EUROfusion

RT-03 Strategies for disruption and run-away mitigation

Discussion on proposals and allocated priorities

rTFLs: V. Igochine, A. Hakola

On behalf of the WPTE TFLs E. Joffrin, M. Wischmeier, M. Baruzzo, A. Kappatou, D. Keeling, A. Hakola, B. Labit, E. Tsitrone and N. Vianello

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Introduction

ITER

DEMO

RT01: Core-Edge-SOL integrated H-mode

RT02: Alternative to type-I ELM regimes

Physics & Control integration

RT03: Disruption & RE mitigation strategies

RT04: Machine generic integrated control

RT05: Physics of divertor detachment

RT08: Physics of high β long pulse scenario

RT09: Physics of energetic particles

RT06: preparation of efficient PFC operation

RT07: Alternative divertor configuration

PEX

Mission 1 | Mission 2

Scientific objectives and machine time

Scientific Objectives
D1 Optimize disruption mitigations by single and multiple shattered pellet injection (SPI) at high plasma current and energy content in an all-metal environment to validate the ITER disruption mitigation strategy
D2 Quantify the required neon quantity for SPI into dilution cooled plasmas for sufficient thermal and current quench mitigation in
D3 Character … m injections techniques
D4 Determine … plasma start-up phase
D5 Interpretative modelling of disruption mitigation dynamics (TSVV-8, TSVV-9) and prediction for ITER
D6 Quantify the radiation asymmetry during disruption mitigation with SPI
D7 Validate the modelling of image currents in conducting structures during disruption with halo current measurements

The scientific objectives were revised and renumbered to emphasise advances and focus attention on the most important ITER problems.

Scientific objectives and machine time

New Scientific Objectives
D8 Develop an understanding of pellet assimilation for plasma densification in shattered pellet injection (SPI) experiments to avoid runaway electron (RE) generation
D9 Develop an understanding of SPI dynamics in off-normal plasmas, such as close to density limit and/or during impurity accumulation
D10 Determine the physics mechanisms leading to benign termination of RE with H and D, specifically in the ITER relevant parameter range
D11 Determine the physics mechanisms generating run-away electrons in the current quench, including during a vertical displacement event (VDE), and in the plasma start-up phase, including electron cyclotron (EC) pre-ionization and EC-assisted burn-through
D12 Perform interpretative modelling of disruption mitigation dynamics, specifically aiming at physics understandings of experimental measurements to extrapolate models to ITER (in collaboration with TSVV-F)
D13 Characterise disruption loads, in particular during VDEs, to improve predictions for ITER
D14 Investigate the role of plasma phenomena (turbulence, MHD, waves, fast ions etc) on the transport and confinement of REs

	AUG	TCV	MAST-U	WEST
2026 -27	62	205	0	75

Allocation of discharges (tentative)

<u>Nominated Research Topic Coordinators:</u>
O. Ficker, C. Reux, U. Sheikh, IO

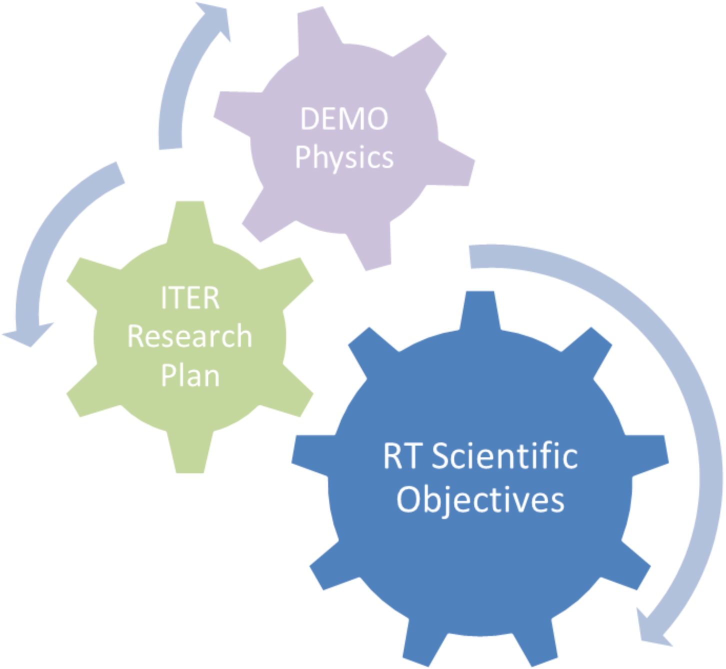
Summary of the proposals

Benign Termination of RE Beams	Umar Sheikh, Cedric Reux
Runaway Electron Mitigation Coil	Umar Sheikh, Alex Battey
RE diffusion via RMP	Andres Orduña
RE generation dependence on plasma shaping	Cédric Reux
Interaction between RE and high frequency waves	Olivier Panico, Joan Decker
Application of 3D fields in synergy with SPI for runaway electron mitigation	Marco Gobbin
Impact of turbulence and MHD on RE transport and confinement	Joan Decker, Umar Sheikh
Studies of runaway generation at plasma start-up	Basilio Esposito
Runaway impact asymmetries	Cédric Reux
TF Ripple Enhancement	Alexander Battey
Startup runaway generation physics in inductive, EC pre-ionization, and EC assisted burn-through scenarios	Pedro Molina
Studying the plasmoid drift in AUG SPI experiments	Ansh Patel
SPI into W-accumulation scenario at AUG	Ondrej Ficker
Influence of W on the runaway electron generation and benign termination scenario	Ondrej Ficker
Alternative runaway electron scenario for ASDEX Upgrade	Gergely Papp
Viability of staggered and dual injection scheme for AUG SPI	Stefan Jachmich
Material assimilation in low Te plasma with AUG SPI	Stefan Jachmich

Requested discharges vs. allocation

Device	# Scientific pulses	# Development pulses	# Allocated pulses	Overbooking fraction
AUG	129	20	62	2.4
TCV	190	65	205	1.25
WEST	96	20	75	1.4

Prioritization scheme



Evaluated according to the criteria:

Meeting the set Scientific Objectives

Size and feasibility

Team effort

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

P1-2026-DEV: experimental priority for 2026: machine time granted but pulse budget might need reduction

P1-2027-DEV: experimental priority for 2027: machine time granted but pulse budget might need reduction

P2-DEV: will be done if time allows after *all* P1 proposals are completed

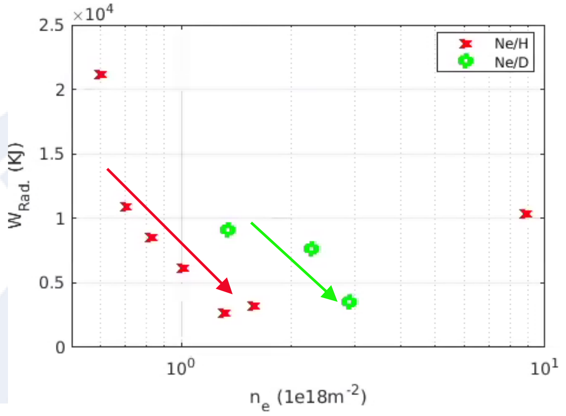
P3: low priority programme/out of scope

PB: piggy-back experiment/pure analysis proposal

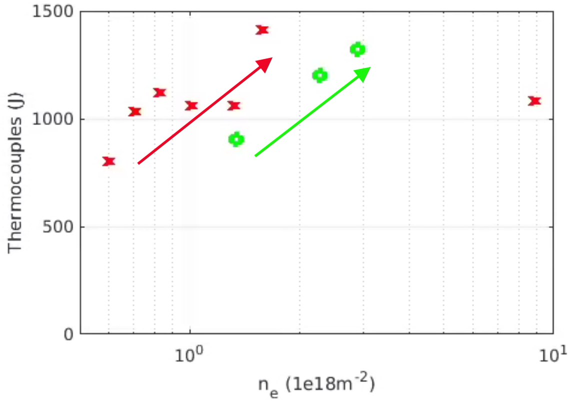
P36: Benign Termination of RE Beams

- **Proponents and contact person:**
  - Umar Sheikh (umar.sheikh@epfl.ch) et al.
- **Scientific Background & Objectives**
  - Benign Termination by D/H injection has scaling limits.
    - The upper pressure limit is critical but unknown, as ITER's scheme exceeds preliminary predictions.
  - TCV showed the RE final collapse depends on the hydrogenic species, not just density. This species effect is vital for ITER to understand (figures →).
  - Modelling is starting to shed light on the mechanisms at the final collapse (see Sheikh IAEA FEC 2025)
- **Experimental Strategy etc:**
  - Establish the upper neutral pressure limit necessary for successful benign termination of the RE beam on AUG and WEST
  - Systematically vary the ratio and timing of Ne and D2 injections to optimize the process and understand recombination timescales on TCV
  - Determine why H and D lead to different final collapse dynamics (e.g., by changing resistivity without altering ne) on TCV and WEST
  - Use new diagnostics (e.g., IR camera views) to get 3D information on the final RE beam collapse and study how the toroidal asymmetry evolves on TCV
  - Compare the time to recombination using SPI vs. MGI on AUG
  - Develop new benign termination scenarios on TCV: using pure D2 only, and limiterless compression

