ramp, add seeding ramp (e.g. N2,tbd) in different proportions to main fuel up to HDL. Repeat adjusting Paux to keep Psep approx. constant at each seeding level. (2-3 Zeff levels plus unseeded ref)
- Delta scan: Push to more 'extreme' scenarios with high delta > 0.4 (δmax (AUG) = 0.6 quoted in Annex to Call), e.g. if for this scenario 0.3 already exists ideally 0.4,0.5,0.6. Scenario development needed?
- On TCV could exploit higher shaping flexibility than AUG but CFC-wall (TBD) and do systematic scan e.g. in 0.1 δ steps.
- Diagnostics: edge profiles in main chamber + divertor diagnostics.

#121: Continuation of HDL studies with metallic wall: max nesep dependence on seeding (Zeff) & δ

P2:
- Check what can be obtained as extreme cases for investigation under #120

- **Proponents and contact person:** christian.perez.von.thun@ifpilm.pl

Scientific Background

- In tokamak reactors will require both high nesep & seeding for exhaust. ITER has high δ ~ 0.5.
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- Diagnostics: edge profiles in main chamber + divertor diagnostics.

Proposed pulses

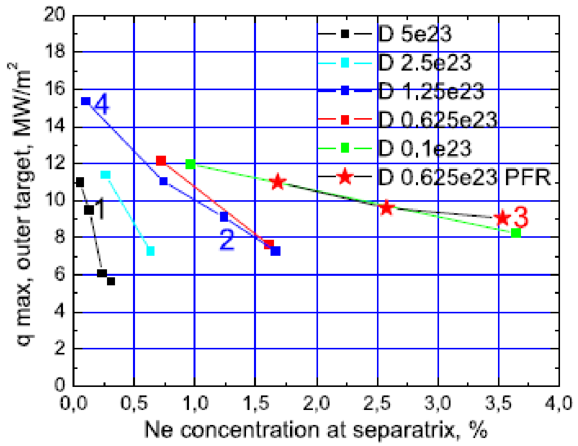
Device	# Pulses/Session	# Development
AUG	>=7 for Z_{eff} >=4 for δ	? ?
MAST-U		
TCV	>= 10 for δ (TBD)	?
WEST		

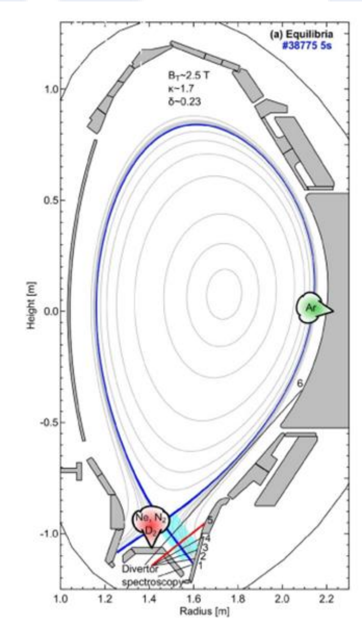
#205: Investigating impact of fuelling/seeding location on impurity compression/enrichment

- **Proponents and contact person:**
  ryoko.osawa@ukaea.uk et al.

- **Scientific Background & Objectives**
  Main chamber fuelling enhanced impurity compression/enrichment compared to divertor fuelling in simulations on ITER[1] and STEP[2]
  - Investigate if the similar impact is obtained in experiments
  - Reveal possible impacts of main chamber fuelling on edge/core plasma

SOLPS-ITER simulation result on ITER[1]





- **Experimental Strategy/Machine Constraints and essential diagnostic**
  Vary fuelling/seeding location on AUG(LSN), MAST-U(LSN, DN), and TCV (LSN, DN) in H-mode
  - Fuelling scan on each location setting and alter the impurity species (Ar, Ne, N2, He)
  - Measure Core_Zeff, Psep CX impurity concentration, and SOL/divertor impurity emission to compare impurity compression/enrichment and upstream impurity concentration across the cases

Proposed pulses

Device	# Pulses/Session	# Development
AUG	22 (LSN)	
MAST-U	20 (LSN, DN)	
TCV	28 (LSN, DN)	
WEST		

[1] E. Kaveeva et al., Nuclear Materials and Energy 35, 101424 (2023).
[2] R. T. Osawa et al., FEC2023.

#205: Investigating impact of fuelling/seeding location on impurity compression/enrichment

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  ryoko.osawa@ukaea.uk et al.

