Work-Package Theory and Modelling (WPTM): 2026 highlights (part I)

Xavier LITAUDON (Project Leader), Gloria FALCHETTO (Project Support Officer) on behalf of the TSVV PIs

CEA lead lab. for WPTM

xavier.litaudon@cea.fr

Thanks to TSVV PIs for their constructive inputs

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

11 TSVV Projects, lead beneficiary and multi-beneficiary involvement

	TSVV titles	Principal Investigator	Lead Beneficiary	Other Beneficiaries involved
A	H-Mode and Small/No-ELM Pedestals	Tobias Görler	*MPG*	CEA, DIFFER, ENEA, EPFL
B	Plasma Particle/Heat Exhaust – Fluid Simulations	Patrick Tamain	CEA	DTU, EPFL, IPP.CR, LPP-ERM-KMS, MPG
C	Plasma Particle/Heat Exhaust – Gyrokinetic Simulations	Daniel Told	MPG	CEA, DIFFER, EPFL, IPP.CR, JSI
D	Plasma-Wall Interactions with Metallic Plasma-Facing Components	Dmitry Matveev	FZJ	CEA, DIFFER, IPP.CR, MPG, VR, VTT
E	Impurity Sources, Transport, and Screening	Guido CIRAOLO	CEA	EPFL, FZJ, IPP.CR, IPPLM, VTT
F	Tokamak Disruptions and Runaway Electrons	Matthias Hoelzl	*MPG*	CEA, ENEA, EPFL, VR
G	Physics of Burning Plasmas	Oleksiy Mishchenko	MPG	CEA, ENEA, EPFL, KIPT, NCSRD, UKAEA
H	Reliable Prediction of Plasma Performance and Operational Limits in Tokamaks	Michele Marin	*EPFL*	CEA, DIFFER, ENEA, EPFL, IPP.CR, IST, LPP-ERM-KMS, MPG, UKAEA, VR
I	Stellarator Optimization	Joaquim Loizu	*EPFL*	CIEMAT, EPFL, MPG, OEAW
J	Stellarator core turbulence	José Manuel García-Regaña	*CIEMAT*	DIFFER, EPFL, MPG, UKAEA
K	Neutral Particle Models	Dmitriy V. Borodin	*FZJ*	CEA, DIFFER, ENEA, FZJ, LPP-ERM-KMS, VTT

Key Objectives/Focus of the 2026-2027 Work-Programme per TSVVs

A	Develop the capability to perform self-consistent, robust, and validated gyrokinetic simulations of L-H transitions, enabling accurate H-mode pedestal profile predictions. Gyrokinetic simulations of small/no-ELM regimes, transferability to future fusion devices, including ITER
B	Turbulent transport in the SOL with physics of neutrals, impurities, isotopes as well as PWI. Generalization to non-axisymmetric geometries
C	Particle/heat exhaust based on gyrokinetic equations under conditions relevant to a semi-collisional edge and SOL, physics of neutrals and impurities. Generalization to non-axisymmetric geometries
D	First-wall erosion, mixed-material formation, dust generation and transport, and fuel inventory as function of neutron damage. Enhanced models to simulate transients
E	W impurity distributions (sources, transport, screening) and impact on performance. Effects of 3D perturbations and ELM suppression on W impurity and seed impurity distributions in ITER
F	Disruptions, in particular in W-devices. model for runaway electron beam generation and losses, dynamics and mitigation to be integrated into modelling tools and nonlinear MHD
G	Mutual interaction of energetic particles, MHD modes, turbulence, and kinetic plasma profiles in tokamak and stellarator
H	Breakdown to termination scenarios - metallic wall conditions (ITER). Model validation, code exploitation and deployment
I	Stellarator optimisation codes with enhanced speed and greater scope
J	3D Gyrokinetic turbulence codes and validation. Reduced turbulent transport models
K	Neutrals, first principles to reduced models and integration fluid and gyrokinetic edge turbulence simulation

WPTM Grant Deliverables and Milestones

ID	*Deliverable Title*	*Date*	*Comments*
TM.D.01	**Report on code dissemination, model validation, and comparison with experimental data (for both tokamaks and stellarators)**	**31.12.2027**	**On track**
TM.D.02	**Report on TSVV Research Software Compliance with EUROfusion Standards (Priority 1 and 2 Criteria)**	**31.12.2027**	**On track**

ID	*Milestone Title*	*Date*	*Comments*
TM.M.01	**Formal coordination established with experimental WPs for model validation and requirement capture for data comparison.**	**31.01.2027**	**on track**
TM.M.02	**Formal coordination established with ACHs in support to TSVV Research Software compliance with EUROfusion standards.**	**31.01.2027**	**on track**

WPTM Grant Milestones deadline 15/01/2027: on track !

- **Formal coordination established with experimental WPs for model validation and requirement capture for data comparison**
- **Formal coordination established with ACHs in support to TSVV Research Software compliance with EUROfusion standards**

Significant progress - No issue to be reported

- **EUROfusion Science Meeting: TSVV Final Reports 2021-2025**
- **Second E-TASC General Meeting: ACH, TSVV PI with PLs**
- **Bi-weekly WPTM coordination meeting with TSVV PIs, representatives of the experimental Work-Packages, DSO representatives**
  - minutes distributed to all and on the WPTM Wiki
  - presentation of the modelling activities and needs made by WPTE & WPSTEL PLs
- **TSVV PIs & WPTM PL Participation in the WPPWIE annual meeting**
- **WPTM Wikis and list of pulses under analysis (e.g. TSVV-H)**
- **Monitoring of the WPTM publications using experimental data**
- **WPTM participation in DSO meetings, WPTM PL member of the HPC/Gateway Project Board and co-chair of the E-TASC board**
- **WPTM PL participation in the IO-IMEG meeting**
  - coming challenge: IMAS transition to the new version 4

TM Grant Deliverables deadline 31/12/2027 Significant progress

- **Report on code dissemination, model validation, and comparison with experimental data (tokamaks and stellarators)**

⇒ **focus on model validation (cf next slides) 2026 highlights from cross TSVV-activities jointly with WPTE, WPSTEL and WPPWIE**

- Gyrokinetic pedestal, Edge and Scrape-off Layer Turbulence in H- mode Plasmas (AUG, TCV)
- The L-H transition in tokamaks (fluids): power threshold, density minimum (multimachine ITPA database)
- Global gyrokinetic simulations in negative and positive triangularity (AUG, DIII-D, TCV, WEST)
- Simulations of the Self-Organized Plasma Vortex as a mechanism for Stable Radiative Divertor (XPR) Operation (WEST)
- Integrated modelling of disruptions and their mitigation, runaway electron beam termination (TCV, WEST, AUG, JET, DIII-D)
- Modelling for W erosion and migration (WEST, AUG) core-edge-SOL self-consistent coupling
- Large scale integrated modelling validation (TCV, WEST)
- Integrated simulations: W-dust ingress & core performance (WEST)
- HFPS Validation ongoing for relatively high β, tritium rich scenarios (JET)
- fuelling : Improved and faster pellet modelling & model validation
- Gyrokinetic Simulations of Magnetic Geometry and Radial Electric Field Effects on Turbulent Transport (Wendelstein 7-X)
- etc …

- **Report on TSVV Research Software Compliance with EUROfusion Standards**

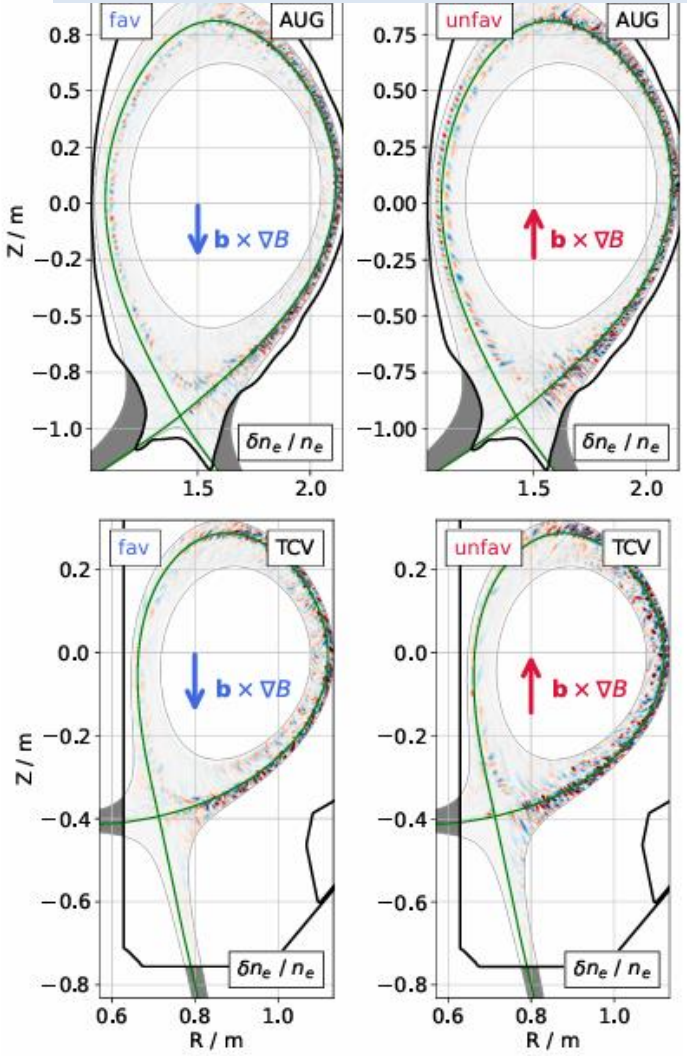
⇒ **New Open source release or under discussion , e.g.:**

- JOREK open source, discussion for the HFPS open source end of 2027 (without all the submodules), FIREWALL: a surrogate model for the rapid assessment of tokamak wall loading and melting by runaway electrons

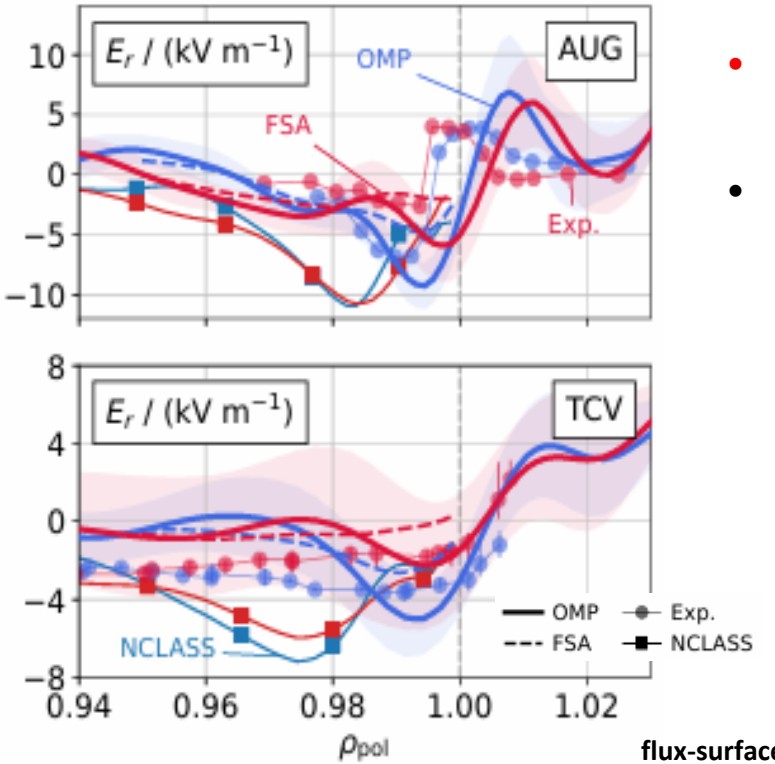
=> But Work-force reduction in 2027 will impact on code dissemination and compliance to standard software

First-principles gyrokinetic simulations of the edge and scrape-off layer in ASDEX Upgrade and TCV

Turbulent Origin of the Edge Radial Electric Field Asymmetry between Favourable and Unfavourable Drift Configurations: importance for L-H power threshold



- **Influence of the ion magnetic drift direction with respect to the active X-point on edge turbulence, transport and radial electric field Er, using first-principles gyrokinetic simulations with the spectral full-f GENE-X code**



- **Magnetic field direction affects level of turbulence both Experiments and Simulation**
- **Er asymmetry is reproduced and is carried by the poloidal flow**
  - Simulations retrieve, within the experimental uncertainties, the deeper Er well measured in fav, despite the nearly identical OMP profiles.
  - Radial force balance shows that the diamagnetic and toroidal contributions nearly cancel at the well, leaving the poloidal flow carrying the asymmetry.

flux-surface averaged (FSA)
outboard midplane (OMP)

[B. J. Frei sub. to PPCF 2026 , EXP Conf. 2026 & B. J. Frei et al., Phys. Rev. Lett. 137, 035103 (2026)]

TSVV-A

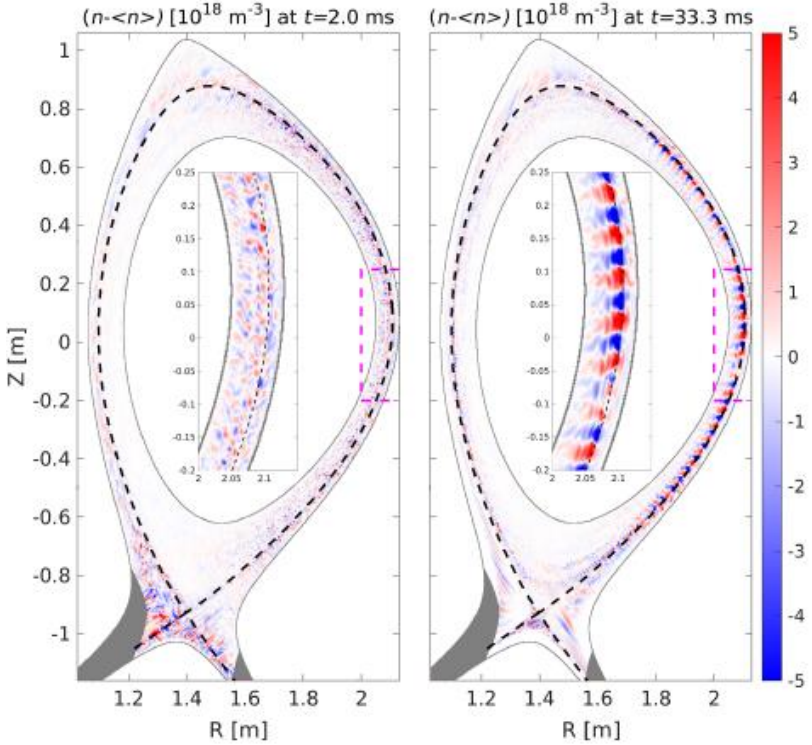
Formation of edge transport barrier in fluid simulations