Higher Wrad at lower ne



Lower conducted energy at lower ne



Device	# Pulses/Session	# Development
AUG	8	4
TCV	30	13
WEST	30	4

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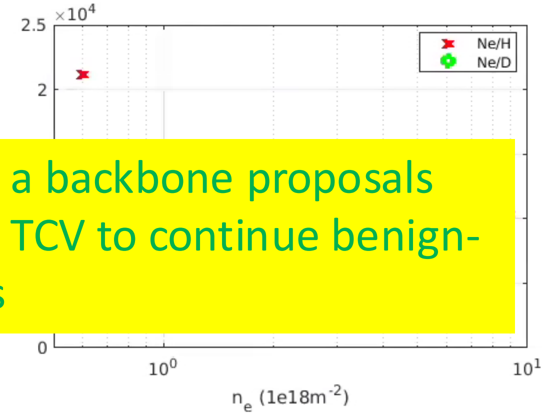
Priority: P1_2026 – a backbone proposals for AUG, WEST and TCV to continue benign-termination studies



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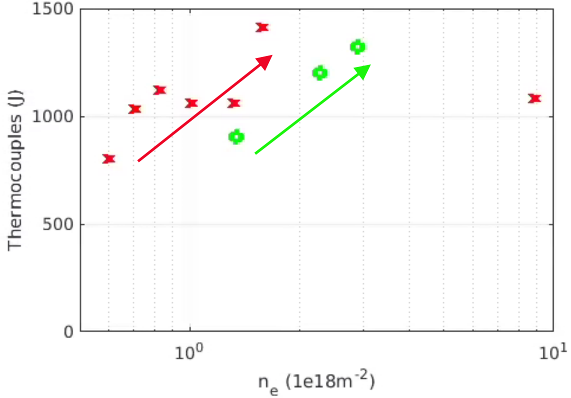
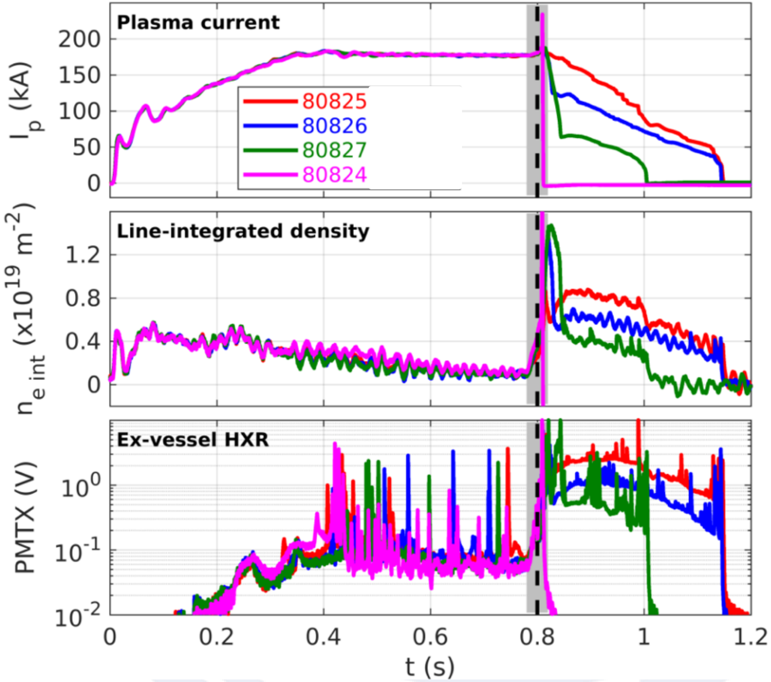


Device	# Pulses/Session	# Development
AUG	8	4
TCV	30	13
WEST	30	4

P37: Runaway Electron Mitigation Coil on TCV

- **Proponents and contact person:**
  - Umar Sheikh, Alex Battey et al.
- **Scientific Background & Objectives**
  - The REMC is being developed for SPARC as the baseline RE mitigation technique.
    - Goal is to introduce a 3D magnetic field to expel REs and prevent formation
  - The REMC will be installed and exploited on TCV starting in 2026 under a EUROFusion grant.
- **Experimental Strategy etc:**
  - Complete scenario development for higher currents
    - Establish reliable high current scenario (10)
    - Scan Z position (5)
    - Scan MGI (amount and species scan) (10)
  - Explore effect of ECRH at the same time as NBH on partial current quench (10)
  - Measure efficacy of REMC
    - Do this with varying resistances in line to reduce coupled current in coil (20)
    - Scan position of the plasma at the time of the disruption to explore coupling and efficacy when offset in position (10)
  - Closed loop operation throughout shot (10)
    - Done to mimic SPARC coil setup
  - Test fast SPARC switch design (5)

Baseline partial CQ scenario to be optimized for increased current



Device	# Pulses/Session	# Development
TCV	40	40

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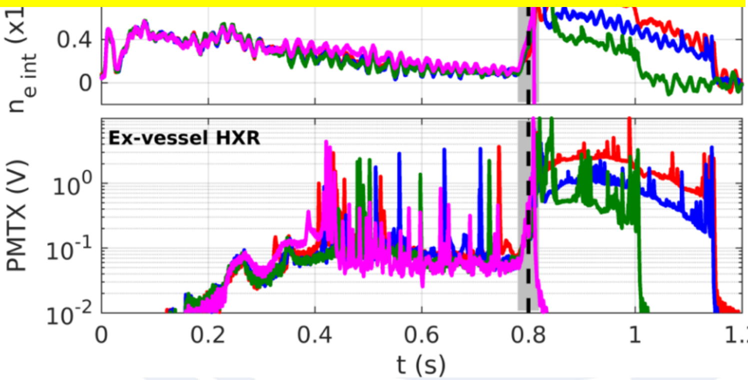
  - Test fast SPARC switch design (5)

Baseline partial CQ scenario to be

Priority: P1_2027 – 1) A new technique for dealing with runaways, which is currently the subject of active research.2) The installation of the coil was supported by EuroFusion.3) The request is too big to accommodate and has to be reduced.



Device	# Pulses/Session	# Development
TCV	40	40

P38: RE diffusion via RMP

- **Proponents and contact person:**
  - A. Orduña: Andres.Orduna@ipp.mpg.de
  - G. Papp
  - A. Burckhart
  - M. Willensdorfer
  - P. Heinrich
  - Sergei Gerasimov

- **Scientific Background & Objectives**
  - Find B-coils phasing that induces the most RE transport.
  - Investigate the effect of the pitch angle on the diffusion coefficient.
  - Compare observations with existing RE transport models.
  - Validate RE distribution function reconstruction techniques.

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Perform a phase scan of the B-coils based on past results (5)
  - Displace the beam towards the LFS to increase the relative RMP strength (3)
  - Decrease the background B strength with the same objective (3)
  - Include MMI to increase the pitch angle and observe whether the diffusion behaves as expected (4)

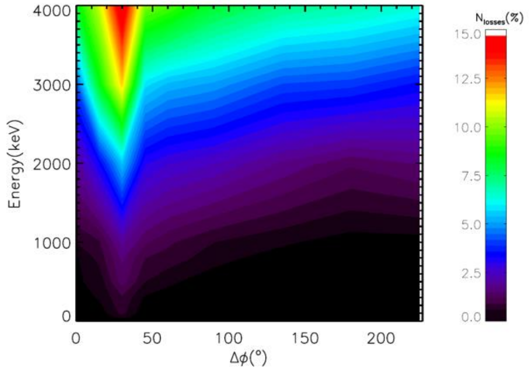


Figure 8. Summary contour of electron losses as function of energy and coil configuration (i.e. phasing).

M . Gobbin NF, 2021

Proposed pulses

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

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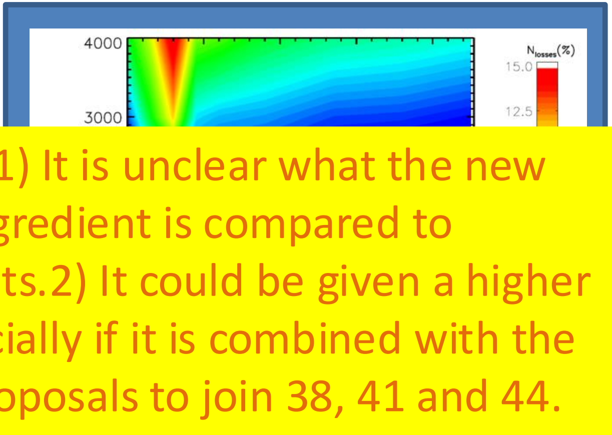

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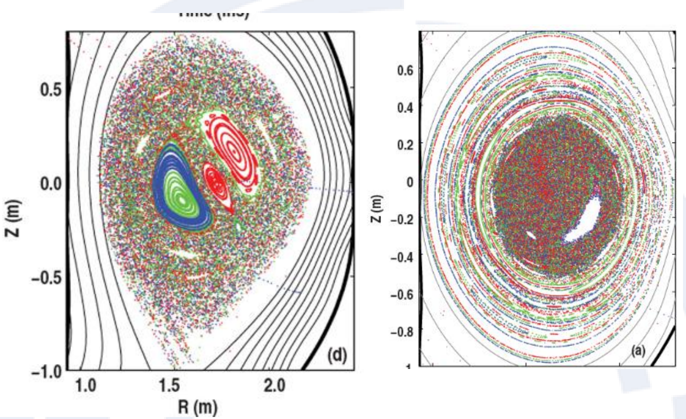
Priority: P2 – 1) It is unclear what the new substantial ingredient is compared to previous results.2) It could be given a higher priority, especially if it is combined with the other RMP proposals to join 38, 41 and 44.