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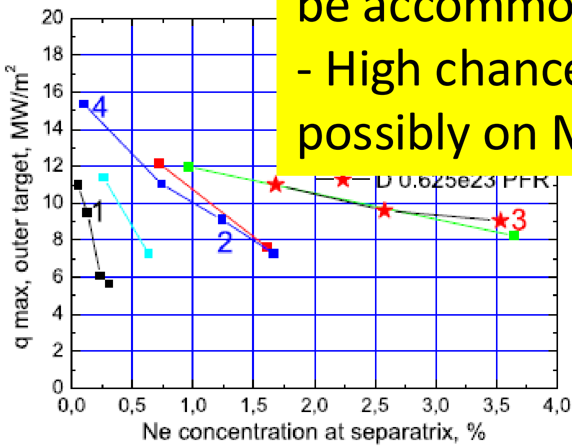
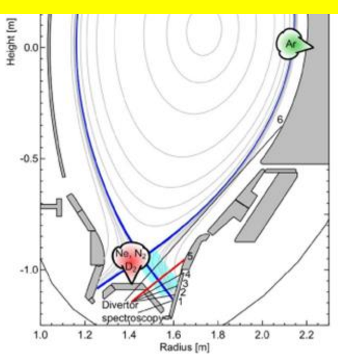
  - Investigate if the similar impact is obtained in experiments
  - Reveal possible impacts of main chamber fuelling on edge/core plasma

SOLPS-ITER simulation





P1 (TCV)/P2(AUG)/P1(MAST-U):
- The shot request is quite high and can't be accommodated entirely
- High chance of exploration on TCV, possibly on MAST-U, difficult on AUG

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  Vary fuelling/seeding location on AUG(LSN), MAST-U(LSN, DN), and TCV (LSN, DN) in H-mode
  - Fuelling scan on each location setting and alter the impurity species (Ar, Ne, N2, He)
  - Measure Core_Zeff, Psep CX impurity concentration, and SOL/divertor impurity emission to compare impurity compression/enrichment and upstream impurity concentration across the cases

Proposed pulses

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Summary

#	Proposal	Priority
15	L2H Studies with Impurity seeding	P2
92	Development of real time XPR/MARFE observer for the new ASDEX Upgrade upper divertor	P1
94	IEDF evolution during detachment onset in WEST divertor	P1/PB
95	Optimisation of XPR entry and exit in WEST for low disruptivity & high fluence operation	P1/PB
96	High-density ECRH-assisted X-Point Radiators in WEST	P1
97	Operational density limit for XPR with pellet injection control in WEST	P1/PB
98	Detachment control based on energy balance and system identification	P2
99	Development of an integrated reduced model for exhaust	P1
100	Enhancing confinement in ELM suppressed X-point radiator regimes through plasma shaping and density control	P1
101	Advanced exhaust control on TCV and MAST-U	P1(TCV)/P2(MAST-U)
102	Continuation of dynamic measurements and control for the plasma exhaust	P2
103	Impulsive detachment experiments in AUG for SOLPS-ITER and JOREK time-dependent validation	P2
104	Upstream downstream ion and electron temperatures	P2
105	ELM buffering in conventional divertor configuration including real-time control	P1 (AUG)/P2(MAST-U)
106	Flow characterization in the divertor	P1 (TCV)/PB(MAST-U)/P2(AUG)
107	X-point radiator high confinement experiment	P2
108	Investigating the impact of plasma-neutral interactions on detachment	P2
109	Effect of divertor turbulence on the heat load footprint	P2 (AUG)/P1(TCV)
110	Investigating the impact of divertor conditions, including impurity seeding, on broadening of the scrape-off-layer power channel	PB
111	Investigation of seeding location on impurity distribution, compression and core contamination	P1
112	Power EXhaust (PEX) databese in H-mode for SOLPS-ITER validation	P1
113	Access and radiative capability of the XPR as a function of triangularity in TCV and AUG DivIIo	P1(TCV)/P2(AUG)
114	XPR and CRD in open vs closed divertor – Neutral compression and Helium exhaust	P1(AUG)/P2(MAST-U)
115	Continuous control from attachment to XPR	PB
116	Pellet fueling into XPR & CRD	PB
117	Fluctuation characteristics and transport in the XPR regime	PB
118	Effect of gas baffling on ELM buffering in TCV	P1
119	Assessing the effect of impurity seeding on upstream SOL conditions, profiles and fluctuations	P1
120	How replacing gas fuelling by pellet fuelling affects upstream SOL properties, divertor conditions, access to divertor detachment	P1
121	Continuation of HDL studies with metallic wall: dependence of maximum sustainable separatrix density in H-mode on impurity seeding (Zeff), plasma shaping (triangularity, closeness to DN) or use of pellets	P2
205	Investigating impact of fuelling/seeding location on impurity compression/enrichment	P1 (TCV)/P2(AUG)/P1(MAST-U):

Foreseen activity for RT05-JET

- Impurity concentrations and their comparison between species
- Trade-off between Ne and Ar: optimal ratio / changes to plasma
    - Is there a benefit of the mixes vs single impurity
- Edge modelling:
    - Mixed Seeding
    - Comparison of N, Ne, Ar
    - XPR vs onset
    - DT – isotope effects (with seeding)
    - Time dependent modelling (gas cut discharges)
- SOL transport (notably changes with Ar): far SOL fluxes, first wall loads
- Radial electric field unseeded vs seeded
- He concentrations/behavior/built-up in DT
- TRANSP simulations (with correct imp. conc.)
- Quantify ITG effect, turbulence behavior with high Zeff
- Influence of pellets
- ELM analysis including stability
- Highest power pulses: Performance & comparison
- Impact of XPR on confinement