ETB formation observed in 2 codes with similar mechanisms via change of turbulence type (Drift Wave --> KBM, kinetic ballooning modes)

Mean field Er formation mechanism investigated with SOLEDGE3X: E_r asymmetry in fav & un favorable conditions

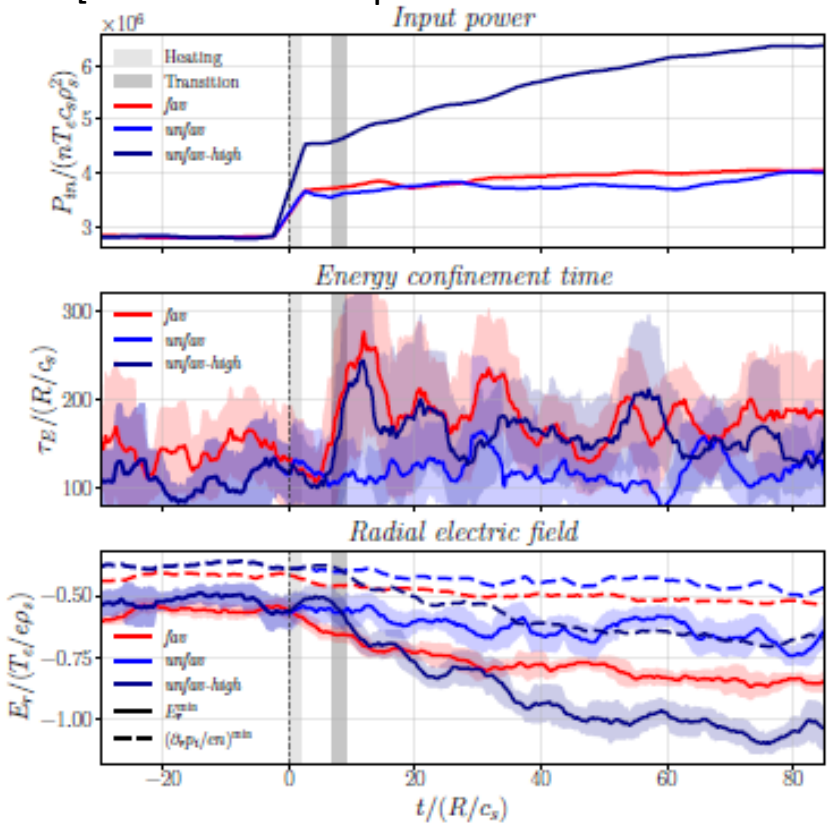
GRILLIX

W. Zholobenko et al *Phys. Rev. Lett.* 136, 075101 (2026)



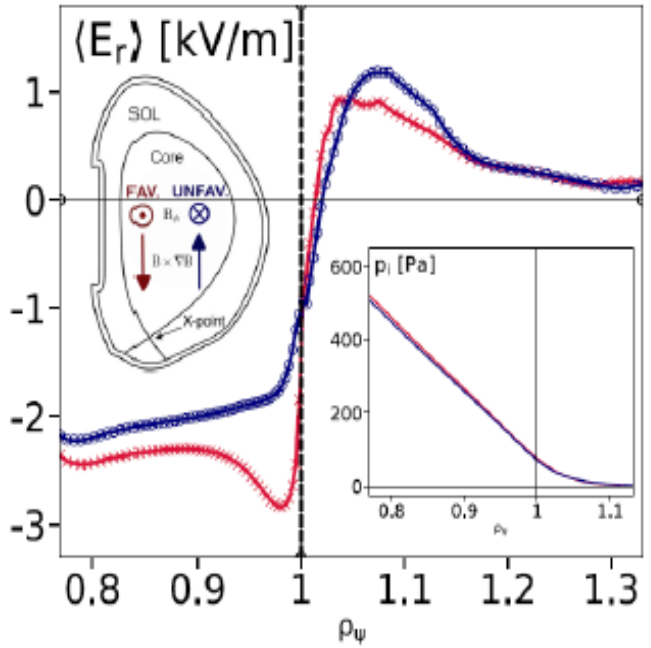
GBS

[B. De Lucca accepted to PRL 2026 & AAPS 2026]



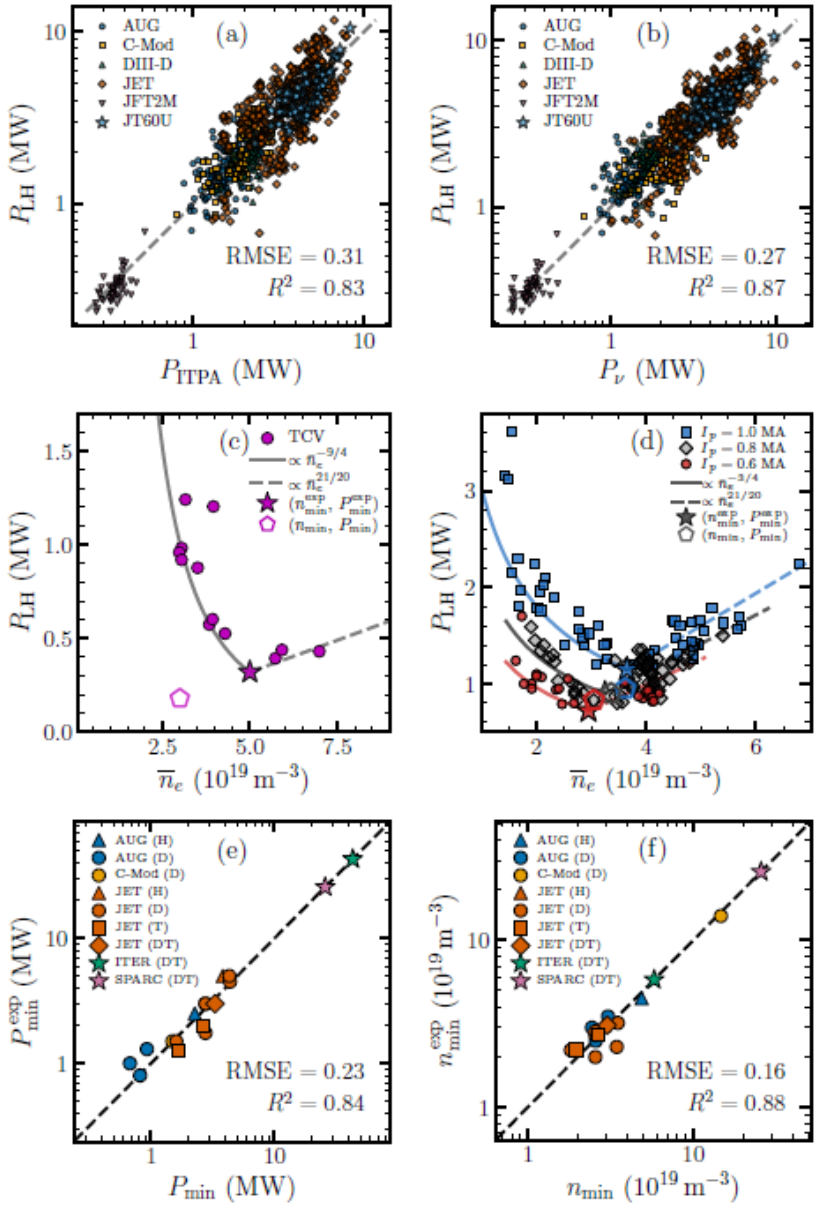
SOLEDGE3X

[[Lambresa, sub. PRL 2026]



TSVV-A-B

Theory of L-H transition in tokamaks (fluid): power threshold and density minimum (multi-machine ITPA database)



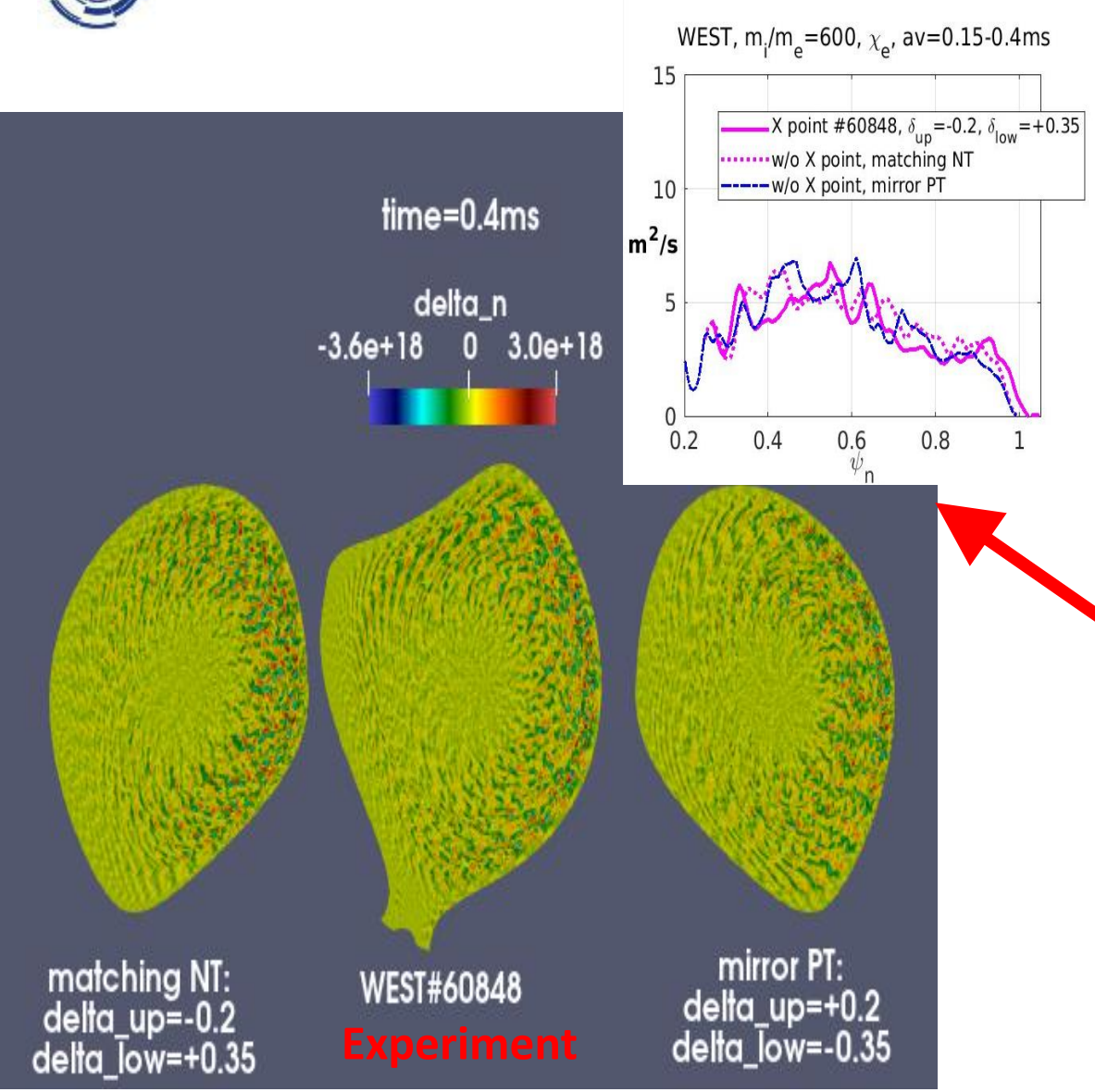
- **First-principles L-H power threshold model derived from flux-driven two-fluid (Braginskii) turbulence simulations (GBS)**
  - The simulations show that electromagnetic drift-wave turbulence spontaneously generates a sheared E × B flow responsible for transport suppression in the edge
- **Analytic derivation with a quasilinear assumptions for edge turbulence**
  - The model has two threshold-power branches:
    - a resistive drift-wave branch dominant at high density
    - and an inertial drift-wave branch dominant at low density
  - Derivation of analytic scaling density/power threshold at minimum density compared to experimental data

- Prediction compared with the ITPA database of high-density, favorable-configuration transitions
- Low density branch compared to AUG and TCV data

[B. De Lucca,P. Ricci, B. Labit, D. Mancini, L. N. Stenger, and Z. Tecchiolli accepted to PRL 2026, AAPS 2026]

TSVV-A-B

Global gyrokinetic simulations in negative and positive triangularity



- **Extensive global gyrokinetic simulations (ITG/TEM) in X-point geometry to compare negative and positive triangularity using JOREK-GK with SOL on WEST, TCV, and DIII-D**
- **Reveal the crucial role of averaged negative triangularity in reducing anomalous turbulence**
  - scans of upper & lower triangularities demonstrate the existence of **threshold on the averaged $\delta < -0.25$ for stabilizing ITG/TEM**
  - In agreement with WEST first NT experiments
- **Important conclusions for guiding coming experiments, design and operation of future NT tokamaks**

[Marina Bécoulet et al PPCF **68** (2026) 035031 & EPS 2026]