Proposed pulses

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

P39: Runaway generation dependence on plasma shaping

- **Proponents and contact person:**
  - Cédric Reux et al., cedric.reux@cea.fr
- **Scientific Background & Objectives**
  - Spontaneous runaway generation during disruptions is more frequent with tokamaks running circular, limited plasmas compared to elongated, diverted tokamaks
  - ITER is a high-elongation, diverted machine ➔ crucial to understand how this observation could affect runaway generation on ITER
  - Two effects studied: magnetic topology differences affecting the stochastization dynamics [Izzo et al., NF 2011] or vertical instability losing runaway before avalanche multiplication [Wang et al., NF 2025], but only in simulation
  - Objective: disentangle effects experimentally (or confirm both are important)
    - Influence of the presence/absence of an X-point
    - Influence of the vertical instability growth rate
- **Experimental Strategy/Machine Constraints and essential diagnostics**
  - Scan the vertical instability growth rate in a limiter shape (trying to overlap the values from the next scan)
  - Scan the vertical instability growth rate in a single-null diverted shape (trying to overlap the values from the previous scan). Repeat in double null.
  - Scan the distance of the primary or secondary X-point from the wall, trying to keep the same elongation and/or vertical instability growth rates as close as possible to the previous scans
  - Elongate a pre-existing beam in flight and check its effect on runaway survival.



Poincare plot of DIII-D simulations: divertor vs. limiter [V. Izzo et al., NF 2011]

Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV		
WEST	20 pulses / 2 sessions	6 pulses (shapes)

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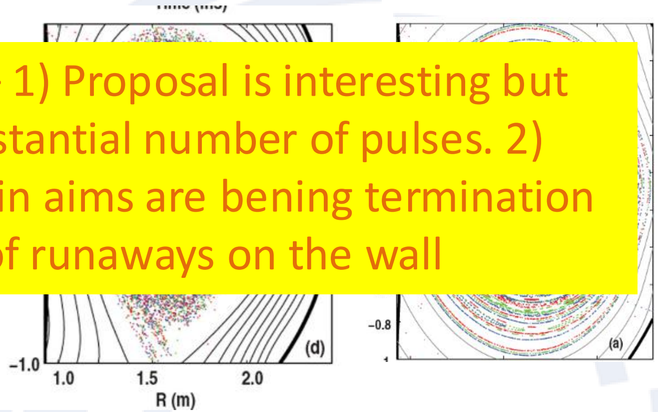
Priority: P2 – 1) Proposal is interesting but requires substantial number of pulses. 2) This year main aims are bening termination and impact of runaways on the wall



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Proposed pulses

Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV		
WEST	20 pulses / 2 sessions	6 pulses (shapes)

P40: Interaction between RE and high frequency waves

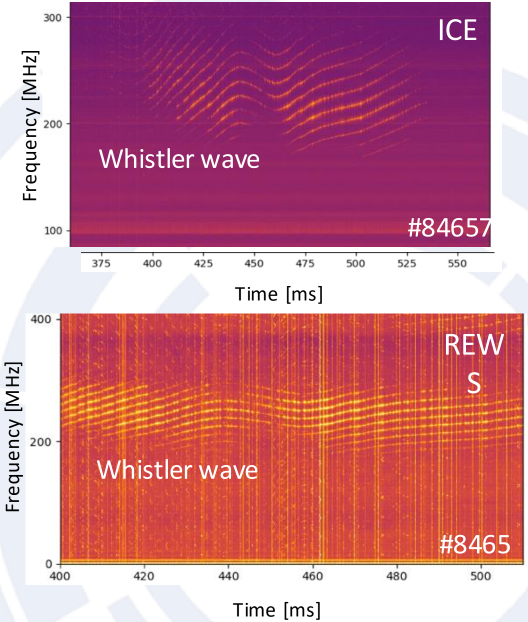
- **Proponents and contact person:**
  - Olivier Panico olivier.panico@epfl.ch et al.

- **Scientific Background & Objectives**
  - Runaway electrons (REs) can severely damage fusion reactors
  - Recent experiments show that high frequency waves (whistlers) can mitigate RE beams:
    - Expulse the RE seed => reduced post-disruption RE density
    - Limit maximum energy of REs

  - **Objectives**: characterize whistler waves together with RE dynamics
    - Properly identify whistler waves and their dispersion relation
    - Study impact of whistlers on RE dynamics

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Develop a solid scenario with both whistlers and runaways [5 pulses]
  - Verify theoretical scaling of whistler wave dispersion relation by scanning magnetic field, density and plasma current [10 pulses]
  - Study role of whistler on RE dynamic: RE confinement and pitch angle scattering [10 pulses]

- **Diagnostics:**
  - RE: HXRS, LaBrDoRE, BGO, PMTX, FILD
  - High frequency waves: ICE, LHPD, REWS



Proposed pulses

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

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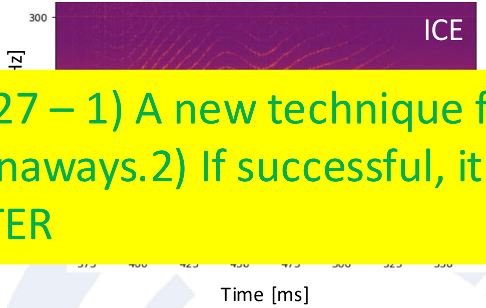
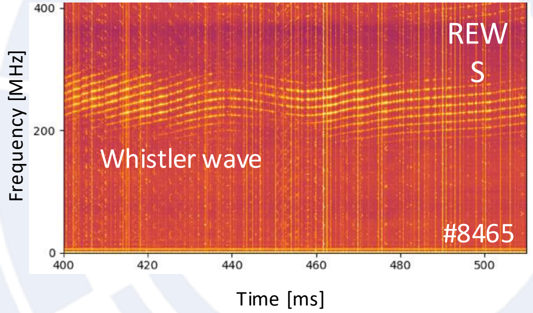


Priority: P1_2027 – 1) A new technique for dealing with runaways.2) If successful, it can be applied to ITER



Proposed pulses

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

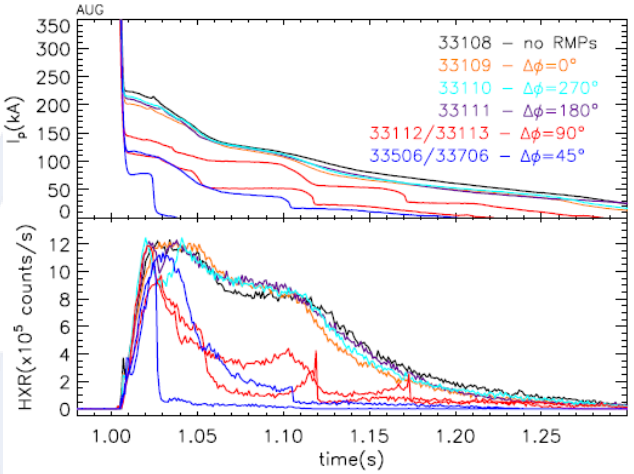
P41: Application of 3D fields in synergy with SPI for RE mitigation

- **Proponents and contact person:**

- M.Gobbin, O.Ficker, L.Marrelli, L.Pigatto, G.Papp, D.Terranova, E.Tomasina, E.Tomesova
  marco.gobbin@igi.cnr.it

- **Scientific Background & Objectives**
  - Magnetic perturbations (MP) are still considered as complementary RE dissipation methods in more devices (DIII-D, JT-60SA,DTT,SPARC) and recently have been applied successfully in AUG and COMPASS [1-2].
  - MP could be used to minimize the RE beam formation if applied prior to the current quench. The reduced RE beam current in this way could be more easily dissipated by SPI.
  - In AUG during a RE beam scenario, we propose to:
  - explore the possibility of reducing the final RE current acting with MP applied from the pre-disruption phase before the SPI injection;
  - determine the B-coil configuration more efficient to guarantee the maximum RE reduction when MP are applied in combination with SPI injection;
  - investigate the effect of MP on the SPI injection (also piggy-backed to other proposals).

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - The same scheme suggested in the proposal "*SPI-triggered runaway electron scenario on AUG*" could apply also to these experiments: 0-8-1MA/2.5T, IWL circular, ECRH 2-4 gyrotrons, D gas.
  - Execution of one reference shot: generation of a RE beam followed by SPI during the RE beam phase without MP (1shot).
  - Apply n=1 MP from a time preceding the disruption (500ms) and the SPI, performing a scan in the B-coil differential phasing (5 shots);
  - Diagnostics: COO interferometer, bolometry, magnetics, fast visible cameras, fast IR camera (desired), HXR, ECE, Ar MGI or Ar SPI to generate the RE beam.
  - For modelling/data interpretation: MARS-F, VMEC, ORBIT.



Past experiments with RE mitigation by MP in AUG: a reduction of the post-disruption RE current is obtained (down to -50%) for the differential phasing between upper/lower coils which maximizes the plasma response to the applied MP.

Proposed pulses

Device	# Pulses/Session	# Development
AUG	6	

[1] Gobbin M at al, Front. Phys. 12:1295082. (2024)
[2] Mlynar J et al, Plasma Phys. Control. Fusion 61 014010 (2019)

Note: This proposal was already submitted and approved (as P2) for the 2025 campaign. Preliminary modeling and analysis activity on the shots with SPI executed during this year is in progress. Some of these objectives require an already developed scenario with SPI injection during a RE beam phase that has not yet been developed.

