

Project Board 16.03.2026

WP W7-X – Status 2025

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Initial information

- Arturo Alonso stepped down as DTFL in December 2025. Daniel Carralero appointed as a new DFTL
- Key updates included forming a Key Physics Gaps group and securing additional resources via PCRs for HELIAS physics, W7-X missions in 2025, and data analysis aligned with the Grand Deliverables.
- A partial recovery of resource levels from before 2022 enabled the recruitment of more researchers, contributing to fast-ion calculations with ASCOT and the implementation of edge drifts in EM3C-Eirene.



High-level goals of WP W7-X

WPW7X: Focuses on contributing to and leveraging W7-X to demonstrate physics questions related to HELIAS line towards fusion reactor:

- The positive effects of optimization on plasma confinement, fast particle behavior, and MHD equilibrium and stability.
- Achieving good plasma confinement in the long-mean-free-path regime at elevated plasma beta.
- Ensuring safe steady-state operation while exploring potential reactor scenarios.

For WPW7X, 2025 is an as-planned continuation of the FP9 strategy. The plan is adapted to technical capabilities, findings and achievements

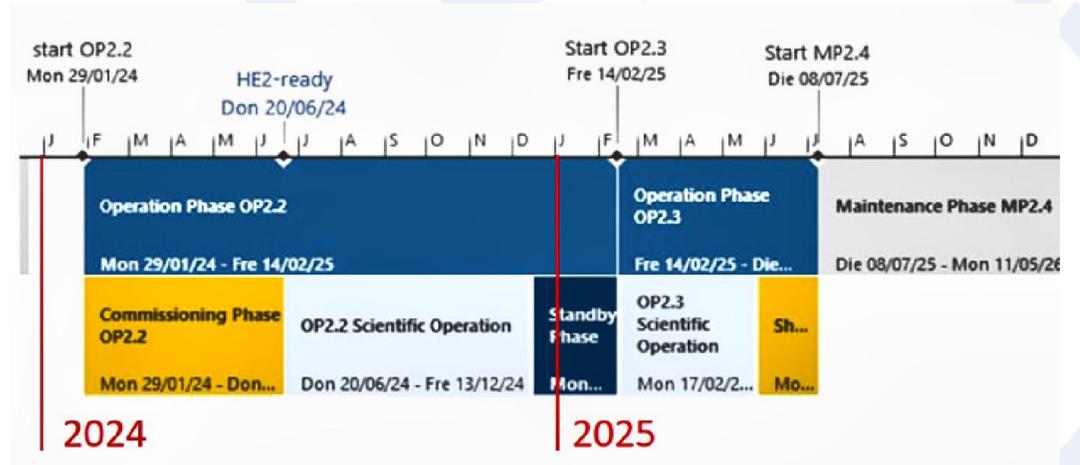
- **Main objective 2025: conduction of campaign W7-X** (heating upgrades, pellet injection, low field operation, wall conditioning/metallic wall, other RTs)
- EU contributions to upgrades in FP9
- Exploitation of 2024/25 campaign
- Physics basis & ITER support



2025 Objectives

WPW7X-2025.O1	Conduct and support the 2025 campaign of W7-X along the Research Topics RT1-11 of the Call for Participation to achieve the Campaign deliverable CD1-39. Thereby contribute to the research topics and campaign deliverables as specified in tables 2-3. The campaign in 2025 will be implemented involving the responses to the 2024/2025 WPW7X Call for Participation.
WPW7X-2025.O2	Exploit the results achieved in the campaigns through the analysis of data from the 2024 W7-X Campaigns , systematic validation in cooperation with TSVV to provide simulation tools for next-step devices. The research topics and campaign deliverables are specified in tables 2-3.
WPW7X-2025.O3	Conduct and support the development of scenarios, wall conditioning and deliver input for the design of a metallic divertor upgrade
WPW7X-2025.O4	Conduct the development of required heating upgrades (ECRH, NBI, ICRH), diagnostics (spectroscopy systems, reflectometry, FILD, video, probes, endoscopes), the divertor manipulator, prepare safe long-pulse, high-power operation by implementing safety interlocks and development of software tools for safe operation.
WPW7X-2025.O5	Support the preparation of the HELIAS physics basis , ITER, ensure information exchange with WPPRD, WPDIV, WPPWIE, WPPrIO, WPTe and continue international collaborations in support of the Mission 8 objectives.