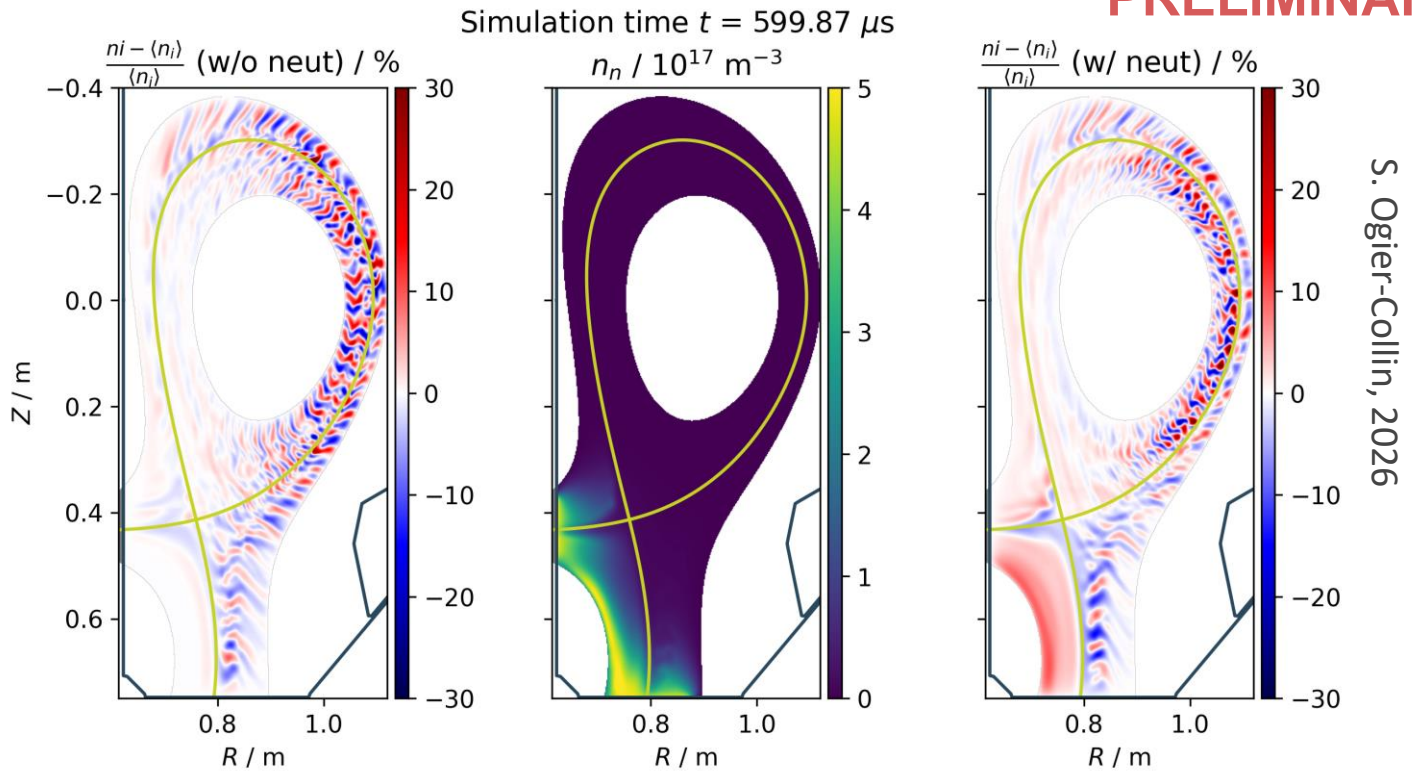
TSVV-A

Plasma Particle/Heat Exhaust – Gyrokinetic Simulations: 2026 highlights and 2027 priorities

Full-f, gyrokinetic edge turbulence code GENE-X coupled to fluid neutrals, enabling self-consistent plasma turbulence-neutral simulations.

Ion-density fluctuations without (left) /with neutrals (right) and neutral density (centre)

PRELIMINARY



2026 highlights

- **GENE-X:** first TCV-X21 turbulence simulations with fluid neutrals
- **Preliminary JET isotope studies:** H, D, T and D–T
- **GYSELA:** derived a gyrokinetic plasma/kinetic neutral operator

2027 priorities

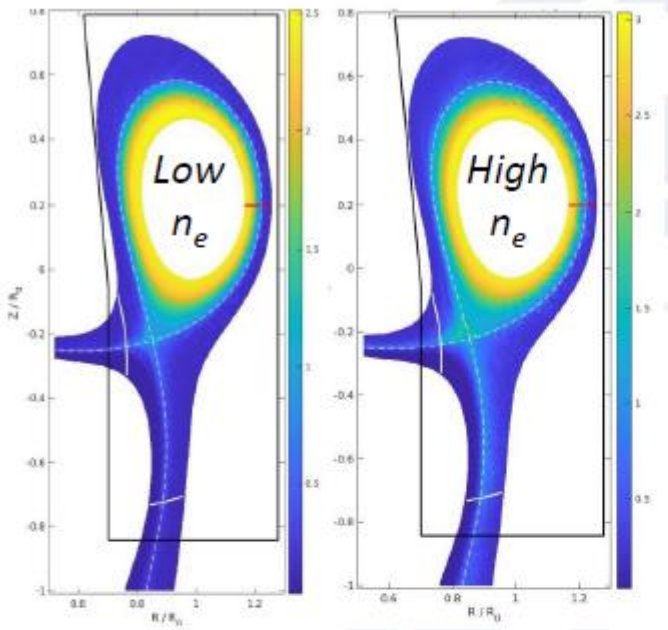
- Validate improved edge/SOL physics in **tokamaks and W7-X**
- Deliver **adaptive PIROCK** time stepping and advance plasma–neutral and impurity models
- Populate the **separatrix database for TSVV-H** and benchmark reduced SOL models

J Roeltgen et al : Simulations of TCV using the coupled GENE-X/Eirene
68th Annual Meeting of the APS Division of Plasma Physics, Chicago, IL, USA, 2nd November 2026.

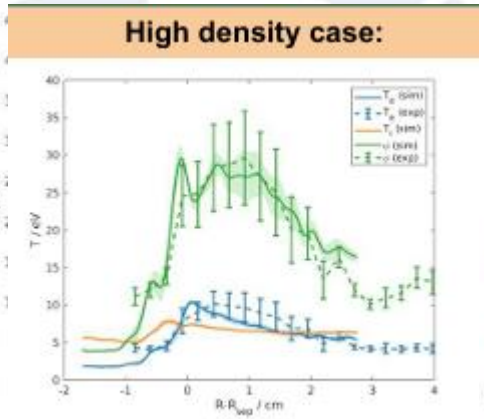
TSVV-C, K

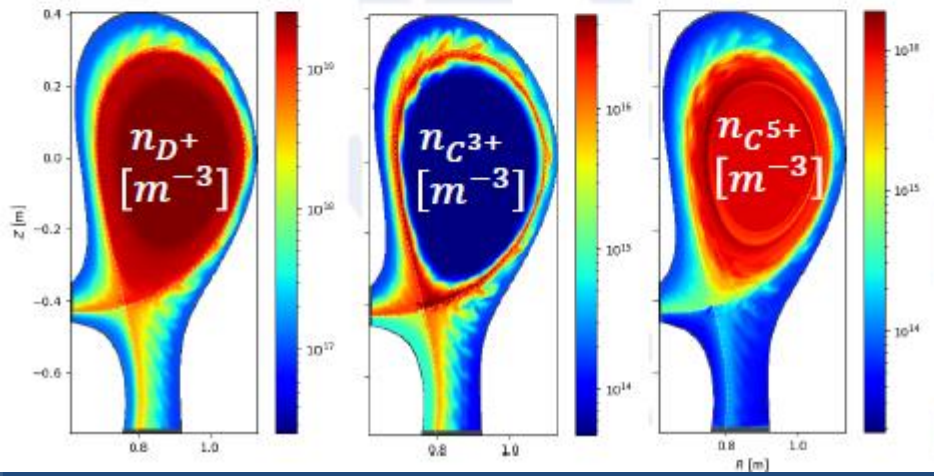
Plasma Particle/Heat Exhaust – fluid Simulations: 2026 highlights

Turbulence simulation in dissipative regime (detachement)- TCV-X23 (2023) — the high-density approach to detachment that required coupled plasma-neutrals



[Stegmeir, https://indico.euro-fusion.org/event/4187/]





[Tamain, submitted to NME]

- **TCV-X23** case addressed by 2 more codes
  - GRILLIX: excellent agreement at mid-plane and target, except heat fluxes (WIP)
  - SOLEDGE-HDG: difficult to get good match both mid-plane and targets
  - For both codes, detachment not reached

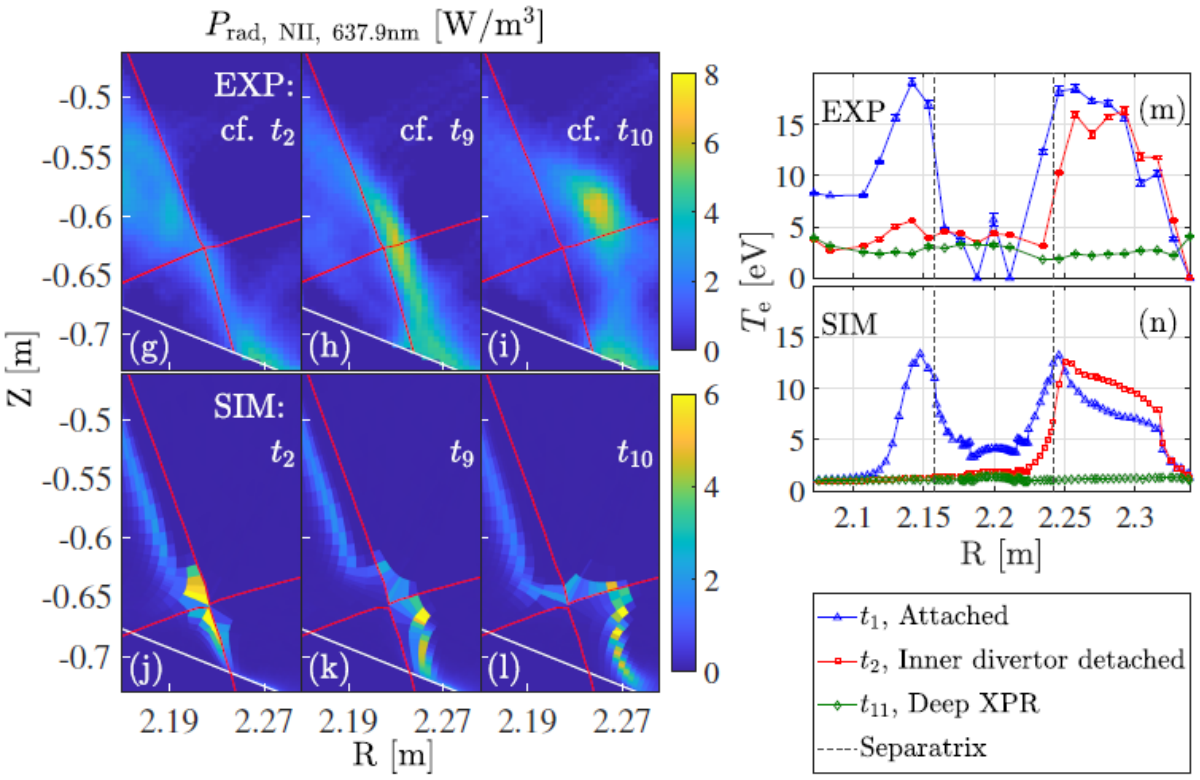
- First step towards **self-consistent turbulent transport of impurities** with SOLEDGE3X
  - TCV-X21 case with self-consistent C sputtering and all C^{i+} (trace)
  - At order 0, $D_\perp^{C^{i+}} \approx D_\perp^{D^+}$
  - First step towards self-consistent seeded regimes (e.g., XPR)

TSVV-B

Simulations of the Self-Organized Plasma Vortex as a mechanism for Stable Radiative Divertor (XPR) Operation on WEST

Reconstructed 2D maps of NII 637.9nm emission: Exp. & synthetic diagnostic

Electron temperature profiles at the divertor targets: Exp. & Simulations



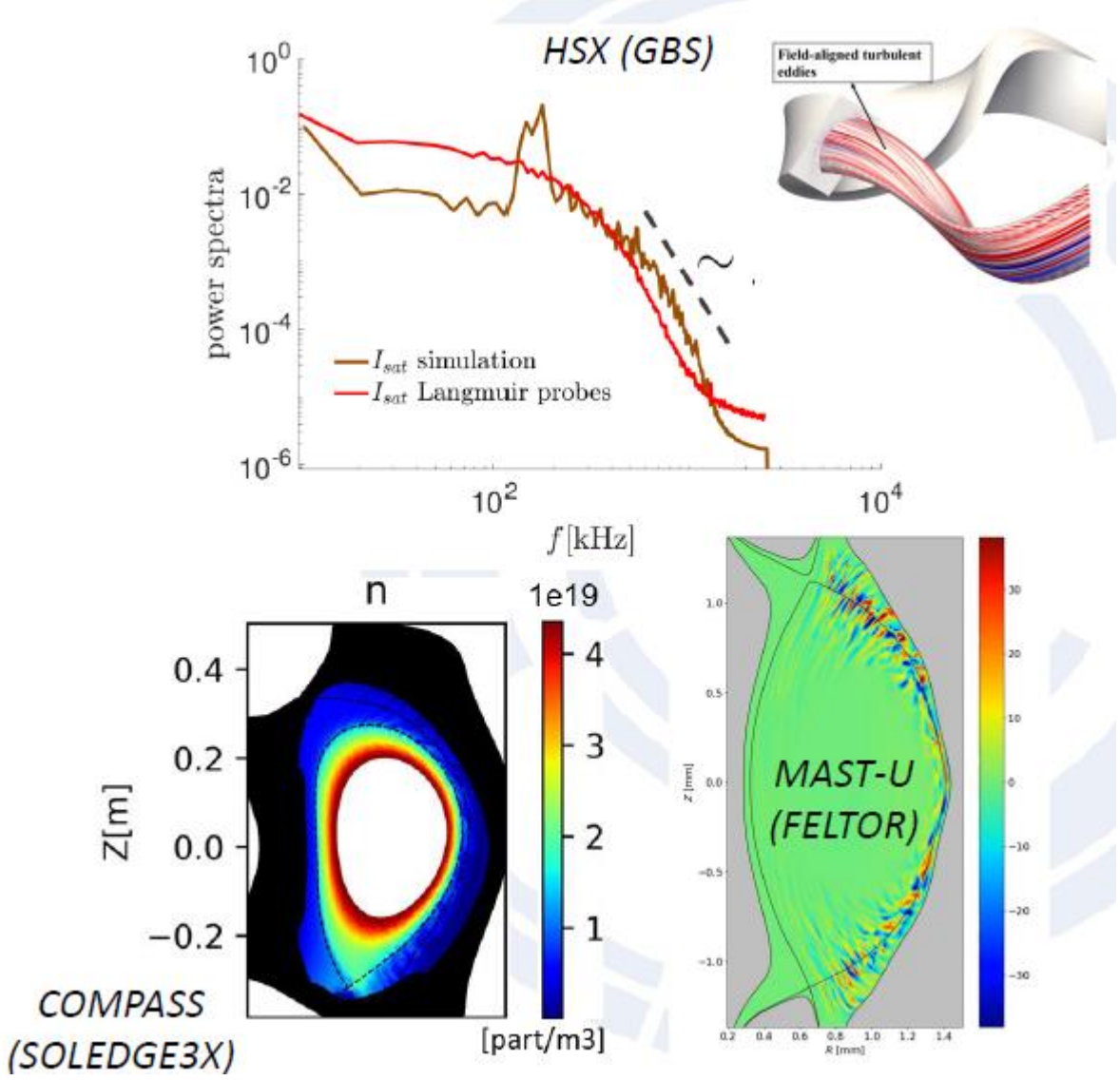
- **First simulation of the dynamics of the fast transition from an attached divertor to a stable XPR regime**
  - SOLEDGE3X-EIRENE with magnetic drifts
  - Reproduce the experimental observations
- **Reveal a previously unrecognized transient, counterclockwise vortex centered on the X-point as the critical mechanism driving XPR onset**
  - Self-organized interplay of **anomalous diffusion** and **EXB drift flows.** The vortex
  - (i) regulates the entry of cold particles and impurities into the XPR region
  - (ii) increases neutral density and impurity concentration above the X-point without overcooling the edge
  - (iii) enables access to a stable XPR regime that has been sustained for 70 s on WEST
- **Simulations provide the physics mechanisms for achieving robust radiative divertor operation in present and future devices**