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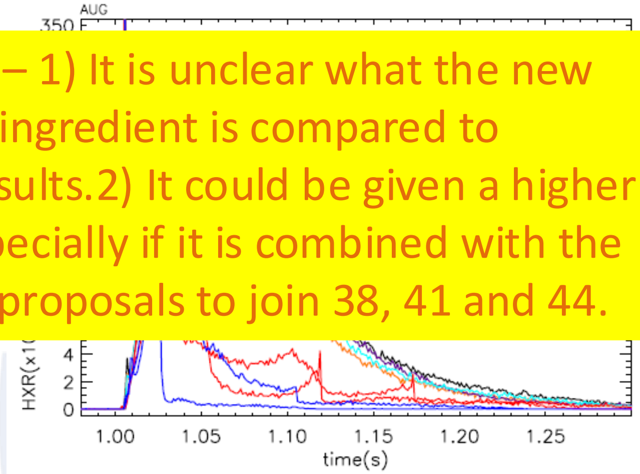

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  - Apply n=1 MP from a time preceding the disruption (500ms) and the SPI, performing a scan in the B-coil differential phasing (5 shots);
  - Diagnostics: COO interferometer, bolometry, magnetics, fast visible cameras, fast IR camera (desired), HXR, ECE, Ar MGI or Ar SPI to generate the RE beam.
  - For modelling/data interpretation: MARS-F, VMEC, ORBIT.

Proposed pulses

Device	# Pulses/Session	# Development
AUG	6	

[1] Gobbin M at al, Front. Phys. 12:1295082. (2024)
[2] Mlynar J et al, Plasma Phys. Control. Fusion 61 014010 (2019)

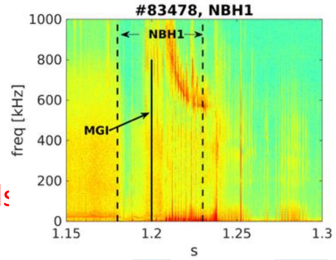
Note: This proposal was already submitted and approved (as P2) for the 2025 campaign. Preliminary modeling and analysis activity on the shots with SPI executed during this year is in progress. Some of these objectives require an already developed scenario with SPI injection during a RE beam phase that has not yet been developed.

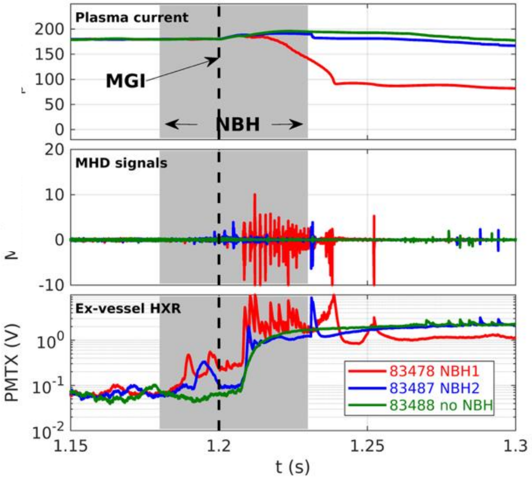
P42: Impact of turbulence and MHD on RE transport and confinement

- **Proponents and contact person**

  Joan Decker et al. (joan.decker@epfl.ch)

- **Scientific Background & Objectives**
  - Radial transport is the primary RE loss channel
  - Characterising RE transport necessary to build predictive models
  - MHD and turbulence can enhance RE transport significantly
    1. **Characterise the effect of turbulence on RE transport**
    2. **Investigate the interplay between MHD and RE dynamics**
    3. **NBI-induced MHD and RE beam formation**





- **Experimental Strategy/Machine Constraints and essential diagnostic**
  1. **Effect of turbulence on RE transport**
     - Build on ECRH-induced RE expulsion experiments, leverage new diags
     - Characterise effect of shaping (triangularity) and ITB formation
  2. **Interplay between MHD and RE dynamics**
     - Ohmic drive in high RE current regime -> MHD equilibrium and stability
     - Apply to both pre- and post-disruption RE beams
  3. **NBI-induced MHD and RE beam formation**
     - Build on existing NBI+MGI CQ scenario
     - Characterise MHD activity and RE radial transport

Proposed pulses

Device	# Pulses/Session	# Development
AUG	4	
MAST-U		
TCV	60	
WEST	4	

P42: Impact of turbulence and MHD on RE transport and confinement

- **Proponents and contact person**

Joan Decker et al. (joan.decker@epfl.ch)

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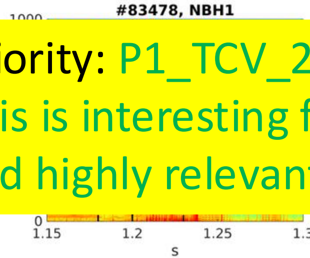
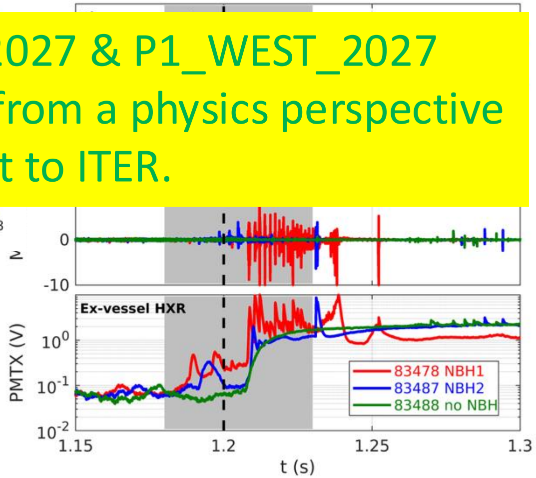


Priority: P1_TCV_2027 & P1_WEST_2027
This is interesting from a physics perspective and highly relevant to ITER.



- **Experimental Strategy/Machine Constraints and essential diagnostic**
  1. **Effect of turbulence on RE transport**
     - Build on ECRH-induced RE expulsion experiments, leverage new diags
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     - Apply to both pre- and post-disruption RE beams
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     - Build on existing NBI+MGI CQ scenario
     - Characterise MHD activity and RE radial transport

Proposed pulses

Device	# Pulses/Session	# Development
AUG	4	
MAST-U		
TCV	60	
WEST	4	

P43: Studies of runaway generation at plasma start-up

Proponents and contact person:

•basilio.esposito@enea.it , cedric.reux@cea.fr, gustavo.granucci@istp.cnr.it, et al.

Scientific Background & Objectives

Background

•Low pre-filled gas pressure for **ohmic plasma initiation** required in ITER → possibly leading to exceeding threshold electric field for the effective Dreicer generation.

•Alternative: **ECRH assisted plasma initiation** may allow operation at a higher pre-fill gas pressure, → in principle beneficial environment to avoid runaways

•However, some experimental evidence (FTU)and theoretical predictions show that ECRH may affect electron distribution function

→ **possibility of runaway electrons in ITER when using ECRH assisted plasma initiation cannot be completely excluded see Figures**.

Objectives

1) explore **runaway dynamics at plasma start-up both with and without the use of ECRH**

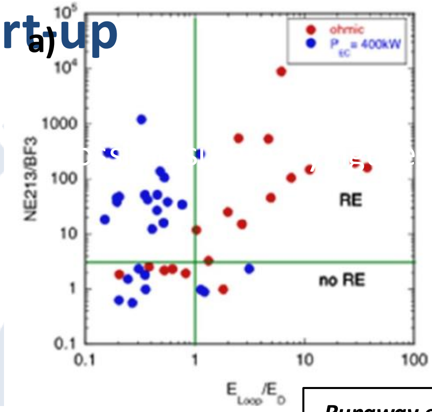
2) determine the most favourable conditions to avoid runaway generation at start-up by **varying the following parameters: (gas pre-fill, with/without ECRH, ECRH power, ECRH injected mode (OM1 and/or XM1 by mode conversion at inner wall reflection with toroidal angle 20° tb**c).

Experimental Strategy/Machine Constraints and essential diagnostic

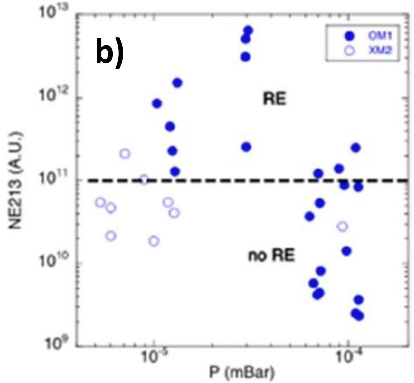
•low density discharge scenario from RT03-2025 runaway experiments

•REIS, visible and fast infrared cameras, ECE, neutrons, ME-HXR

a)



b)



Runaway electron presence in EC-assisted start-up discharges in FTU
a) as a function of E/E_D
b) as a function of pressure

Proposed pulses

Device	# Pulses/Session	# Development
WEST	15	2

P43: Studies of runaway generation at plasma start-up

Priority: P1_WEST_27 and try to do this partially in piggy-back

Proponents and contact person:

•basilio.esposito@enea.it , cedric.reux@cea.fr, gustavo.granucci@istp.cnr.it, et a

Scientific Background & Objectives

Background

•Low pre-filled gas pressure for **ohmic plasma initiation** required in ITER → possibly leading to exceeding threshold electric field for the effective Dreicer generation.