Research Topics include:
High performance conditions
High beta scenario development
Long-pulse operation and wall conditioning.
Low field operation



New activity launched within WP W7-X
 Identification of critical physics uncertainties associated with the Stellarator DEMO, the corresponding research gaps, and how these can be addressed within the scope of WP W7X. Target date: June 2025



Status heating systems: ECRH (MPG, KIT, Polito, NCSRD)

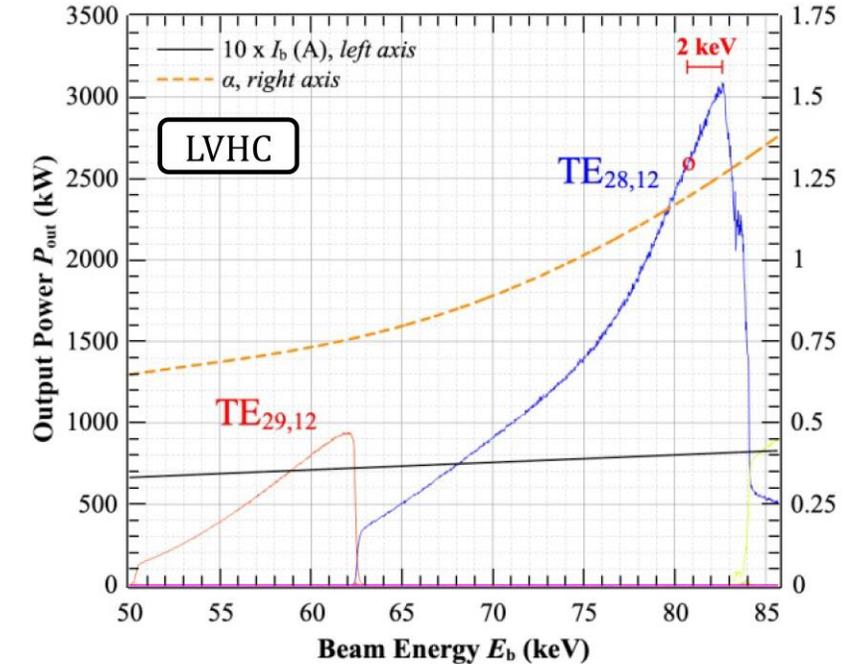
NKUA simulation of TE28.12 mode at <2 MW

- **1.5 MW gyrotrons:**

- Optimized the TH1507U 1.5 MW gyrotron cavity to suppress parasitic backward-wave modes that had limited CW output to about 1.3 MW at W7-X; new cavity and offset beam tunnel were designed, manufactured and integrated into the KIT short-pulse prototype.
- Achieved very good simulation–experiment agreement for short-pulse operation of the present 1.5 MW TH1507U gyrotron at W7-X by introducing an improved fit to the Cryomagnetics magnet geometry, which is now used as the validated reference for further design and upgrade studies

- **2 MW gyrotrons:**

- Established the theoretical feasibility of a 2 MW, 140 GHz conventional-cavity gyrotron for W7-X.
- Performed detailed start-up and space-charge simulations for the 2 MW TE28,1228,12 design, showing that >2 MW output can be reached after beam neutralisation



LVHC having a 2-keV margin from mode loss¹

α	R_b (mm)	P_{out} (MW)	η_{elec} (%)	ρ_{out} (kW/cm ²)
1.2	10.1	2.61	41.3	2.46

¹Use of the TH1507U diode gun

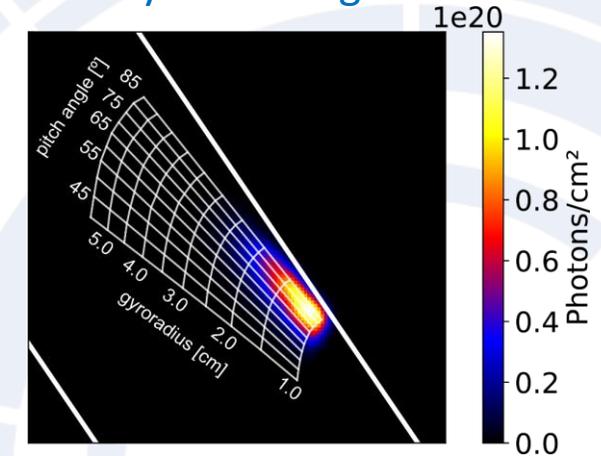


Status of major enhancements projects within WP W7-X

SFILD (Univ. Seville)