[H. Yang et al. accepted in Phys. Rev. Letter 2026 WPTE & TSVV-E]

WPTE & TSVV-E

Plasma Particle/Heat Exhaust – fluid Simulations: 2026 highlights

Extensive validation efforts including stellarators

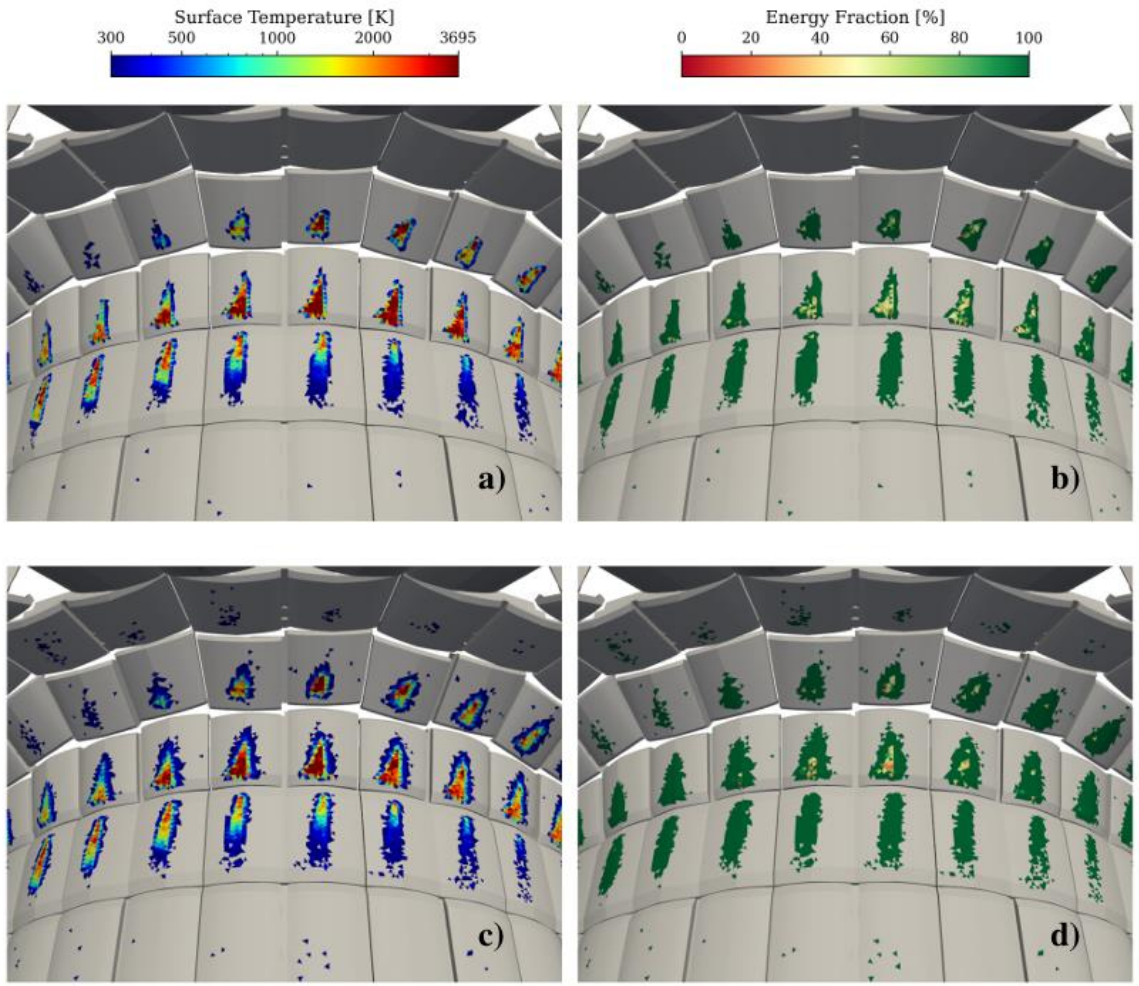


- **Validation exercises in progress against a large variety of machines and configurations**
  - TCV long leg, MAST U, COMPASS, AUG X pt target, JET
- **Applications to TJ-K, HSX (Helically Symmetric eXperiment) and W7 AS demonstrated and extension to W7 X on going**
  - Reference case “a la TCV X21” being discussed for stellarator

TSVV-B WPTE, WPSTEL

A surrogate model for the rapid assessment of tokamak wall loading and melting by runaway electrons

Thermal response of the full ITER vessel to Runaway electron incidence with input from the 4 JOREK simulations



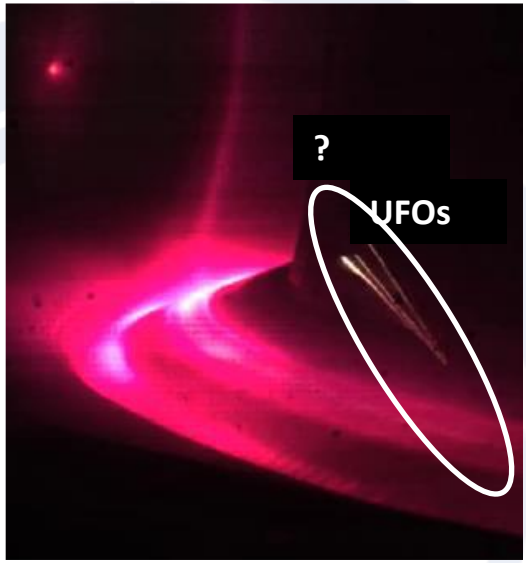
- **FIREWALL (Fast Integrated Runaway Electron WALL loads), a surrogate model that combines a database of GEANT4 volumetric energy-deposition profiles with a one-dimensional heat-diffusion solver for each wall element**
  - Open source software
  - Fast physics-based framework enabling large-scale screening of disruption scenarios while directing high-fidelity costly workflows to the critical wall regions when/if required.
- **Rapid identification where the first wall is threatened by melting**
  - Regions remaining below the melting point can be assessed directly with FIREWALL
  - reaching melting : automatically identified as requiring subsequent high-fidelity treatment of melting, vaporization and the detailed component geometry

[VJ. Svensson, T. Rizzi, S. Ratynskaia, H. Bergström LV. Greco M. Hoelzl and P. Tolias sub. POP 2026]

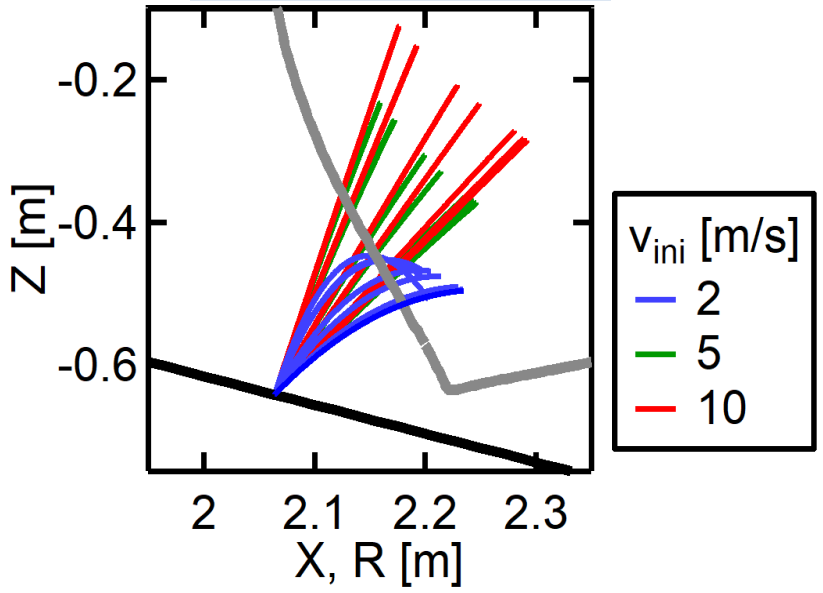
TSVVs D & F

Integrated simulations: W-dust ingress in WEST long pulse operation

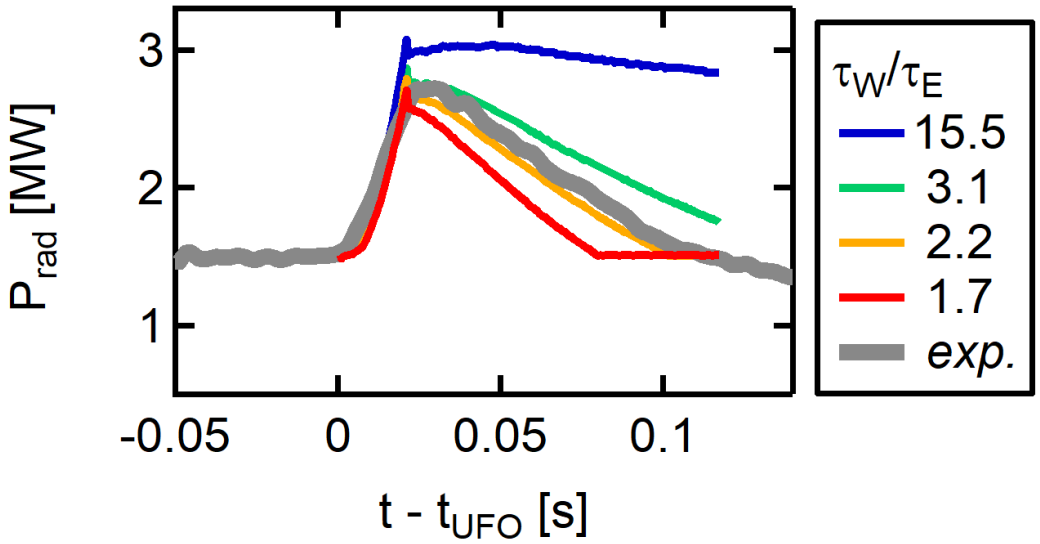
- **Integrated models from Wall to the core of W-dust ingress and impacts on long pulse operation (peaks of radiated power, disruption,…)**
  - W-UFOs generated from W-deposits formed during long pulse operation
  - Combined models of dust penetration with plasma evolution using integrated simulations
- **Integrated modelling of WEST long pulse operation**
  1. From W-flake trajectory to tungsten source u*sing* DUSTTRACK
  2. From W-source to its impact on operation (core radiation) using HFPS



Dust trajectories



Core radiation after UFO



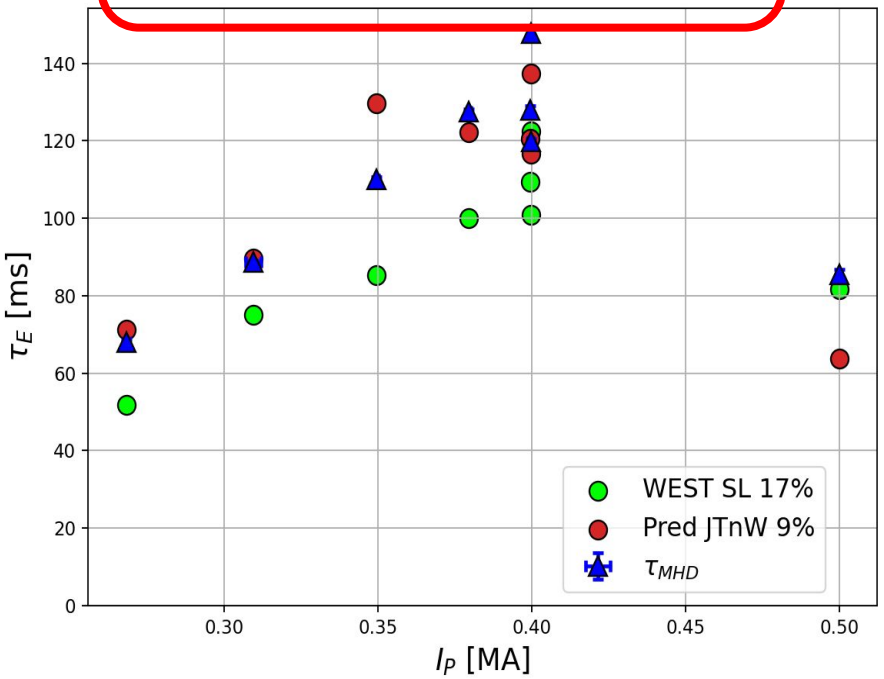
WPTE, TSVV-H

Towards Large scale integrated modelling

Systematic large-scale HFPS simulation against the TCV and WEST database (2027), building on 2026 proof of concept (8-pulses from WEST)

Confinement scaling with current: HFPS vs empirical scaling law

WEST Scaling Law= 17%
Full Simulation= 9%



Simulation Name	J Diffusion	Heat Transp.	Particle Transp.	Impurity Transp.
Pred J	✓	✗	✗	✗
Pred JT	✓	✓	✗	✗
Pred JTn	✓	✓	✓	✗
Pred JTnW	✓	✓	✓	✓