•Alternative: **ECRH assisted plasma initiation** may allow operation at a higher pre-fill gas pressure, → in principle beneficial environment to avoid runaways

•However, some experimental evidence (FTU)and theoretical predictions show that ECRH may affect electron distribution function

→ **possibility of runaway electrons in ITER when using ECRH assisted plasma initiation cannot be completely excluded see Figures**.

Objectives

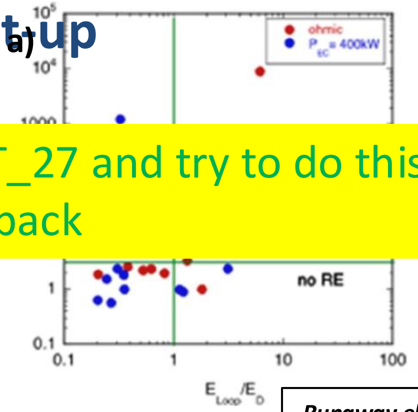
1) explore **runaway dynamics at plasma start-up both with and without the use of ECRH**

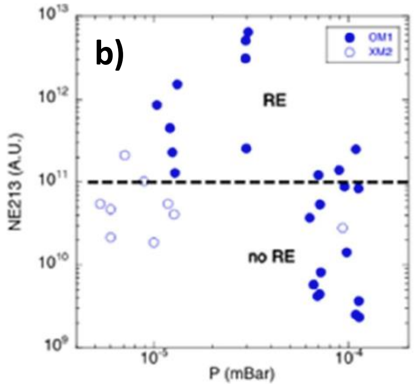
2) determine the most favourable conditions to avoid runaway generation at start-up by **varying the following parameters: (gas pre-fill, with/without ECRH, ECRH power, ECRH injected mode (OM1 and/or XM1 by mode conversion at inner wall reflection with toroidal angle 20° tb**c).

Experimental Strategy/Machine Constraints and essential diagnostic

•low density discharge scenario from RT03-2025 runaway experiments

•REIS, visible and fast infrared cameras, ECE, neutrons, ME-HXR





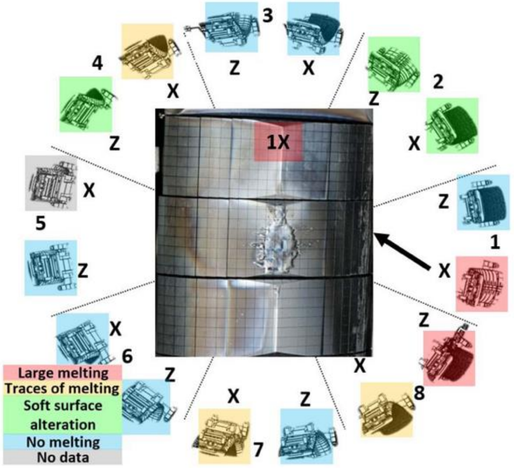
Runaway electron presence in EC-assisted start-up discharges in FTU
a) as a function of E/E_D
b) as a function of pressure

Proposed pulses

Device	# Pulses/Session	# Development
WEST	15	2

P44: Runaway impact asymmetries

- **Proponents and contact person:**
  - Cédric Reux et al., cedric.reux@cea.fr
- **Scientific Background & Objectives**
  - Runaway electron beam impacts are known to be toroidally asymmetrical (Reux et al. NF 2015, Jepu et al., NF 2024), focusing heat loads on an even smaller area.
  - The pattern is consistent over several years of experiments, but is neither completely deterministic on a pulse-by-pulse basis, nor exhibits a defined toroidal period.
  - Two assumptions can be made to explain the pattern:
    - PFC misalignments
    - Intrinsic 3D nature of the beam either due to TF ripple or MHD instabilities locking always at eh same places due to error fields, or a combination of both
  - The objective is to determine which factors play the largest role in the pattern.
    - Measure the minimal misalignment needed to focus the impact on a single limiter
    - Measure the dependence between the magnitude of the error field and the asymmetry (if any)
- **Experimental Strategy/Machine Constraints and essential diagnostics**
  - Use the longest possible runaway beam scenario
  - Scan the position of the sample manipulator from behind all other limiters +2 cm up to fully brought forward, if possible ahead of other objects radially.
  - Scan the magnitude of the RMP using B-coils in a n=1 perturbation.
  - Repeat the RMP scan with a n=2 pattern
  - On WEST (exploratory) : scan the ripple by switching off one or several TF coils, depending on what is technically possible.



Runaway impact pattern over the whole JET-ILW lifetime – Jepu et al., NF 2024

Proposed pulses

Device	# Pulses/Session	# Development
AUG	28	0
MAST-U		
TCV		
WEST	4 (exploratory)	4

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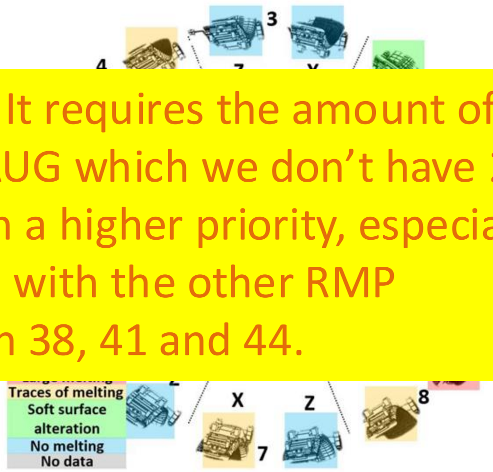
- **Experimental Strategy/Machine Constraints and essential diagnostics**
  - Use the longest possible runaway beam scenario
  - Scan the position of the sample manipulator from behind all other limiters +2 cm up to fully brought forward, if possible ahead of other objects radially.
  - Scan the magnitude of the RMP using B-coils in a n=1 perturbation.
  - Repeat the RMP scan with a n=2 pattern
  - On WEST (exploratory) : scan the ripple by switching off one or several TF coils, depending on what is technically possible.

Priority: P2 – 1) It requires the amount of discharges for AUG which we don't have 2) It could be given a higher priority, especially if it is combined with the other RMP proposals to join 38, 41 and 44.



Runaway impact pattern over the whole JET-ILW lifetime – Jepu et al., NF 2024

Proposed pulses

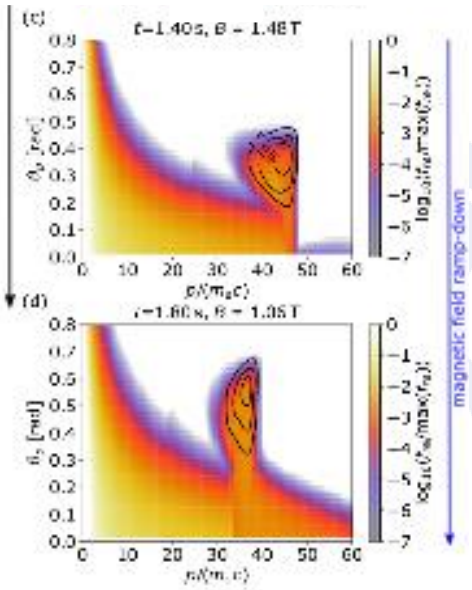
Device	# Pulses/Session	# Development
AUG	28	0
MAST-U		
TCV		
WEST	4 (exploratory)	4

P45: Toroidal Field Ripple Manipulation for RE Studies

- **Proponents and contact person:**
  - Alexander.battey@epfl.ch
  - Umar Sheikh
  - Basil Duval
  - Joan Decker

- **Scientific Background & Objectives**
  - Explore the resonance between runaway electrons and toroidal field ripple
  - Novel hardware upgrade will allow for the ripple amplitude to be scanned for systematic comparison with modeling
  - Determine the effect of ripple n-number and amplitude on maximum RE energy as measured by MANTIS

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Leverages the existing RE scenario
  - MANTIS
  - Standard RE diagnostic suite



T.A. Wijkamp etal 2024 Nucl.Fusion 64 016021

Proposed pulses

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

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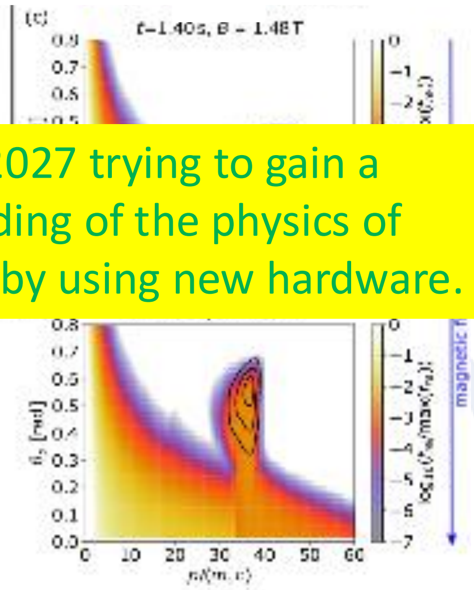
- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Leverages the existing RE scenario
  - MANTIS
  - Standard RE diagnostic suite

Priority: P1_TCV_2027 trying to gain a deeper understanding of the physics of runaways for ITER by using new hardware.