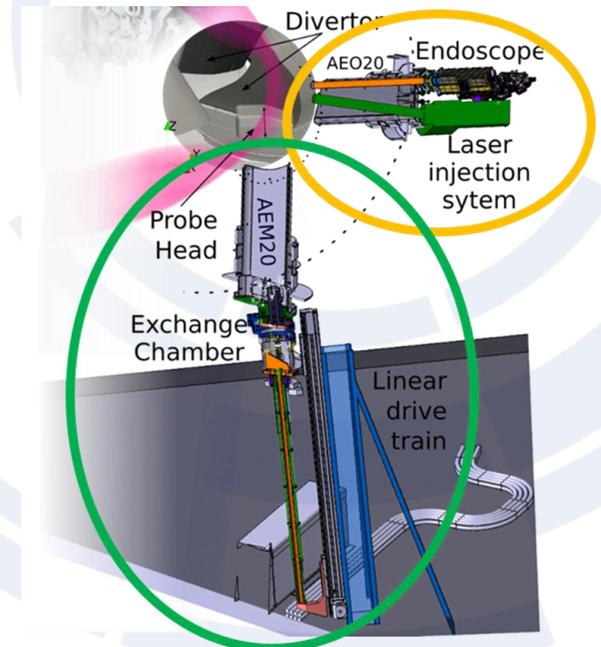
Topic	Activities in 2025
Modelling	<ul style="list-style-type: none">sFILD synthetic signal from ASCOT+FILDSIM to characterise H and He beams signal including a realistic collimator and noise
Optics	<ul style="list-style-type: none">A conceptual design of the optical system already existsDesign of the clamping system for the in-vessel installationPerformance lab testing
Scintillator	<ul style="list-style-type: none">Facilities prepared for scintillator characterization and testing (CNA and US)Characterisation to select the best candidate in terms of luminescence response and degradation

sFILD synthetic signal



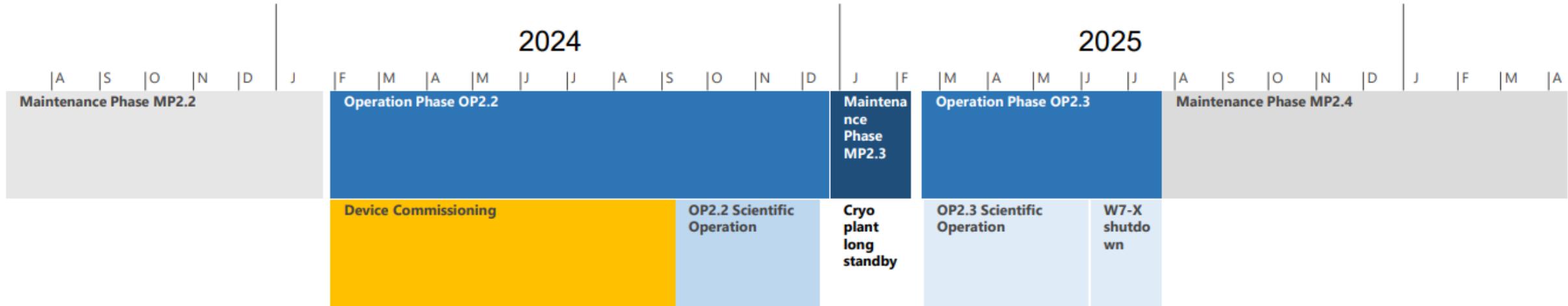
MATEO (FZJ)

- New DO for MATEO due to retirement of Olaf Neubauer (→ Wolfgang Biel)
- Documentation for MATEO in advance to the DDR finished
- Provision of MATEO handling prototype completed, assembly of MATEO base system ongoing.
- Concept development for the MATEO observation system, hardware development postponed to prioritize the base system.





Campaign in 2025



- Experimental campaign OP2.3 in 2025 performed successfully. Initial delay to repair of the faulty transformer fully compensated with additional experimental days in OP2.2 & OP2.3
- From mid-July longer maintenance phase planned until mid of 2026.
- 17 Beneficiaries involved in exploitation of W7-X
- EUROfusion proposals in the campaign > 40%. One-team approach allows for fully engaged experimental team consisting of IPP and external contributors.