Validation & Uncertainty Quantification approach

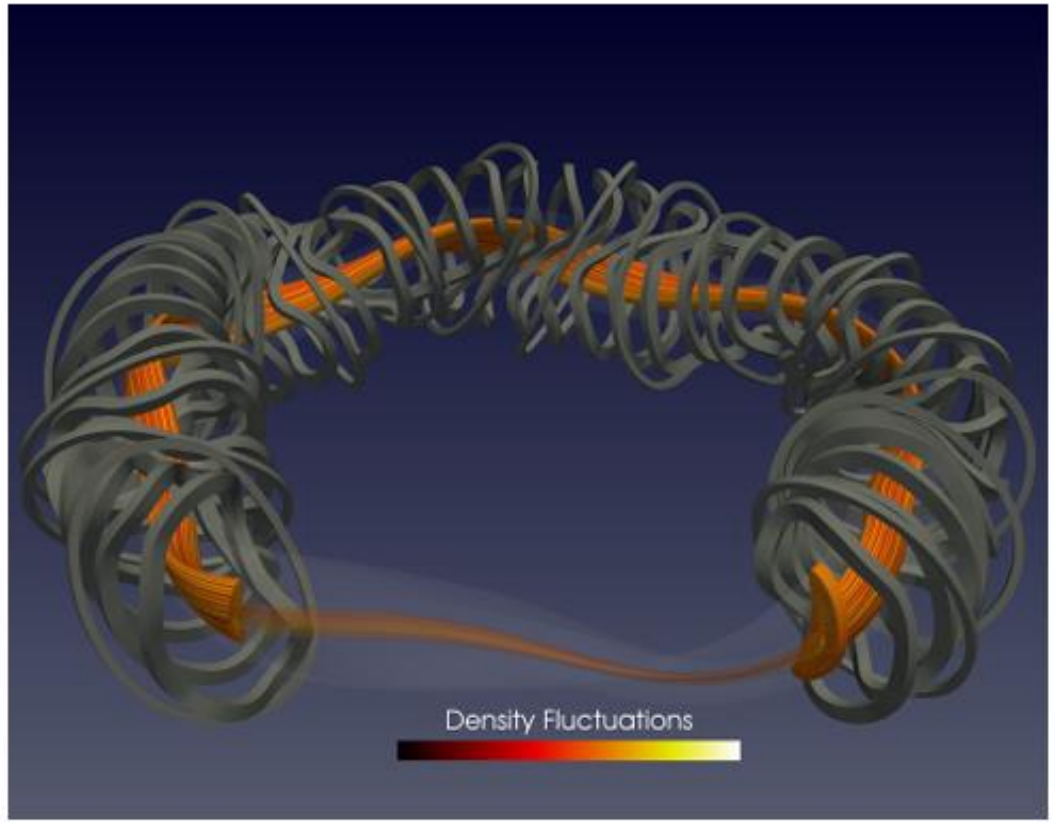
- Moving from an initial proof of concept to simulate up to 100 cases L-mode IMAS data, incorporating TGLF-SAT2 with impurity transport
- Developing modular tools to handle automated run submission, real-time monitoring, and error auto-correction
- Applying statistical metrics to quantify simulation reliability

[Enzo Vergnaud 29th TTF Workshop, to appear in PPCF 2026 & PhD thesis]

WPTE, TSVV-H

Global Gyrokinetic Simulations of Magnetic Geometry and Radial Electric Field Effects on Turbulent Transport in Wendelstein 7-X

Density fluctuations from a radially global GENE-3D simulation in W7-X, illustrating the 3-D character of the turbulence.



- A controlled parametric study, in which the Er profile is systematically varied in amplitude and radial location, confirms that transport suppression follows the classical shear decorrelation criterion, being strongest where the shear rate exceeds the linear growth rate over the widest radial extent.

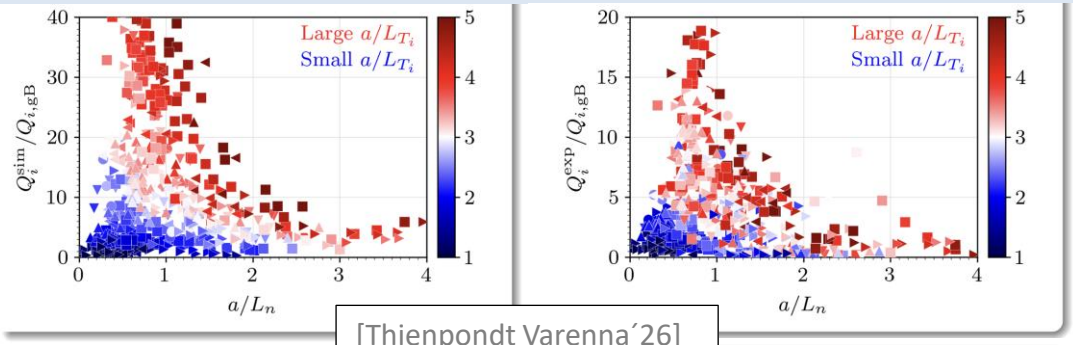
[A. Bañón Navarro *et al* 2026 *Nucl. Fusion* **66** 106021]

TSVV-J

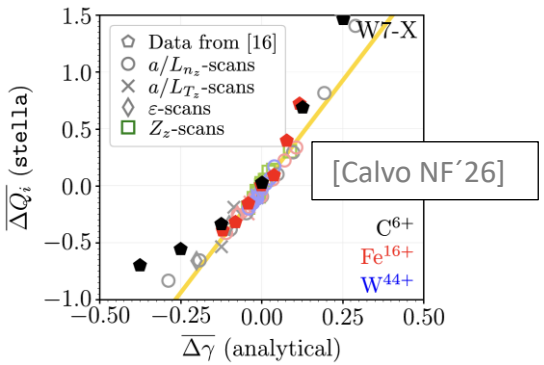
Stellarator core turbulence 2026 Highlights (non-exhaustive)

All work is progressing as planned, with no significant deviations

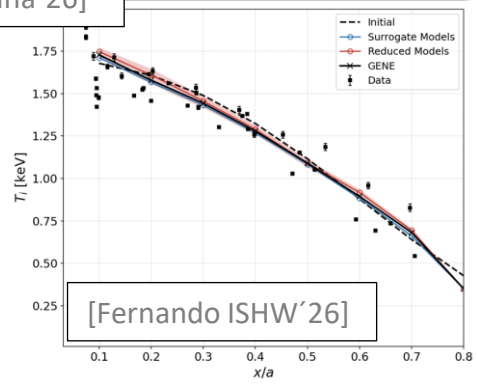
Simulated ion heat flux Exp. ion heat flux



[Thienpondt Varenna´26]

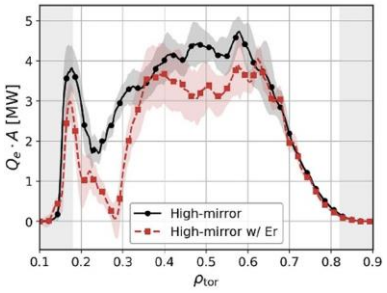


[Calvo NF´26]

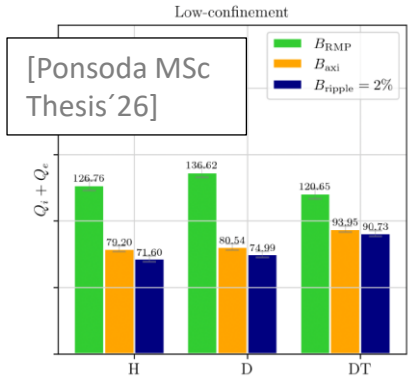


[Fernando ISHW´26]

[Bañón-Navarro NF´26]



[Ponsoda MSc Thesis´26]



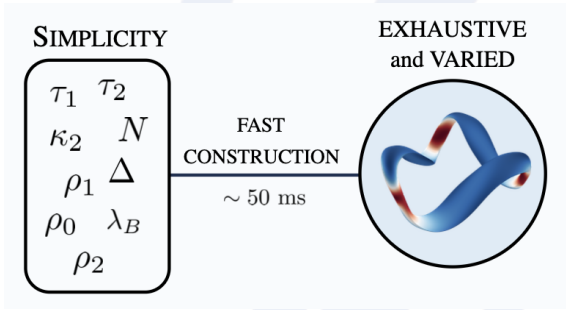
- **Deepening on the impact of geometry on turbulence**
  - **Massive cross-campaign validation of turbulent transport in W7-X** with emphasis on density and temperature gradients role [Thienpondt-Varenna´26]
  - **Effect of the neoclassical radial electric field on turbulent transport** in W7-X configuration space further studied with GENE-3D [Bañon-Navarro NF´26]
  - **Quick analysis tool for stellarator turbulent transport** based on precalculated datasets ongoing (W7-X, Heliotron-J and TJ-II DBs produced so far) [Regaña NF´26, in progress´26]
- **Development of reduce models**
  - **Surrogate models** and of scaling laws of heat and particle transport in **W7-X** have been formulated [Fernando ISHW´26]
  - **Analytical model for the role of impurities on ITG** in arbitrary geometry remarkably correlated with nonlinear simulations [Calvo NF´26].
  - **ITG dispersion-relation solver for any flux-tube geometry**, benchmarked against GENE [Morren, in prep´2026].
- **3D Tokamak modeling**
  - **stella has been applied for ITER** in L and H mode scenarios considering VMEC equilbria **incl. 3D ripple pertubations and RMP** [Ponsoda MSc Thesis´26].

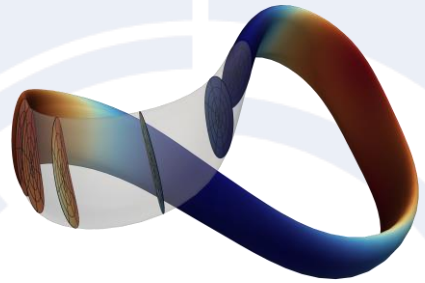
TSVV-J

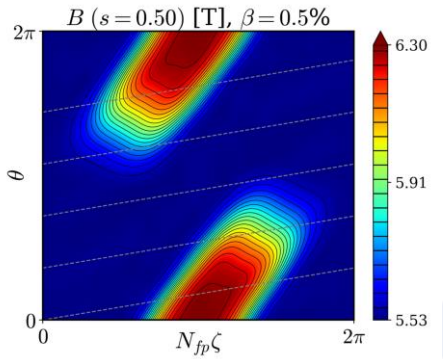
Stellarator Optimization 2026 selected highlights

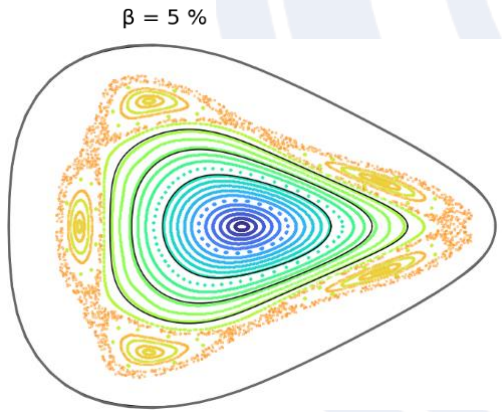
Tools cover fast screening of candidates (database), optimization over complex shapes, new confinement concepts (piecewise omnigenity), and realistic validation (equilibria with islands + alpha losses).

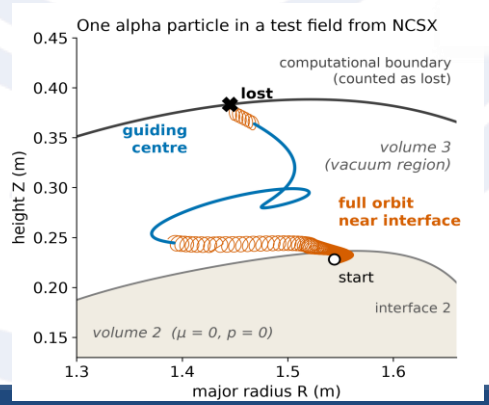
- **SIMSOPT (**optimization framework) **+GVEC (**3D ideal-MHD equilibrium solver) optimizable, enables optimization of strongly shaped configs
- **800’000 QI-stellarators database** based on near-axis expansion and reactor relevant physics properties
- **CIEMAT-pw1** configuration (good neoclassical confinement, alpha confinement and MHD stability) close to piecewise omnigenity satisfying physics requirements to be reactor candidates.
- **SPECTRE** now computes robust MHD equilibria with islands, applied to reactor-relevant QI configurations.
- **SIMPLE (fast guiding center code for estimating particle loss)** can now trace alpha particles with realistic SPECTRE equilibria.