T.A. Wijkamp etal 2024 Nucl.Fusion 64 016021

Proposed pulses

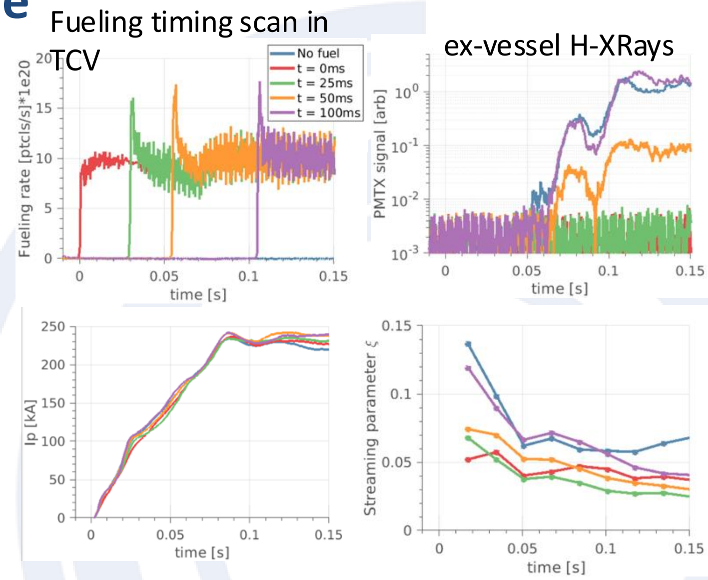
Device	# Pulses/Session	# Development
AUG		
MAST-U		
TCV	20	5
WEST		

P46: Physics of runaway generation during the tokamak start-up phase including inductive, EC assisted burn-through and EC pre-ionization

- **Proponents and contact person:**
  - Pedro Molina-Cabrera, Mathias Hoppe, Joan Decker, Stefano Coda, Panagiotis Papagiannis, Christos Tsironis, Dimosthenis Vallis, Umar Sheikh

- **Scientific Background & Objectives**
  - Burn-through simulations are actively progressing but must move towards rigorous validation including uncertainty quantification and a comparison metric.
  - Burn-through simulations including runaway electrons have only been compared with experiments in the JET tokamak.
  - Experiments are proposed in AUG, TCV, and WEST to develop well-diagnosed plasmas with and without runways during the startup to serve as a comprehensive data-set for validation and to test our understanding of the effects of size, B-field, and wall material
  - Once a robust scenario is developed, it is proposed to apply EC power before and after the breakdown to observe the effects EC power has on the runaway generation and transport.

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Develop identical plasma shape LSN, delta = 0.3, and kappa = 1.3 on all 3 machines
  - Vary prefill density and fuelling during burn-through/ramp-up phase while maintaining a large E field to develop a large amount of start-up runaways. Scan both density and applied E-field once a robust scenario is found
  - Apply EC power before and after the breakdown to see effects on runaway population. Scan power input and timing after breakdown.
  - Runaway diagnostics in every machine are vital for this mission (H-Xrays, ECE, Neutron detectors, visible-light cameras)



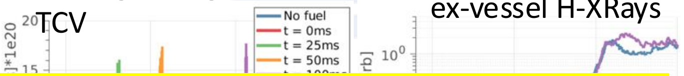
Proposed pulses

Device	# Pulses/Session	# Development
AUG	12	10
MAST-U	0	0
TCV	20	2
WEST	20	2

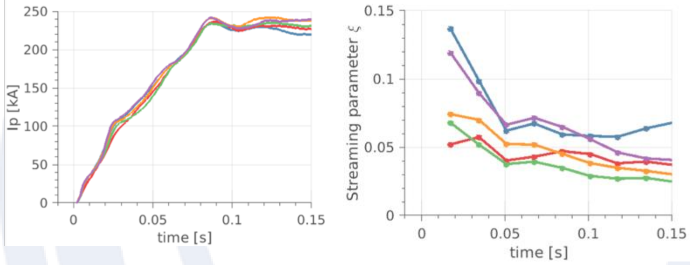
P46: Physics of runaway generation during the tokamak start-up phase including inductive, EC assisted burn-through and EC pre-ionization

Fueling timing scan in TCV

ex-vessel H-XRays



Priority: P1_TCV_2026 & P1_WEST_2026 important startup studies but P2_AUG due to lack of required pulses.



- **Proponents and contact person:**
  - Pedro Molina-Cabrera, Mathias Hoppe, Joan Decker, Stefano Coda, Panag… Christos Tsironis, Dimosthenis Vallis, Umar Sheikh

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Proposed pulses

Device	# Pulses/Session	# Development
AUG	12	10
MAST-U	0	0
TCV	20	2
WEST	20	2

P47: Studying the plasmoid drift in AUG SPI experiments

- **Proponents and contact person:**
- Patel Ansh, G. Papp, P. Heinrich, S. Jachmich, U. Sheikh, A. Moreau, W. Tang, M. Hoelzl, P. Halldestam
  Anshkumar.Patel@ipp.mpg.de

- **Scientific Background & Objectives**

  Quantify the plasmoid drift effect for different fragment parameters (size and speed) along with possible drift suppression with neon doping in the pellet
  - AUG SPI in unique position due to multiple guide tubes and shatter heads configuration
  - First dedicated shots to study the effect of different fragment sizes and speeds on the drift

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Standard SPI H-mode model used in previous campaigns, utilizing the flexible AUG SPI system
  - 5 different shattering configurations (for different frag sizes and speeds) and 4 different neon content values (=20 shots)
  - Better usage/upgrades of diagnostics
    - Fast cameras observing material penetration tested with different filter and exposure settings
    - New dispersion interferometer tested in 2025 allowed for measurements of fast transients of density rise
    - Updated time difference between pellet arrival and Thomson Scattering laser firing to allow for material assimilation measurements while avoiding strong ablation background light

Proposed pulses

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

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    - New dispersion interferometer tested in 2025 allowed for measurements of fast transients of density rise
    - Updated time difference between pellet arrival and Thomson Scattering laser firing to allow for material assimilation measurements while avoiding strong ablation background light

Priority: P1_AUG_2026 1)High importance for modelling and ITER. 2) Numbers should be reduced (50%?). We can not afford to make all these pulses.

Proposed pulses

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

P48: Influence of tungsten (W) on the runaway electron generation and benign termination scenario

- **Proponents and contact person:**

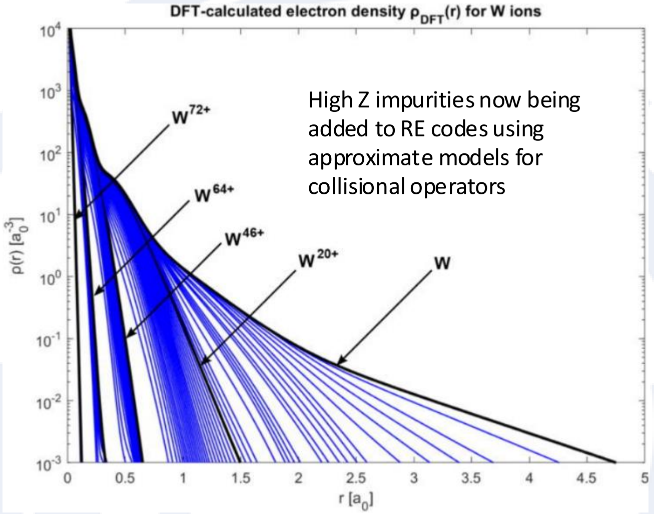
Ondrej Ficker (ficker@ipp.cas.cz), Umar Sheikh, Cédric Reux, Jedrzej Walkowiak, Axel Jardin, Vladislav Plyusnin, Sergei Gerasimov, Gergely Papp, Matthias Hoppe, Peter Halldestam and others

- **Scientific Background & Objectives**
  - Addressing RT3 D10 and D11
  - **ITER relevant impurity affecting RE generation and mitigation?**

[1] Design scenario with enhanced W concentration during disruption with RE generation

[2] Quantify the effect of tungsten if possible.

[3] Increase the W concentration in post-disruption RE beam and observe the effects on benign termination if any.



High Z impurities now being added to RE codes using approximate models for collisional operators

[Walkowiak et al. *Phys. Plasmas* 29, 022501 (2022)]

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Standard or alternative RE scenario at AUG and WEST
    - Optimise timing of W LBO during MGI/SPI disruption with RE beam generation
    - Depending on observed results select a suitable scan (current, Ar pressure, etc.)
    - For effects on benign termination, trigger LBO in the recombined phase and terminate the beam by compression after a delay allowing the spreading of the W pollution

Working RE generation and benign termination scenario crucial.
All available RE, disruption and W diagnostics desirable.

Proposed pulses

Device	# Pulses/Session	# Development
AUG	4	1
MAST-U		
TCV		
WEST	3	1

P48: Influence of tungsten (W) on the runaway electron generation and benign termination scenario

- **Proponents and contact person:**

Ondrej Ficker (ficker@ipp.cas.cz), Umar Sheikh, Cédric Reux, Jedrzej Walkowiak, Vladislav Plyusnin, Sergei Gerasimov, Gergely Papp, Matthias Hoppe, Peter Hall… others

Priority: P2 – 1) It's interesting, but we can't afford to conduct all the studies, and this is not the most urgent issue for ITER currently.

- **Scientific Background & Objectives**
  - Addressing RT3 D10 and D11
  - **ITER relevant impurity affecting RE generation and mitigation?**

[1] Design scenario with enhanced W concentration during disruption with RE generation

[2] Quantify the effect of tungsten if possible.