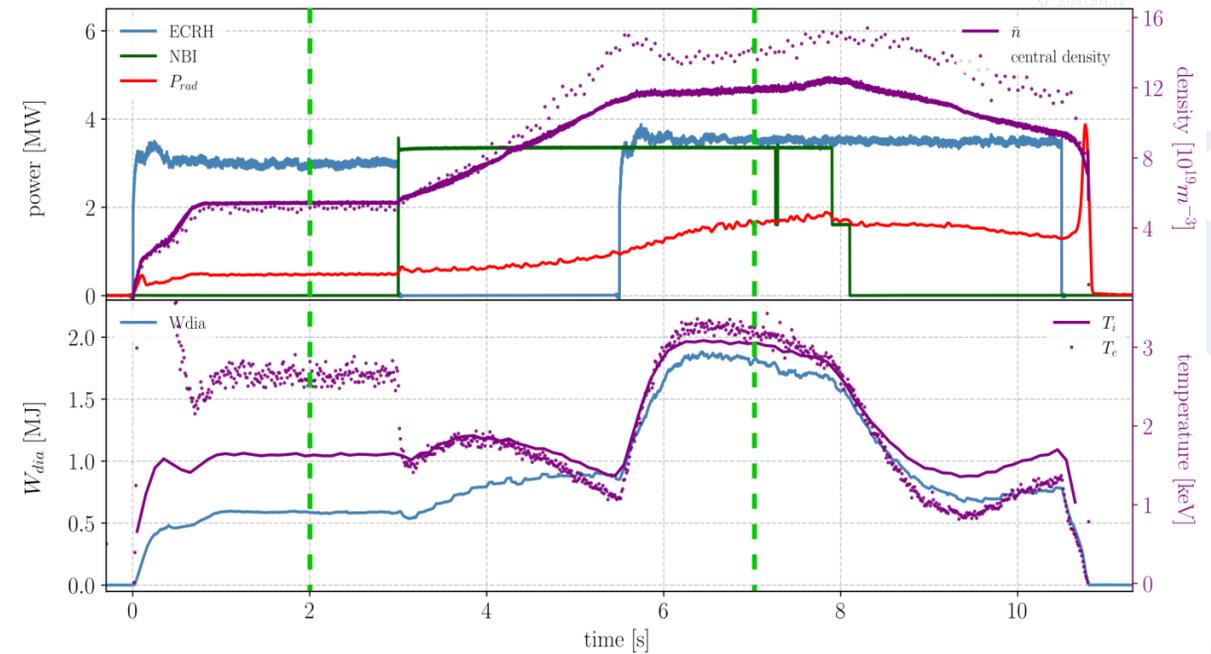


Main scientific results of 2025 campaign

S. Bannmann, et al., IAEA-FEC 2025

WP W7-X focuses on contributing to and **leveraging W7-X** to demonstrate physics questions related to HELIAS line towards fusion reactor:

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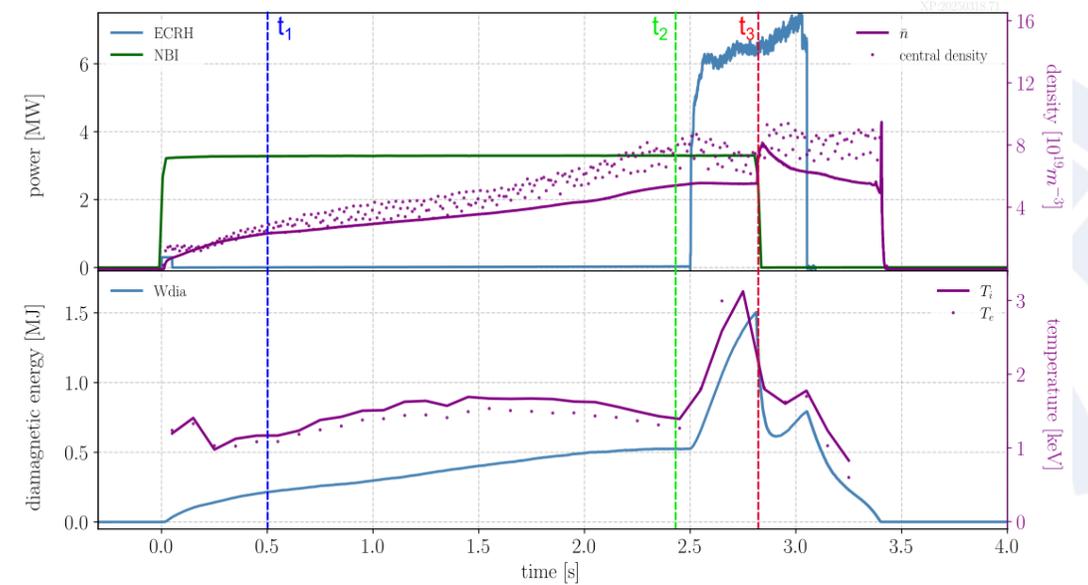