TSVV-I

Conclusion

- **The new WPTM set-up : in full swing since January 2026**
  - TM management tools set-up: Indico, IDM, Wiki, IMS, Pinboard, Shared zone with TSVV PIs for working documents
  - Regular Coordination meetings with TSVV PIs established
  - Coordination with the other WPs in place
- **The formal WPTM milestones are on track to be reached as planned**
- **Significant progress on the grant deliverables, with notable 2026 highlights and publications for all TSVVs building on the 2021-2025 effort**
  - 175 new ENTRIES under WPTM ON THE PINBOARD!
- **From May to October 2026, time was also spent descoping the 2027 TSVV deliverables to match the allocated resource (c.f. next presentation) with some scope reduction on surrogate model development and Compliance of research Software with EUROfusion standards to be assessed by end of 2027**

Work-Package Theory and Modelling (WPTM): 2027 objectives (part II)

Xavier LITAUDON (Project Leader), Gloria FALCHETTO (Project Support Officer) on behalf of the TSVV PIs

Thanks to TSVV PIs for their constructive inputs

CEA lead lab. for WPTM

xavier.litaudon@cea.fr

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Resource considerations for 2027: Recap

- **End of 2025 : TSVVs selection done with the E-TASC scientific board at a level 5 PPY/Y for TSVV A-J, 3 PPY/Y for TSVV K for 2026-2027 following exactly call specification** (30% lower than in 2021-2025)
- **Calculation with the actual salary/per beneficiary leads to budget above TM budget ceiling in k€**
- **WPTM-PL decision to provide PPY as selected in 2026 and to reduce PPY in 2027 by 28 % (uniformly across all TSSVs/beneficiaries) to stay within the budget ceiling (5864k€ in CC)**
- **In the course of 2026 (May – October) the 2027 TSVV deliverables have been updated (de-scoping) by the TSVV PIs to match the budget ceiling with 3.6 PPY TSVV A-J and 2.1 PPY TSVV K in 2027**
  - **TM descoped activities have been set in priority 3 for the Oct 2026 General Assembly presentation/discussion on the EUROfusion budget**
- **At the Oct 2026 General Assembly, extra resource 1 PPY (64k€ EC) has been allocated to WPTM to cover the PL/PSO in 2026 (no PL/PSO when the call was issued)**
  - With the agreement of the PMU, 64k€ EU Contribution corresponding to 13,56 PM @50% has been set aside as non-allocated resource in the 2027 budget

Consideration on the 2027 “extra 64k€ EC resource”

- ~~Opt. 1: distribute 13.6PM uniformly across 11 TSVVs with limited impact~~
- **Opt. 2 preferred by PL/PSO & TSVV PIs: Agree on 3 up to 4 activities, taken from the descoped 2027 deliverables or from new urgent needs**
- **Prioritisation criteria: selected activities must be**
  - **(i) aligned with WPTM Grant Deliverables and/or topics in new EUROfusion-IO collaboration,**
  - **(ii) be completed by end of 2027.**

Prioritization & first estimate of “extra resource” in PM Non Allocated

1. **Coupling SOLPS-ITER with HFPS (IO support on SOLPS-ITER development) (new)** — **5-6 PM**
   - Building on lessons learnt from the coupling with ETS (David Coster)
2. **Extend compliance of CARIDDI (3D eddy-current code for conducting structures) and FIREWALL with EUROfusion software requirements (**possible support from ACH**); coupling of FIREWALL to HFPS with extended capabilities:** — **4-5 PM**
   - Extending the FIREWALL heat-transport model beyond the melting point (new)
   - Extending the Monte-Carlo (MC) volumetric heating database (new)
   - Extending the MC surrogate database for secondary product (ejected electrons, neutrons, photons, impurity atoms) & incorporating diagnostics (new)
3. **Parallelization DREAM for coupled JOREK-DREAM disruption simulations: validation & ITER applications** — **4-5 PM**
4. **IMASification of Stellarator tools (with ACH support/resource ?) & 3D equilibrium tools developed for stellarators for ITER applicatios: e;g. Nonlinear 3D equilibria with and without islands** (ITER error fields, toroidal field ripple and resonant magnetic perturbation coils) — **4 PM**

To cover the 4 “new” 2027 TM activities: request of 17 to 20 PM vs 13.6 PM

2027 plans for code integration with fast and accurate surrogate models

Core transport	impurity transport	Core transport	energetic particles	Transport
TGLFNN	**FACIT**	**QLKNN_7_11**	**ATEP**	**GENE surrogate**
Developed	Developed	Developed	Developed	Proof of Principle
Coupled	Coupled	Coupled	Coupled*	Coupling foreseen
More capable versions might come online	Verified against NEO	Previous versions coupled and available	Assuming resources are available	Not yet available, but interest exists

HFPS

Pedestal stability	MHD	ICRH	fast core–edge coupling and divertor/exhaust predictions	
KAHRU (ENR surrogate MISHKA)	**EQSTABIL**	**PLIKES**	**EDGE2DNN**	**SOLPSNN**
Developed	Developed	Developed	Developed	Developed, limited
Coupling ongoing	Coupled	Coupled	Coupled	Coupled
Current overprediction under investigation	Tested on relevant scenarios	Conditional on code development	At least on EDGE2D acceleration	Numerically stable and multiple scenarios

- **Extra activity : coupling SOLPS-ITER & FIREWALLto HFPS following lessons learnt from ETS+ SOLPS-ITER**
- **HFPS transition to IMAS version 4 in 2027**

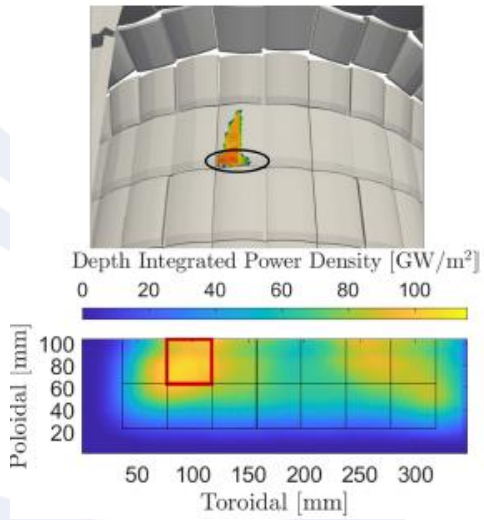
[TSVV-H and all TSVV]

Disruption, RE and impact on the W wall at high current

TSVVs: D, F

Deliverables to be recovered with extra resource

- JOREK-DREAM coupling and parallelization of DREAM for efficient RE calculation at high current
  - Delay in addressing the highest risk for ITER high-current operation: simulation of the dependency of RE current on the pre-disruption plasma current. Importance of seed generation and losses vs avalanche multiplication effect (high current simulation)
- compliance with EUROfusion standard software (CARIDDI and FIREWALL) that will impact code dissemination and users involvement
- RE induced damages on W PFC wall (FIREWALL) : development of thermo-mechanical model with W (Geant4-MEMENTO-LSDYNA): vaporisation, melting , release of debris
- WPs Impacted: TE, PWIE (delay in the validation)
- ITER-EUROfusion collaboration impacted :
  - “Physics Basis for ITER scenarios” : Disruptions
  - disruption mitigation : strategy for benign termination of RE plasmas
  - Runaway electron avalanche (RAE) behaviour and predictive model validation



Conclusion

- **There is broad agreement that the TSVV projects have been a major catalyst for progress in theory and simulation within EUROfusion**
  - **They have built a community and led to the significant progress reported here**
- **There is a consensus with WPTM on the approach for managing the "extra-resource" in 2027**
- **There is consensus that extending "TSVV-like activity" beyond 2027 is a necessity**
  - **In 2027, TSVV human resources are already below the survival threshold (–50% ppy compared to 2021–2025)**
  - **Projects are surviving in 2027 largely on inertia from previous years: e.g. PhD students, postdocs, short term contracts hired on the strength of earlier funding prospects**
- **Annual in-person TSVV meetings essential to maintain high scientific productivity and team spirit**
- **A validated, accurate plasma model is central to fusion power plant design and to preparing operation (cf. FJ & XL presentations next EFPW)**
  - **System codes: interface between the plasma and the engineering systems:** factor ~3 uncertainty on P_{fus} for a DEMO-like plant
  - **Pulse design simulators/digital twins: prepare operation based on accurate, validated plasma models**
- **Next slides are the summary 2027 deliverables and descoped ones per TSVVs**

TSVV-A H-Mode and Small/No-ELM Pedestals: 2027 Deliverables

Label	Description	Topics
D.9	Scientific report characterizing turbulence, heat & particle transport in GYSELA simulations featuring both ITG & TEM instabilities but occupying various places in the (grad(n),grad(T_i), grad(T_e)) parameter space – qualitative comparison to I-mode regimes **Reduced scope: GYSELA comparisons with experimental I-mode regimes will be dropped or significantly reduced in scope.**	***1***
D.10	Report on the obtained results of JOREK-GK modelling of L/H transition	
D.11	Report on the neutral model impact in GENE-X flux-driven power ramps (12/2027); **Reduced scope: The progress relies on neutral model developments in TSVV-C that is reduced in scope , e.g. if time schemes such as PIROCK are required to achieve relevant simulation time scales.**	***1, 2***
D.12	Report on the impact of sub-ion scale ETG transport on flux driven power ramps on GENE-X (12/2027) **Reduced scope: Fewer cases studied with additional sub-ion scale models in GENE-X and fewer comparisons/assessments of available ETG models.**	***1***
D.13	Reports/Publications on JET/TCV no/small-ELM regimes and AUG QCE/EDA-H-mode studies performed with GENE/GENE-X with assessments of ETGs, quasi-linearity and TGLF comparisons on a test basis **Reduced scope: GENE turbulence characterizations of small-ELMs regime at JET limited to ion-scale transport processes, with potential impact of ETGs related transport left unexplored. The number of considered AUG discharges needs to be cut back.**	***1, 8***
D.14	Conference publication on JOREK-GK ITG/TEM turbulence simulations with RMPs in different tokamaks (COMPASS, HL2A, AUG) (12/2027) **Reduced scope: The number of JOREK-GK ITG/TEM turbulence studies with RMPs will be reduced: HL2A will be dropped, AUG will be covered less extensively**	***1, 3***
D.16	Report on verification of SAP/KEY with saturation rules against NL GK in pedestal and - depending on outcome - release of JAX-ified SAP, KEY codes for integrated modelling (12/2027) **Reduced scope: may have to drop one of the two frameworks, which will impact ability to predict pedestal as well as ability of PIE ENR to work with TSVV-A output**	***1, 7***
D.17	Report on revised GBS based L-H/H-L scalings with latest code upgrades and/or refined parameter scans	

TSVV-B Plasma Particle/Heat Exhaust – Fluid Simulations – 2027

Label	Description	Topics
D1.2	Analysis of turbulence and transport in detached regime in the frame of the TCV-X23 experiments *(CEA, EPFL, MPG, DTU, KUL)* **Reduced scope: Contribution of some of the TSVV-B codes to TCV-X23 reference case analysis (turbulence in high density regimes) will be dropped as priority given to validation exercises. This is at least the case for the FELTOR and GRILLIX contributions, as well as for the reduced turbulence model in SOLEDGE-HDG.**	**1, 2, 8**
D1.3	First evaluation light impurity turbulent transport in 3D edge turbulence simulation *(CEA, EPFL)* **Reduced scope: Evaluation of the turbulent transport of impurities in the edge plasma, a fully novel topic on which reduced fidelity mean-field models rely on turbulence codes to get an answer, will be limited to very first proof-of-principle studies. This will impact the effort towards reducing the uncertainty in the parameter tuning of mean-field models that are heavily used to determine the operational space of future machines.**	**2**
D1.4	Demonstrate capability to model D-T plasmas both for mean-field and turbulence applications *(CEA, DTU)* **Dropped: Implementation of a fluid closure and neutrals model adapted to D-T simulations is a large endeavor and only first steps can be completed by the end of 2027 .**	**2**
D2.3	Analysis of near SOL transport in L-mode and H-mode conditions in TCV and AUG *(CEA, EPFL, MPG)*	
D3.3	Analysis of impact of divertor leg length and flux expansion on turbulence in TCV *(EPFL)*	
D3.4	Study of heat exhaust in Advanced Divertor Configurations in the new AUG upper divertor *(MPG)*	
D4.2	FELTOR code with support for non-axisymmetric equilibria *(DTU)*	
D4.4	Full-scale simulation of W7-X in island divertor geometry and comparison with experimental data *(MPG)*	
D5.1	Investigate the dependence of the SOL width on key parameters in edge turbulence simulations in L-mode *(CEA, MPG)* **Reduced scope: Investigation of the dependence of the SOL width on key parameters in edge fluid turbulence codes will be drastically reduced in ambition (use of simplified geometry, limited range of scan). This is a very time- and resource-consuming activity as some of the scans (especially the one in toroidal field) are challenging, in realistic X-point geometries. Fundamental activity to validate the capability of our codes to reproduce experimental scaling laws before applying them to predictive studies. Topic that identified as critical for ITER's operation.**	**1**
D5.2	Investigate the dependence on key parameters of the SOL width imbedded/implied by the RANS model(s) in L-mode *(KUL)*	
D6.5	SOLEDGE-HDG edge fluid code with capability to model impurity physics + report on progress with drifts implementation *(CEA)*	
D6.6	STYX-EIRENE package usable in 3D in turbulence simulations and in time-dependent mode *(CEA)*	
D6.7	Couple synthetic emission diagnostics and Doppler back-scattering to TSVV-B codes with IMAS interface *(CEA, DTU)*	

TSVV-B Plasma Particle/Heat Exhaust – Fluid Simulations – 2027

Label	Description	Topics
D6.8	Updated RANS model description applicable to SOL in variety of L-mode regimes *(KUL)* **Reduced scope: Extension of reduced turbulence models to advanced SOL regimes (high density, detached…) will be limited in scope. This will delay the implementation of these models in SOLPS-ITER and their availability to the rest of the modelling community.**	**7**
D6.9	Sheath boundary conditions across reactor relevant range of collisionalities, for arbitrary plasma mix *(IPP.CR)* **Reduced scope: The deployment in edge fluid codes of advanced sheath boundary conditions requires large resources as it will likely change significantly the numerical stability of the codes and the way they can be run. Exploring such changes is time-consuming and we will not be able to carry this task. The implementation in codes of newly derived boundary conditions will be postponed beyond 2027.**	**2**
D7.2	Report on progress of numerical methods for FCI to handle complex wall geometries beyond the immersed boundary approach *(MPG)*	
D7.3	Port full turbulence model of GRILLIX and SOLEDG3X to GPU *(CEA, MPG)*	
D7.4	Report on attempt at extending the HDG discretization method to handle 3D edge plasma a simulations (CEA)	
D7.5	Test of scalability of FELTOR to large number of GPUs and implementation of high priority recommendations *(DTU)*	
D8.2	TSVV-B codes compliant with priority 2 criteria of EUROfusion standard software recommendations (exception: priority 1 criteria for SOLEDGE-HDG) *(all)*	
D8.3	Individual or collective training for new users of TSVV-B codes on request from WPs or individual collaborators *(all)*	

TSVV-C Plasma Particle/Heat Exhaust – Gyrokinetic Simulations 2027

Label	Description	Topics
D.6	GENE-X with adaptive PIROCK. Report on benchmarking and against existing schemes in GENE-X, including stellarator cases and impurities/neutrals models **At risk : adaptive PIROCK a high-performance time integration for coupled plasma/neutrals simulations.**	**1,2,6,8**
D.7	Reports or publications on simulations with enhanced physics (e.g. collisions, neutrals, impurities) in GENE-X **Reduced scope : Validation and user support capacity will be reduced compared to original plans.**	**1,2,6,8**
D.8	Report or publication on benchmark of kinetic impurity model in JOREK-GK; comparison with JOREK fluid model with kinetic impurities (and neutrals) **At risk to be dropped : This deliverable was already planned without co-funding, but will be at risk because the personnel carrying it are co-funded through other affected projects (TSVV-A)**	**1,2,8**
D.9	Report or publication detailing the surrogate model implemented in GYSELA for sheath boundary condition, including its first application in turbulent regime with kinetic electrons **Reduced scope : Strong impact in the future because of reduced available funding for new PhD projects, impacting development and availability for validation.**	**1,2,8**
D.10	report or publication on derivation + implementation of kinetic source for plasma-neutral interaction in Gysela-X++, accounting for ionization and charge exchange – first comparison to its fluid counterpart (in Gysela-X++ or VOICE) **Reduced scope : Strong impact in the future because of reduced available funding for new PhD projects, impacting development and availability for validation.**	**1, 2, 8**
D.11	D11 Report or publication on the 5-dimensional version of Gysela-X++	
D.12	Database of edge/SOL boundary condition outputs (radial electric field and related quantities) from GK simulations, prepared for use in integrated modelling, accessible to TSVV-H **Reduced scope : minimum viable version will be implemented**	**7, 8**
D.13	Report on reduced models and physics implications; **design of cross-code post-processing tool** **Dropped: Cross-code tool will be deprioritized, limiting/delaying the ability to feed reduced models with data from various codes**	**7, 8**
D.14	Report or publication on BIT1 simulation results of transient events and/or impurity/neutral studies **Reduced scope : Reduced number of simulations / parameter studies**	**2**