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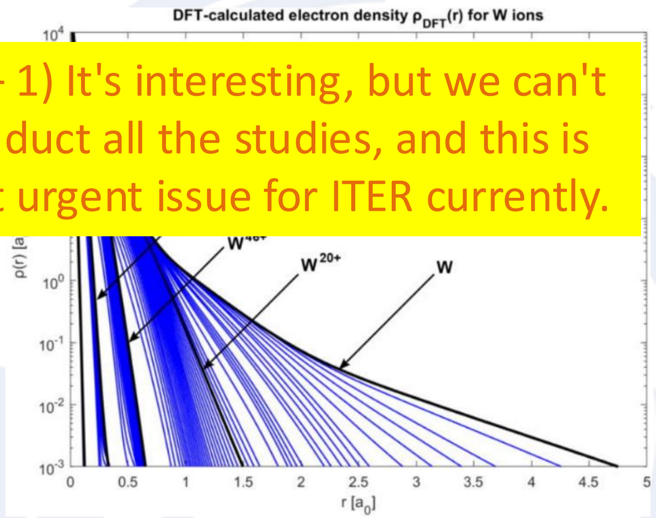


[Walkowiak et al. *Phys. Plasmas* 29, 022501 (2022)]

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Standard or alternative RE scenario at AUG and WEST
    - Optimise timing of W LBO during MGI/SPI disruption with RE beam generation
    - Depending on observed results select a suitable scan (current, Ar pressure, etc.)
    - For effects on benign termination, trigger LBO in the recombined phase and terminate the beam by compression after a delay allowing the spreading of the W pollution

Working RE generation and benign termination scenario crucial.
All available RE, disruption and W diagnostics desirable.

Proposed pulses

Device	# Pulses/Session	# Development
AUG	4	1
MAST-U		
TCV		
WEST	3	1

P49: SPI into tungsten accumulation at AUG

- **Proponents and contact person:**

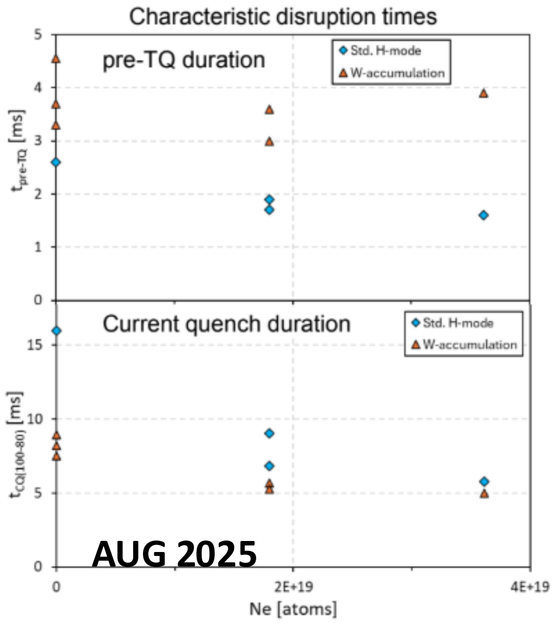
Ondrej Ficker (ficker@ipp.cas.cz), Stefan Jachmich, Umar Sheikh, Gergely Papp, Paul Heinrich, Peter Halldestam, Ansh Patel, Andres Orduna Martinez, Andrew Moreau

- **Scientific Background & Objectives**
  - Pre-TQ times significantly varied with W accumulation (both on JET and AUG)
  - Crucial for proper DMS setup – is the MHD mode structure significantly affecting the characteristic times
  - *Characterize how W accumulation together with critical MHD instabilities affects the SPI disruption*
  - *Understand whether prolongation of pre-TQ time*

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

- Start with previous reference #43194
- Enhance MHD activity (ideally mode lock) during SPI injection either by timing or using RMPs
- SPI setup Pure D2 and 2 different Neon contents (same as in 2025)
- Staggered scheme into the configuration with logest pre-TQ time
- Complement internal proposal on W concentration influence on SPI disruptions

All available SPI diagnostics (Dispersion interferometer, fast cameras, bolometers, etc.) + W spectroscopy

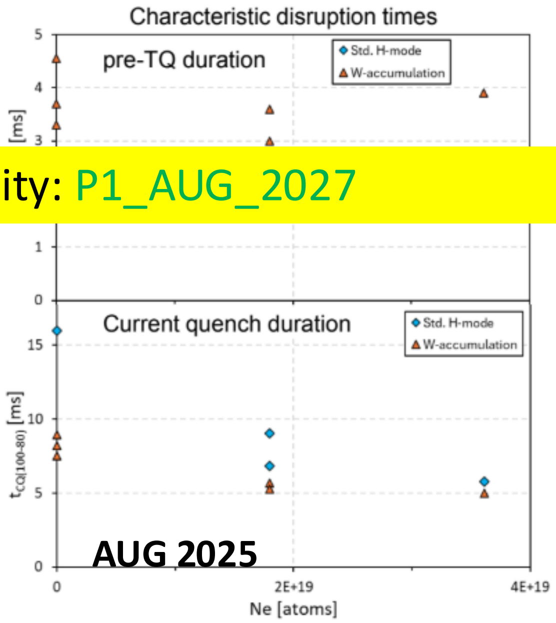


Proposed pulses

Device	# Pulses/Session	# Development
AUG	6	2
MAST-U		
TCV		
WEST		

P49: SPI into tungsten accumulation at AUG

Priority: P1_AUG_2027



- **Proponents and contact person:**

Ondrej Ficker (ficker@ipp.cas.cz), Stefan Jachmich, Umar Sheikh, Gergely Papp, Paul Heinrich, Peter Halldestam, Ansh Patel, Andres Orduna Martinez, Andrew Moreau

- **Scientific Background & Objectives**
  - Pre-TQ times significantly varied with W accumulation (both on JET and AUG)
  - Crucial for proper DMS setup – is the MHD mode structure significantly affecting the characteristic times
  - *Characterize how W accumulation together with critical MHD instabilities affects the SPI disruption*
  - *Understand whether prolongation of pre-TQ time*

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

- Start with previous reference #43194
- Enhance MHD activity (ideally mode lock) during SPI injection either by timing or using RMPs
- SPI setup Pure D2 and 2 different Neon contents (same as in 2025)
- Staggered scheme into the configuration with logest pre-TQ time
- Complement internal proposal on W concentration influence on SPI disruptions

All available SPI diagnostics (Dispersion interferometer, fast cameras, bolometers, etc.) + W spectroscopy

Proposed pulses

Device	# Pulses/Session	# Development
AUG	6	2
MAST-U		
TCV		
WEST		

P50: Alternative runaway electron scenario for ASDEX Upgrade

- **Proponents and contact person:**

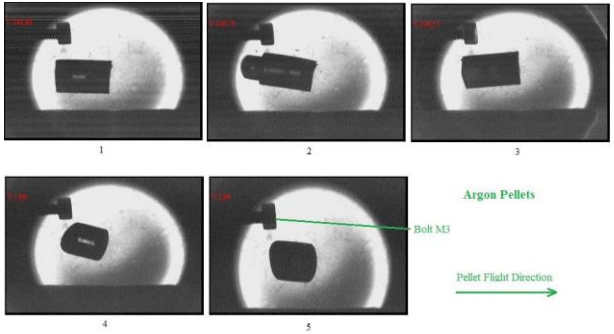
Gergely Papp, P. Heinrich, P. Halldestam, A. H. Patel, A. Orduna-Martinez, J. Decker, U. Sheikh, O. Ficker, M. Hoppe, V. Bandaru
gergely.papp@ipp.mpg.de

- **Scientific Background & Objectives**

  The goal is to develop an alternative runaway electron scenario on ASDEX Upgrade, and to perform param. scans.
  - Modeling input for combined SPI+RE model validation (little data available so far)
  - Potential alternative AUG RE scenario in case of in-vessel MGI valve issues mid-campaign
  - Scenario development aided by DREAM simulations

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Needs development of Ar SPI recipes on non-shot days!
  - Injection of Ar pellets into typical MGI RE scenario plasmas, such as e.g. #41337 (limiter, L-mode, ne =3e19)
  - If that fails, use fuelling valve argon injection or develop flat-top RE scenario
  - Needs Ar SPI, disperision interferometry, bolometry, HXR, ECE, fast cameras (vis+IR), MANTIS

Shadowgraphy of argon pellets during commissioning (PELIN)



Proposed pulses

Device	# Pulses/Session	# Development
AUG	8	3
MAST-U	-	-
TCV	-	-
WEST	-	-

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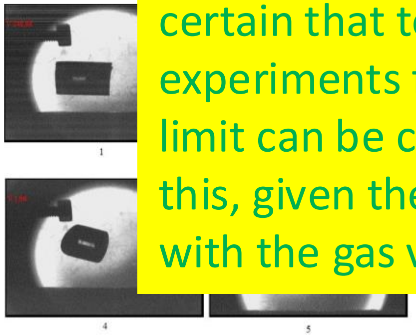


Priority: P1_AUG_2026 This is because it is not possible to be certain that termination experiments for the high-pressure limit can be conducted without this, given the current situation with the gas valves in the AUG.