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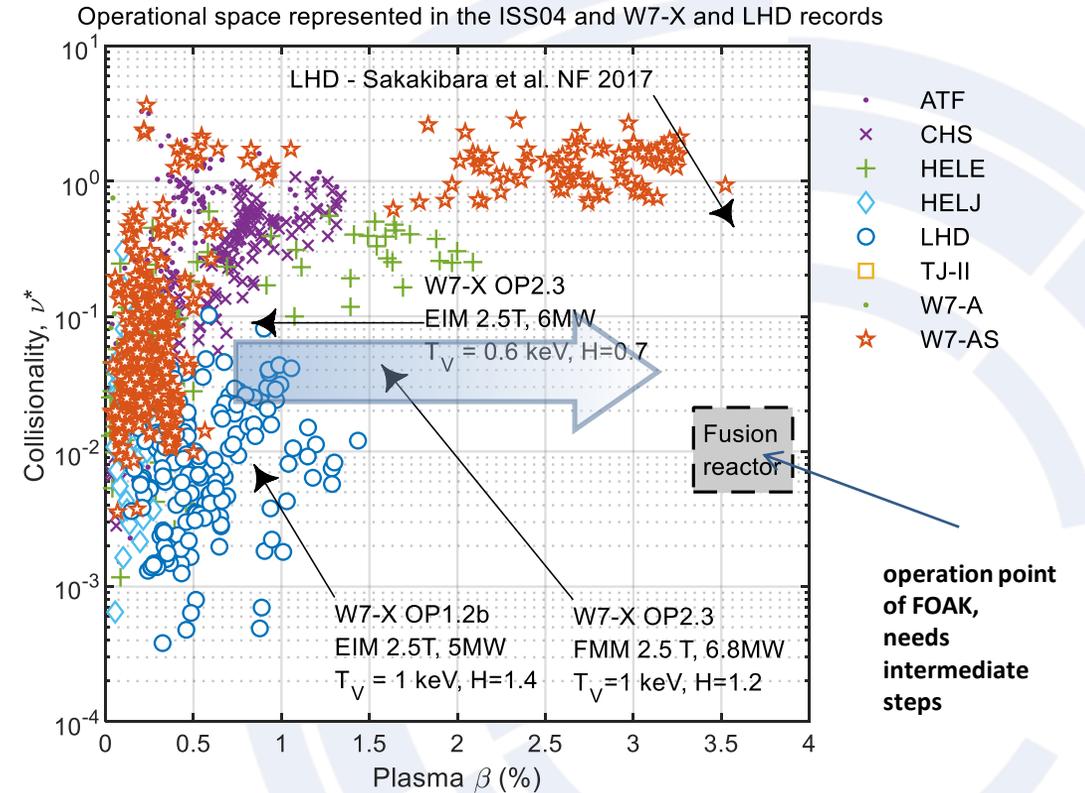




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Progress depends also on available power.
At the moment $P_{tot} > 13$ MW, >20 MW required