TSVV-D Plasma-Wall Interactions with Metallic PFC 2027 Deliverables

Label	Description	Topics
D9, D10	**SP1. Wall lifetime, dust and impurity migration.** Surrogate model for PWI in ERO2.0 for vector quantities: outgoing energy and angular distributions of reflected and sputtered particles, application to (static) rough surfaces. **Reduced scope: material combinations restricted to the most ITER-relevant proof-of-concept cases, limited effort for model training, resulting in limited benefits of the new model against existing approaches.**	**3, 7, 8**
D11	W core densities and residence times based on extended ERO2.0 impurity tracing with imposed impurity transport coefficients, validation and ITER predictions. **Reduced scope: risk not to be able to finalize iterative improvement of impurity transport coefficients using higher fidelity core transport codes (towards HFPS) and related data exchange via IMAS, risk for framework validation and ITER predictions.**	**3, 8**
D12	Self-consistent simulations of transport of W impurities generated by dust ablation (MIGRAINe-ERO2.0 time-dependent framework), validation and ITER predictions. **Reduced scope: limited capability for workflow validation and predictive simulations with time-dependent ablation sources.**	**3, 8**
D13	**SP2. Fuel retention in neutron-damaged wall materials.** Damage-induced trap model implementation in FESTIM. **Reduced scope: restricted number of defects and interaction mechanisms that can be investigated, limited effort for model optimization – risk of restricting the model to insufficient number of defects/reactions for proper description of underlying processes.**	**3,8**
D14	Global scale estimates of fuel retention, permeation and outgassing, validation and ITER predictions. **Reduced scope: based on input from D13, limited model parameterization will affect the validation and quality of predictive simulations for ITER.**	**1, 2, 8**
D15, D16	**SP3. Consequences of transient events :** modelling thermo-mechanical response of PFCs to RE impact with new Geant4-LSDYNA workflow, validation and ITER predictions. **Reduced scope: concerns regarding successful finalization of full thermo-mechanical model development for W response to RE impact and respective model validation, which are very high priority for ITER.**	**4, 8**

TSVV-E 2027 Deliverables

- Derivation of turbulent and neoclassical transport coefficients in the pedestal when instabilities are driven by ions from gyrokinetic simulations. Paper or conference contribution.
- Report on the comparison between results from reduced models applied on WEST and AUG experiments
- Report on SOLEDGE3X plasma backgrounds for ITER scenarios with and wo RMPs (CEA)
- Contribution at PFMC-20 conference on impact of AUG plasma scenarios on tungsten erosion and migration, publication in Phys. Scr.
- Paper and conference contribution about final results of ERO2.0 validation on AUG experiment and preliminary results for W7-X and ITER predictions.
- Presentation and/or paper on the results of W transport in ITER scenarios using reduced models enriched with bayesian inference of tungsten transport coefficients in the pedestal
- Report on the estimation of 3D perturbation effects on W and seeding impurity distributions in ITER reference scenario with the EMC3-EIRENE-KIT code package
- Paper or conference contribution on derivation from GK simulations of turbulent and neoclassical transport coefficients in the pedestal where instabilities are driven by ions and electrons. (CEA)

TSVV – E Impurity Sources, Transport, and Screening
2027 Impacted Milestones

Label	Description	Topics
M1.10	Estimation of effective coefficients for impurity transport from kinetic modeling: Derivation of (D, v) maps for impurity transport in edge and pedestal regions considering 3D equilibria effects **Reduced scope : reduced number of cases under consideration**	**3, 7, 8**
M3.1	SOLEDGE3X and EMC3-EIRENE plasma backgrounds for ITER scenarios with and without RMPs **Reduced scope :** 3D workflow at risk. no validation on AUG and application for ITER	**3, 7, 8**
M3.2	ERO2.0 for ITER/W7-X: Simulations for full-W ITER and W7-X with 3D backgrounds finished **Reduced scope : ERO2.0 simulations for ITER will be not completed.**	**3, 7, 8**
M4.3	Application to ITER scenarios: implementation of the modelling in ITER baseline and hybrid scenario in order to assess the behaviour of W impurity in the steady-state phase for a large range of pedestal parameters. **Reduced scope : Reduced range of parameters will be considered. Possibility of a postdoc with IO for completing this deliverable**	**3, 7, 8**

TSVV-F Tokamak Disruptions and Runaway Electrons 2027 Deliverables

- **RE impacts in AUG and WEST** using DREAM and JOREK (with WP TE)
- **Benign RE beam termination mechanisms** – model validation, explain device-to-device differences
- **RE beam scrape-off at the wall**
- **Role of intrinsic impurities** in disruption mitigation of ITER
- **3D RE beam impacts in ITER at ~4 MA** assessed with JOREK and JOREK-DREAM (if time allows)
- **FIREWALL model to predict RE wall heating and damage** completed (with TSVV-D)
- **RE transport coefficients due to 3D MHD** quantified for lower-dimensional codes

- **Major developments** include:
  - enhanced companion plasma models in JOREK & DREAM
  - JOREK-DREAM coupling
  - import/export of RE distribution functions from DREAM (1D2V) into JOREK (2D2V)
  - virtual thermography diagnostic for validation, experiment interpretation & prediction
  - adaptations for compliance with EUROfusion standard software requirements in JOREK, DREAM, CARIDDI and FIREWALL
  - Enhanced large angle collision operators in DREAM and LUKE for avalanching & RE plateau

TSVV-F 2027 Impacted deliverables

- **Impacts central goal to establish a hierarchy of multi-fidelity models for REs and disruptions**
  - Completion of JOREK-DREAM coupling for RE generation calculations over long time scales
  - Parallelization of DREAM, affecting DREAM standalone and JOREK-DREAM coupled simulations
  - Compliance of CARIDDI and FIREWALL with EUROfusion standard software requirements

- **Impact on applications**
  - Delays validation of RE generation & benign beam termination models
  - Delays JOREK-DREAM simulations for ITER
  - Impacts benign termination simulations
  - Impacts RE beam scrape-off studies
  - Impacts RE wall damage studies jointly with TSVV-D
  - Applications in WP TE, WP DES and for ITER delayed or forced to use lower fidelity

- **Codes impacted & Capability**
  - JOREK-DREAM: Missing ability to carry out novel RE generation calculations over long time scales
  - DREAM: Incomplete parallelization strongly restricts scope of comprehensive physics studies
  - CARIDDI and FIREWALL: Delayed / missing compliance with EUROfusion standard software requirements restricts dissemination and efficient data exchange

TSVV-G Physics of Burning Plasmas 2027 Deliverables

Label	Description	Topics
D.6	Global gyrokinetic simulations of energetic-particle physics in JET, MAST-U, W7-X, ~~JT60-SA~~, ITER, ~~Stable *Quasi-I*sodynamic configuration~~, fusion plasmas. High beta regimes in stellarator plasmas assessing the KBM instability. **Reduced scope : nonlinear simulations of ~~reactor size~~ plasmas including turbulence may become impossible if the resources are reduced (ORB5, EUTERPE)**	**5**
D.7	Studies of the transients and self-consistent back-reaction of the phase-space transport on fusion power and burn control using reduced-model framework. **Reduced scope : studies of burn control and power deposition in fusion plasmas will not been carried out to a full extent if the resources are reduced (ATEP, LIGKA/HAGIS)**	**7**
	Further improvement of zonal-state evolution models (theory) including soliton-structure formation and effect on the saturation of the Alfvénic instabilities.	
	XTOR-K simulations of sawteeth and nonlinear tearing instabilities in the presence of the energetic particles.	

TSVV-H Reliable Prediction of Plasma Performance and Operational Limits in Tokamaks - 2027 Deliverables

- One JT60-SA and one ITER high beta simulation stored on the gateway
- Report on EP transport in ITER
- Report on the transport of tungsten after a dust contamination event.
- Report on comparison between HPI2 and HPI2NN on simulations including turbulent transport with either QuaLiKiz or TGLF.
- HFPS-COCONUT simulation with QuaLiKiz and multiple isotopes stored on the gateway.
- TCV, WEST simulations with identical settings on at least 100+100 discharges
- HFPS simulation with MISHKA on an ideally limited JET discharge stored on the gateway. Sensitivity study on MISHKA settings.
- Report on large scale validation exercise, comparing different models and assessing the performance and feasibility of neural network surrogates of transport models.
- Report on the second HFPS training and support session

TSVV-H Reliable Prediction of Plasma Performance and Operational Limits in Tokamaks: 2027 Impacted Deliverables

Label	Description	Topics
WP1-2	*WP1 Integrating Modelling Workflow orchestration and module coupling framework* - Integrate new IMASsified workflows within HFPS **Reduced scope: It would not allow for the integration and test of all target reduced models based on NN in HFPS .** **Testing of SOLPSNN, EDGE2DNN and MISHKANN might have to be reduced to a single case. Without sufficient testing, no meaningful support for fast and accurate Core-Edge integrated simulations will be available for the other work-packages. This will also reduce our potential to collaborate with WPTE, for example with RT-01 on Neon seeded scenarios**	1, 3, 5, 7, 8
WP2.1	*WP2 key physics modules validation- High beta and energetic particle impact on transport* **Reduced scope: ATEP within HFPS will be coupled and validated, but not used to extrapolate towards JT-60SA and ITER. Priority will be given to model validation for ATEP, required before reliable extrapolation.** **Milestone dropped: One JT-60SA and one ITER high beta simulation stored on the gateway . Report on EP transport in ITER**	5, 7, 8
WP2.3-D2	*WP2 key physics modules validation- WP2.3: SOL-Core integration - Test the fast surrogate or simplified modules* **Reduced scope: Simplified edge models coupling and testing within ASTRA would not be performed within TSVV-H.** **No direct implementation in ASTRA of reduced edge models will be possible. Work to enable the modelling of XPR within HFPS will continue**	1, 3, 5, 7, 8
WP2.4-D2	*WP2 key physics modules validation- WP2.4: Pedestal modelling WP2.4-D2: Test resistive MHD calculations within integrated modelling* **Reduced scope: JET simulation with pedestal predicted by CASTOR (resistive MHD) would not be performed** **Impact the modelling of the pedestal. While it should be possible to test the ideal MHD with MISHKA and compare the prediction between the ETS and HFPS, it will not be possible to expand this work to resistive MHD. Impact the collaboration with the ENR on reduced model development for the pedestal and with the other related TSVVs. Note that, since the fusion performance is very sensitive to pedestal conditions, this effectively introduces a large uncertainty for any extrapolation of the fusion power in future machines (ITER, VNS, ARC, BEST etc.).**	3, 5, 8
WP4.D2	*WP4: Large scale validation WP4-D2: Demonstrate large-scale automated simulation execution, storage, and validation* **Reduced scope: The large-scale validation of TCV and WEST discharges will be reduced** **The large-scale validation program might be weakened, with reduced number of shots being considered, no edge modelling included and probably no pedestal modelling. An interpretive workflow to provide for sources and confinement calculation will still be developed, but it might not be possible to reach the level of maturity necessary for routine use.**	8

CEA

TSVV-I Stellarator Optimization: 2027 objectives

- **Complete GVEC free-boundary and apply it to shaped configurations with coils.**
- **Coil planarity in the database: a systematic search for quasi-isodynamic QI stellarators with simple (planar or nearly planar) coils.**
- **Global optimization via quasi-isodynamic (QI) database seeding**
- **Continue improving “CIEMAT”-QI configurations (ITG, electromagnetic turbulence...).**
- **Explore combinations of QI and piecewise omnigenous (pwO) to better satisfy other constraints (elongation, coil simplicity…).**
- **Benchmark SPECTRE with HINT (NIFS, Japan) 3D equilibrium in reactor-relevant free-boundary finite-beta equilibria.**
- **Couple SIMSOPT and SPECTRE to perform single-stage optimization in QI designs at finite beta.**
- **Release of SIMPLE -SPECTRE coupling , including virtual casing and wall loads with an island divertor.**

TSVV-I Stellarator Optimization: 2027 Impacted Deliverables

Label	Description;	Topics
SD6.8 SD6.9	SD6.8 : EMC3-EIRENE performance prediction in divertors with unpaired x-points SD6.9: Effect of edge optimization on divertor performance **Dropped: the study of the effect of edge optimization on divertor performance with high-fidelity codes;**	**6**
SD2.3, SD2.4	SD2.3 Interface SIMPLE-SIMSOPT to treat regions beyond LCFSSD2.4:Extension of SIMPLE to treat divertor region and evaluate wall losses **Dropped: the interfacing of efficient orbit-following codes with optimization codes, with a reliable prediction of energetic particle losses on the walls;**	**6**
SD3.3	SD3.3: W7-X configurations optimized for the generation of transport barriers **Dropped : the application of newly developed topological tools to the study and optimization of internal transport barriers in stellarators and validation in W7-X;**	**6, 8**
SD7.2:	SD7.2: Characterized piecewise omnigeneous configuration space **Dropped : the exploration of piecewise omnigeneous stellarator configurations, which offer the potential of simpler coil designs without compromising the confinement performance.**	**6**
SD7.4	SD7.4: Divertor concept for a tokamak-QA hybrid **Dropped the design of divertor concepts for a quasi-axisymmetric (QA) tokamak-stellarator hybrid.**	**6**

- **Risk : incorporation of divertor physics and alpha particle losses into stellarator optimization, and exploring the space of optimal stellarator shapes in order to ensure the lowest possible coil complexity.**

TSVV-J 2027 Milestones and Deliverables

- **Deeper physics**: zonal flows, turbulence self-interaction, multi-scale simulations, and the effect of the neoclassical E_r on turbulence.
- **Reactor relevance**: heavy-impurity transport and high-β turbulence across configurations, including tokamaks.
- **Towards reduced models**: extension of the most mature turbulence studies towards reduced models.
- **Validation**: W7-X OP2.4 and OP2.5 as a natural testbed for these studies.
- **Code development** towards EUROfusion standard softward: availability on gitlab and IMASification as next steps in 2027.