Proposed pulses

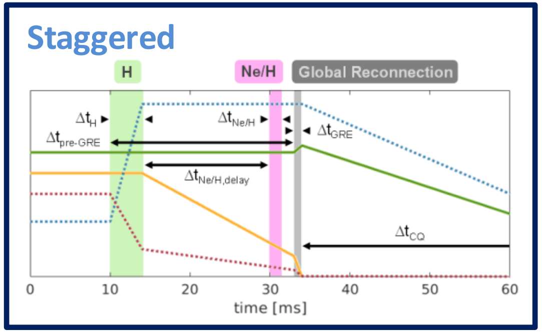
Device	# Pulses/Session	# Development
AUG	8	3
MAST-U	-	-
TCV	-	-
WEST	-	-

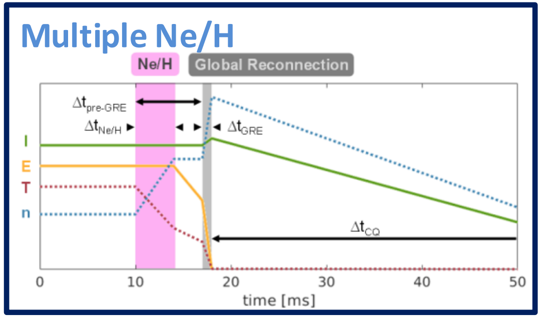
P51: Viability of staggered and dual injection schemes using AUG SPI

- **Proponents and contact person:**
  Stefan Jachmich, Gergely Papp, Umar Sheikh, Ansh Patel, Paul Heinrich, Ondrej Ficker, Andrew Moreau

- **Scientific Background & Objectives**
  - The staggered injection scheme has several advantages:
    - Slow energy loss
    - Electron temperature cooling
    - Less neon required for W_{th} load mitigation during GRE
  - Issues arose from the limited core fuelling in the first phase due to plasmoid and rocket effect for LFS injection
  - Studies been conducted to reduce plasmoid effect
  - Objectives:
    - How large is the densification prior CQ onset for RE avoidance?
    - What is minimum required Neon amount for final thermal load mitigation during GRE?
    - Is the scheme applicable to plasmas with intrinsic impurities (W, Ne)?

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Essential: SPI, fast camera, bolometers, standard diagnostic for density measurements.
  - First injection with D or Ne-trace D, followed by Ne/D when max density reached: might require small timing scan (+/- 2 ms)
  - Reduce or increase Ne-fraction depending on outcome of previous pulse (frad?)
  - Apply to second target plasma: either W-accumulation (if reproducible) or seeded
  - References with dual injection (i.e. dt=0 ms) required





Proposed pulses:

Device	# Pulses	# Development
AUG	12	0
MAST-U	0	0
TCV	0	0
WEST	0	0

P51: Viability of staggered and dual injection schemes using AUG SPI

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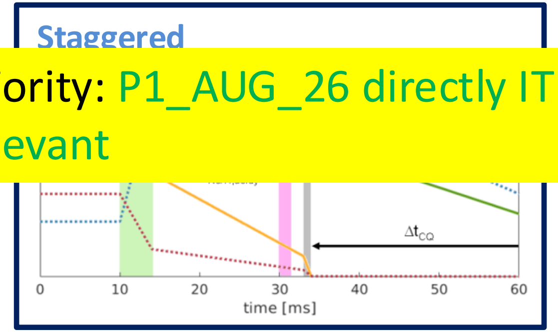
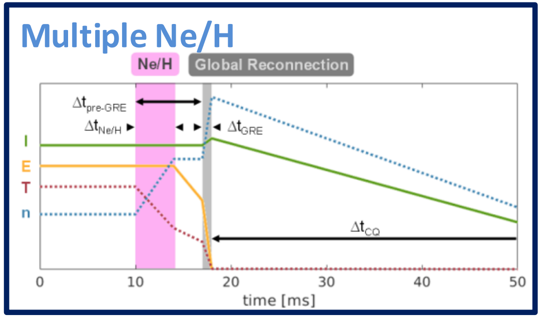


Priority: P1_AUG_26 directly ITER relevant



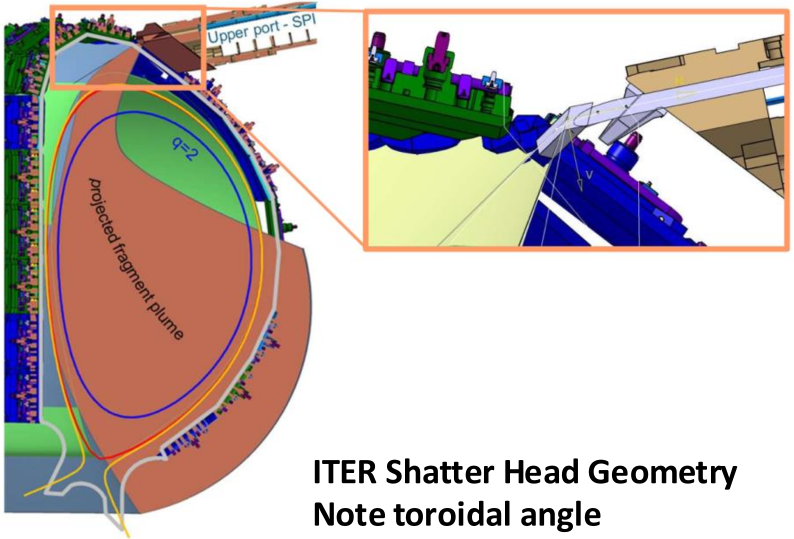
Proposed pulses:

Device	# Pulses	# Development
AUG	12	0
MAST-U	0	0
TCV	0	0
WEST	0	0

P52: Material assimilation in low Te plasma with AUG SPI

- **Proponents and contact person:**
  - Stefan Jachmich (stefan.Jachmich@iter.org), Umar Sheikh, Javier Artola, Gergely Papp, Ansh Patel, Paul Heinrich, Ondrej Ficker, Peter Halldestam, Sergei Gerasimov

- **Scientific Background & Objectives**
  - The ITER DMS must provide a backup method for plasma termination and magnetic energy dissipation in the event of a missed pre-TQ injection.
  - This function is essential due to the typically low electron temperature (Te) at this late stage, which severely compromises fuel assimilation.
  - ITER DMS utilises toroidally tilted shatter heads.
    - AUG SPI is the only system that can replicate this



ITER Shatter Head Geometry
Note toroidal angle

- **Experimental Strategy/Machine Constraints and essential diagnostic**
  - Essential: Dispersion interferometer, SPI, fast camera, bolometers, TS.
  - Build upon MGI injection for density limit scenario
    - 3-4 neon fractions (depending on results)
  - SPI to be triggered on CQ-detection or pre-timed

Proposed pulses

Device	# Pulses/Session	# Development
AUG	5-6	0
MAST-U	0	0
TCV	0	0
WEST	0	0

P52: Material assimilation in low Te plasma with AUG SPI

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  - Stefan Jachmich (stefan.Jachmich@iter.org), Umar Sheikh, Javier Artola, Gergely Papp, Ansh Patel, Paul Heinrich, Ondrej Ficker, Peter Halldestam, Sergei Gerasimov

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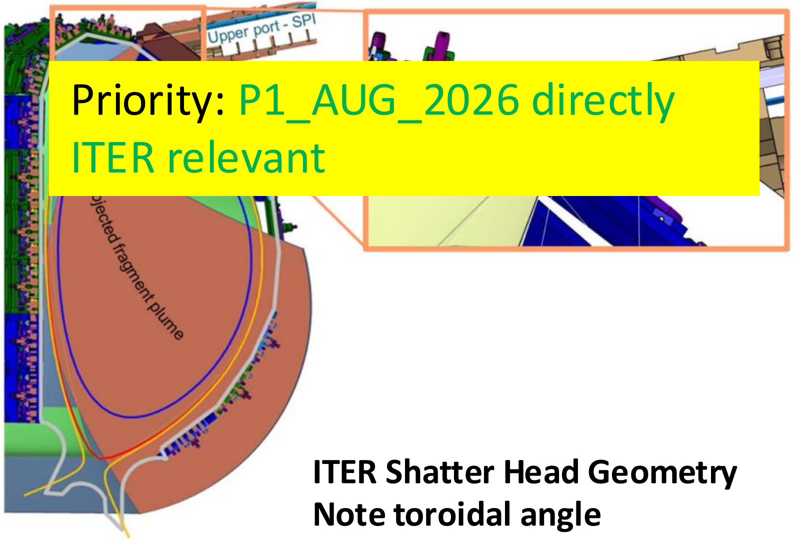

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Proposed pulses

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AUG	5-6	0
MAST-U	0	0
TCV	0	0
WEST	0	0

Conclusions

- The main objectives were reformulated due to archived progress and new questions for ITER
- **Largest contributor to the scientific programme** is TCV in 2026 with dedicated experiments on AUG and WEST
    - ✓ Aim to take the multimachine aspects into account even in the absence of JET
    - ✓ Ample machine time on TCV to fit at least the P1 proposals in and time may allow executing also parts of P2 proposals
- **The programme focused primarily on the following subjects:**
    - ✓ Benning termination experiments (in particular high pressure limit)
    - ✓ Unresolved problems of SPI
        - ✓ Plasmoid drift
        - ✓ Staggered and dual injection schemes
        - ✓ Material assimilation
    - ✓ Novel methods which should give the physical understanding
        - ✓ Interaction with waves
        - ✓ Interaction with coils