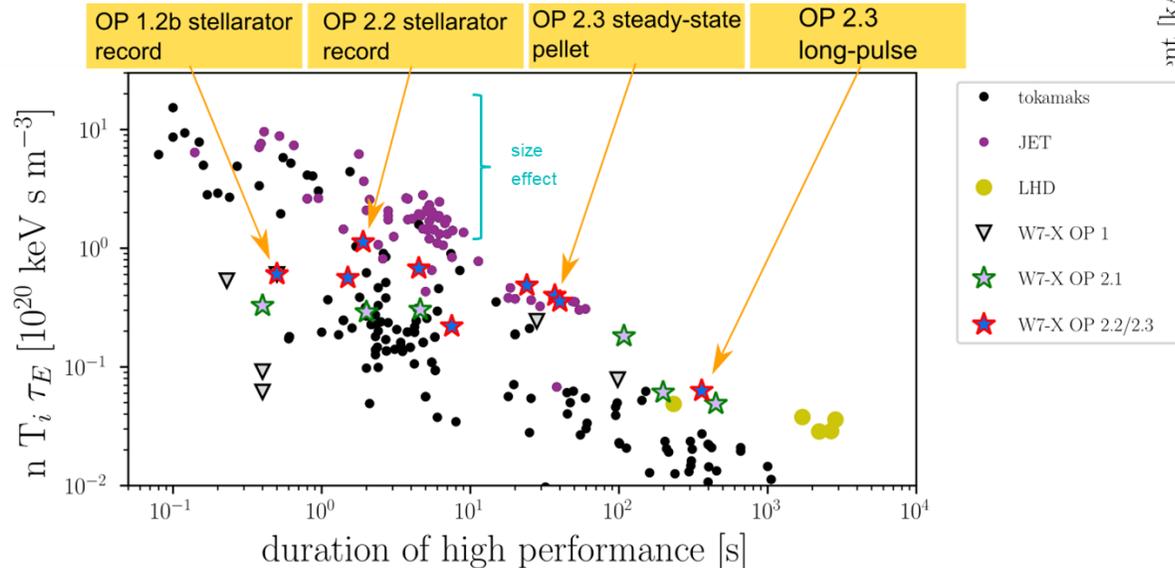
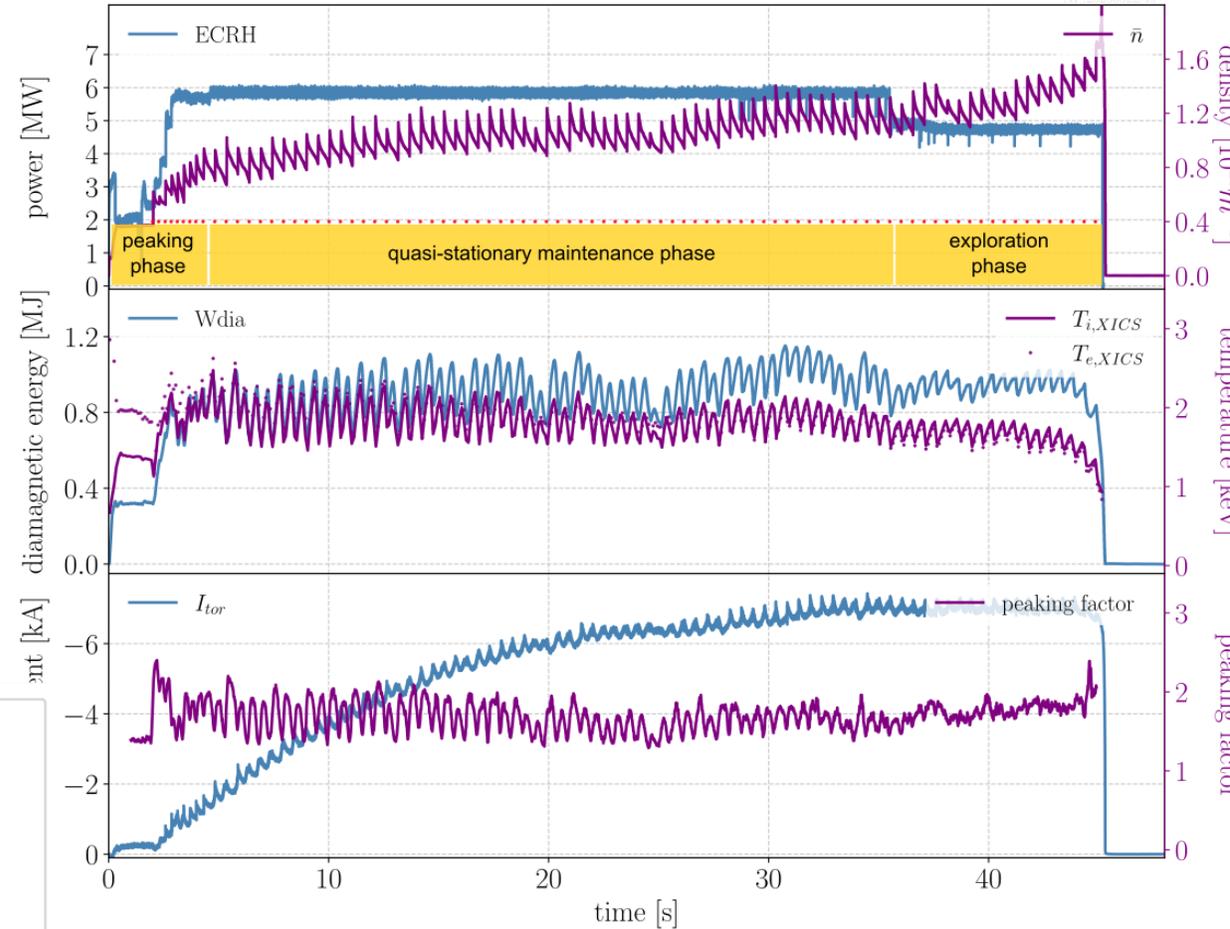