Deliverable / Milestone	Description
M.RM-QL-FLUXES	Model for fluxes with quasilinear weights computed from dispersion solver combined with saturation rules.
D.RM-ESTURB	Study of electrostatic turbulence in arbitrary 3D magnetic geometry by means of reduced models developed in 2026 work plan.
D.BETALIMITS	Assessment of β limits in stellarators via high-resolution stella simulations in flux-tube and flux-annulus geometries.
D.HEAVY-Z-TRANSP	Comprehensive study of tungsten transport in reactor-relevant W7-X scenarios, stellarator reactor candidates from TSVV-I, and ITER with 3D perturbations.
D.NEOTURB-GLOB	Study of nonlocal neoclassical effects on the radial electric field (Er) and, in turn, the effect of this on global turbulence using EUTERPE for W7-X and other optimized configurations.
D.GK-MULTISCALE	Investigation of multi-scale effects in stellarator turbulence.
D.ADVANCED-ZF	Study zonal flow dynamics in W7-X in light of recent work on the toroidal secondary mode in tokamaks.
D.RM-VS-NONLINEAR	Analysis of nonlinear flux-tube simulations in multiple stellarator geometries (W7-X, HSX, NCSX) at varying collisionality and pressure-gradient compositions comparing results with reduced-model predictions.
D.TURB-SELFINTER	Study of turbulence in low-shear stellarators near rational flux surfaces determining the strength of parallel self-interaction and its potential to enhance performance.

TSVV-J 2027 Scope reduction

- **Deeper physics**: zonal flows, turbulence self-interaction, multi-scale simulations, and the effect of the neoclassical E_r on turbulence.
- **Reactor relevance**: heavy-impurity transport and high-β turbulence **across configurations, including tokamaks**.
- **Towards reduced models**: extension of the most mature turbulence studies towards reduced models.
- **Validation**: W7-X OP2.4 and OP2.5 as a natural testbed for these studies.
- **Code development** towards EUROfusion standard softward: availability on gitlab and **IMASification** as next steps in 2027 (with ACH support).

Deliverable / Milestone	Description
M.RM-QL-FLUXES	Model for fluxes with quasilinear weights computed from dispersion solver combined with saturation rules.
D.RM-ESTURB	Study of electrostatic turbulence in arbitrary 3D magnetic geometry by means of reduced models developed in 2026 work plan.
D.BETALIMITS	Assessment of β limits in stellarators via high-resolution stella simulations in flux-tube and flux-annulus geometries.
D.ADVANCED-ZF	Study zonal flow dynamics in W7-X in light of recent work on the toroidal secondary mode in tokamaks.
D.RM-VS-NONLINEAR	Analysis of nonlinear flux-tube simulations in multiple stellarator geometries (W7-X, HSX, NCSX) at varying collisionality and pressure-gradient compositions comparing results with reduced-model predictions.
D.TURB-SELFINTER	Study of turbulence in low-shear stellarators near rational flux surfaces determining the strength of parallel self-interaction and its potential to enhance performance.

D.HEAVY-Z-TRANSP and high-β turbulence: W7-X configurations and campaigns take priority, while newly optimized stellarators and ITER with 3D perturbations are deprioritized.

IMASification: scaled back, although we have requested support for it in the call for ACH support.

TSVV-K Neutral Particle Models: 2027 Deliverables

- **WP0: Overall project management and code maintenance**
  - Report on the code status and its interfaces and future development plans for usage in the other TSVV-codes.
  - Updated EIRENE version released through JuGit base repository and associated repositories at ITER and EUROfusion,
- **WP1: Model hierarchy and interfaces**
  - Report on validity and accuracy of enhanced AFN model through rigorous comparison with EIRENE, incl. D-T simulations and integration of new fluid models into SpH scheme
  - Tested and performance optimized KDMC version in Neptune
  - Report on implementation/verification of time dependent mode for reduced resolutions turbulence case (SOLEDGE3X-EIRENE), incl. corresponding STYX2.0 interface and documentation of proper parameter tuning.
  - Verified EIRENE module including time dependent recycling model.
  - Technical demonstration of a 3D turbulent simulation of a medium size tokamak including full physics neutrals with SOLEDGE3X-EIRENE, leveraging the EIRENE OpenMP parallelization layer and grid decoupling (coarser grid for neutrals) in collaboration with TSVV-B
- **WP2 Collisional radiative models**
  - EIRENE release with consolidated MsV version of ModCR, including documentation
  - Publication on validation of the EIRENE version containing the new ModCR module and demonstrating the new capabilities and performance.
  - Extended molecular database including T and D-T, and report on application with SOLPS-ITER to i) JET-ILW T and D-T, and ITER; ii) if available, utilize for JT-60SA H and D

TSVV-K Neutral Particle Models: 2027 Impacted Deliverables

Label	Description	Topics
D.7, 8, 9 (2026)	**WP2- Develop high fidelity collisional-radiative models for H, D, T neutrals further, apply them to mixed fuel plasmas, and assess properties of charge-exchange neutrals Collisional radiative models (CRM)** **Reduced scope:** - Provision of at least 2 instead of 3 datasets for new/standalone collisional radiative model ModCR (and for PLOUTOS) including for hydrogen isotope containing molecules with resolution by vibrational ~~(rotational)~~states for mixed species. - Report on the significance of isotope effects and qualification of the uncertainties including those due to the missing/inaccurate A&M data - Report on ModCR (with PLOUTOS data) verification ~~against other codes (e;g. Yacora)~~ and validation against one (instead of two) experiment (JET or PSI-2)	1, 2, 7, 8
D.15, 17, 18, 19	**WP1- Establish a multi-fidelity model hierarchy for the physics of neutrals, ranging from first principles models to reduced representations, and integrate it into fluid and gyrokinetic edge turbulence simulations. Exploit synergies with TSVV-B and TSVV-C.** **Reduced scope:** D15 Report on validity and accuracy of enhanced AFN model through rigorous comparison with EIRENE, incl. D-T simulations and integration of new fluid models into SpH (Spatially Hybrid) scheme advanced : no implementation of molecules into Advanced fluid neutrals (AFN) and fluid-kinetic hybridisation (FKH) to prioritise kinetic diffusion Monte-Carlo (KDMC) development. D17 : Report on implementation/verification of time dependent mode ~~for reduced turbulence case in~~ SOLEDGE3X-EIRENE, incl. corresponding STYX2.0 interface and documentation of proper parameter tuning D18 : ~~Verified~~ EIRENE module including simplified time dependent recycling model D19 : Technical demonstration of a 3D turbulent simulation of a medium size tokamak including full physics neutrals with SOLEDGE3X-EIRENE ~~leveraging the EIRENE Open-MP parallelization layer~~ and leveraging grid decoupling (coarser grid for neutrals) in collaboration with TSVV-B	1, 2, 7, 8
D.20,22	**WP2- (2027) Develop high fidelity collisional-radiative models for H, D, T neutrals further, apply them to mixed fuel plasmas, and assess properties of charge-exchange neutrals Collisional radiative models (CRM)** **Reduced scope:** D20: EIRENE release with consolidated Milestone Version of ModCR, including documentation but with the 2026 reduced scope for CRMs D21: Extended molecular database in EIRENE including T-T and D-T and report on application with SOLPS-ITER to i) JET-ILW T-T and D-T, ~~and ITER~~; ii) JT-60SA H and D (if specific data available)	1, 2, 7, 8

FAIRNESS



Transparency
Collaboration
Loyalty

OPENNESS



Open doors
Open hearts
Open minds
Open ears

COMMITMENT



Ownership
Critical thinking
Determination
Respect

DIVERSITY



Cooperation
Equal opportunities
Inclusion

Back-up

TSVV-B Plasma Particle/Heat Exhaust – Fluid Simulations
2026 Impacted Deliverables

Label	Description	Topics
D1.1	Assessment of impact of baffles on turbulence and plasma conditions in high-density regime in TCV *(CEA, EPFL)* **Reduced scope: CEA contribution cancelled as deemed as lower priority than some of the 2027 deliverables.**	**2**
D6.2	Couple another edge turbulence code to EIRENE or KINDNES, likely starting with GRILLIX *(CEA, DTU, EPFL, MPG)* **Reduced scope: Coupling of KINDNES to another turbulence code cancelled as deemed as lower priority than some of the 2027 deliverables. This would limit the mutualization of tools among European codes.**	**2**
D7.1	Implement KINDNESS kinetic neutral solver in GPU-compatible version of GBS *(EPFL)* **Dropped: *Similarly to D6.2, future developments of the KINDNESS code, including its GPU-ization postponed beyond 2027, limiting the upscaling of GBS simulations to larger machines.***	**2**

Impacted codes capabilities (not exhaustive/no specific order) following human reduction vs approved TSVV proposals

- **GENE-X**
  - improved T_e pedestal predictions through the implementation of sub-grid ETG models
  - neutral model implementation (PIROCK adaptive time-stepping)
- **GENE**
  - multi-scale turbulence characterizations
  - comparisons with / assessments of reduced models such as TGLF
- **GYSELA**
  - Implementation of kinetic source for plasma-neutral interaction in Gysela-X++
  - Surrogate model implementation for sheath boundary condition
  - No validation on “no ELM I-mode regime”
- **SOLEDEG3X and EMC3-EIRENE coupling to ERO2.0** for 3D workflow validation and application for ITER
- **EIRENE:** reduced scope for Collisional Radiative Models
- **KINDNESS (kinetic neutral model):** no coupling to other codes than GBS
- **JOREK-GK** ITG/TEM turbulence studies with RMPs: limited cases
- **JOREK-DREAM:** capability to carry out run-away generation calculations over long time scales in MHD quiet scenarios.
- **DREAM:** incomplete parallelization does not allow the same level of comprehensive physics studies
- **CARIDDI and FIREWALL** compliance with EUROfusion standard software requirements
- **ASTRA :** no EUROfusion support and loss of experts (focus mainly on HFPS & to lesser extent on ETS)
- **HFPS:** Integration of QLK_NN_11, CASTOR, MEQ and tests for broader exploitation of EDGE2DNN, SOLPSNN, PLIKES, ATEP, EQSTABIL
- **STELLA:** IMASification of outputs for systematic database analysis
- **ERO2.0, MIGRAINe:** Applicability of PWI surrogate, W transport from wall to core and time-dependent dust ablation sources
- **FESTIM, PFC-T-T:** Damage-induced trap model parameterization and implementation for validation and predictive applications
- **Geant4-MEMENTO-LSDYNA framework:** finalization of full thermo-mechanical model for W material response to RE impact

Overview of the scientific topics impacted by the work-force reduction per TSVV

	TSVV	1. SOL heat flux decay length, pedestal and L-H transition	2. Advanced regimes without ELMs	3. Core-pedestal-SOL-wall workflow including 3-D effects	4. Disruption, RE and impact on the W wall	5. High beta plasmas and fast particle effect	6. Stellarator core turbulence and Optimization	7. Reduced models	8. Validation and UQ
A	H-Mode and Small/No-ELM Pedestals	X	X					X	X
B	Plasma Particle/Heat Exhaust – Fluid Simulations	X	X					X	X
C	Plasma Particle/Heat Exhaust – Gyrokinetic Simulations	X	X				X	X	X
D	Plasma-Wall Interactions with Metallic Plasma-Facing Components			X	X			X	X
E	Impurity Sources, Transport, and Screening			X				X	X
F	Tokamak Disruptions and Runaway Electrons				X			X	X
G	Physics of Burning Plasmas					X		X	
H	Reliable Prediction of Plasma Performance and Operational Limits in Tokamaks	X		X		X		X	X
I	Stellarator Optimization			X			X		X
J	Stellarator core turbulence			X			X	X	X
K	Neutral particle models	X	X					X	X

Resource considerations

- **TSVVs call issued with 5-6 PPY/Y for TSVV A-J, 3 PPY/Y for TSVV K for 2026-2027** (30% lower than in 2021-2025)
  - Following replies to the call : 45% overbudget despite all proposals within 6 PPY/Y
  - Within one week TSVV PIs went down to the minimum limit : 5 (3) PPY/Y (without UKAEA)
  - PIs revised the deliverables & PPY following recommendations from E-TASC Scientific Board
- **Issue 1 for PL/PSO: 1 PPY/Y not included in the 2026-2027 budget estimate (activity previously managed by PMU when call issued)**
- **Issue 2 for TSVVs: Calculation with the actual salary/per beneficiary for 2026-27 leads to budget above TM budget ceiling in k€**
- **TM decision to provide PPY as selected in 2026 and to reduce PPY in 2027 by 28 % (uniformly across all TSSVs/beneficiaries) to stay within the budget ceiling (5864 k€ in CC)**
  - Mismatch between deliverables and allocated PPY: **3.6 PPY TSVV A-J and 2.1 PPY TSVV K in 2027**
- **Mission budget: 97 k€/year (direct cost) not sufficient to hold at least one in-person meeting per TSVV/Y + E-TASC general meeting and does not include PL/PSO missions (Project Board, E-TASC, HPC Board, FSD ...)**
  - Request: 130 k€ for 105 participants with one week mission per year

Back-up

- Establishing the coupled JOREK–DREAM framework as a new tool in the modelling hierarchy for runaway electrons (REs) will enable phase-space-resolved simulations of the entire current quench (CQ) in large tokamaks such as ITER, including the self-consistent vertical motion of the plasma. This approach is valid as long as magnetohydrodynamic (MHD) activity during the CQ remains weak.
- When MHD activity becomes strong enough that this assumption breaks down, the 2D JOREK–DREAM simulation will be continued directly as a full 3D simulation with JOREK alone. Achieving these goals requires substantial work on parallelising the coupled parts of both codes, including algorithmic adaptations and porting to GPUs.
- relevant to TSVV-D. Present calculations of RE wall loads must rely on ad hoc assumptions about the RE distribution in phase space, which introduces large uncertainties into assessments of wall damage. Combining JOREK–DREAM simulations of the CQ with JOREK-standalone simulations of the RE beam termination will provide much more accurate input for FIREWALL- and GEANT4-based analyses.