Main scientific results of 2025 campaign

O. Grulke, IAEA-FEC 2025

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Status Grand Deliverables & Milestones

ID	Title in CWP	Due Date	Status	IDM
W7X.D.10	Verified and validated stellarator gyrokinetic codes for the calculation of turbulent transport (TSVV-13)	31.12.2025	completed	(EFDA_D_2RDZHB v1.0)
W7X.D.11	Report on conducted scenario & campaign preparation (focus: high-power steady-state operation)	31.12.2025	completed	EFDA_D_2T3M6A v1.2)
W7X.D.12	Assessment report on HELIAS optimization (with data from carbon PFC operation)	31.12.2025	completed	(EFDA_D_2NT558 v1.1)
W7X.D.13	Report on conducted scenario & campaign preparation (focus: PFC upgrades)	31.12.2025	completed	(EFDA_D_2T3E35 v1.1)
W7X.D.14	Comparative assessment of the HELIAS reactor physics basis with respect to other stellarator concepts (with International Collaborations).	31.12.2025	completed	(EFDA_D_2T8P9N v1.1)
W7X.D.15	Modern European stellarator optimization code and its use to determine options for next-generation devices. (TSVV-12)	31.12.2025	completed	(EFDA_D_2NCKL6v1.1)
W7X.M.05	High-beta HELIAS operation at low collisionalities	31.12.2025	achieved	
W7X.M.06	Operation with High power and long-pulse completed and 2 GJ energy turn-around achieved (pulse lengths up to 600 s, long-pulse detachment).	31.12.2025	achieved	



Key Physics Gaps towards HELIAS reactor (MPG, CIEMAT, EPFL, FZJ, PMU)

1. Heat and particle exhaust	wydarzenia 2
2. MHD equilibrium and stability	wydarzenia 2
3. Core Transport & Confinement	wydarzenia 3
4. Fast particle confinement and interaction with Alfvén waves	wydarzenia 7
5. Plasma-wall interaction and PFCs	wydarzenie 1
6. Scenario integration	wydarzenie 1
General Meetings	wydarzenia 7



Key Physics Uncertainties and Related Investigation Needs towards Stellarator Reactor

Authors:

M. Jakubowski, K. Aleynikova, P. Aleynikov, A. Alonso, S. Bozhenkov, S. Brezinsek, J. Fellingner, I. Calvo, D. Carralero, A. Dinklage, J. Geiger, J. M. García-Regaña, T. Kremeyer, H. Laqua, J. Loizu, A. Mishchenko, D. Naujoks, C. Slaby, N. Panadero, V. Perseo, F. Reimold, J. Romazanov, J.L. Velasco, F. Warmer, V. Winters, M. Wischmeier

<https://idm.euro-fusion.org/?uid=2T9PQA>

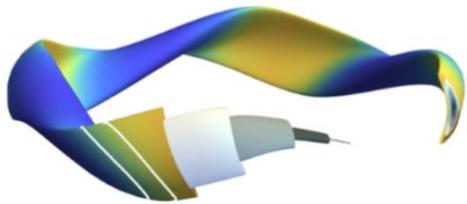


TSVV12, TSVV13 (successfully accomplished)

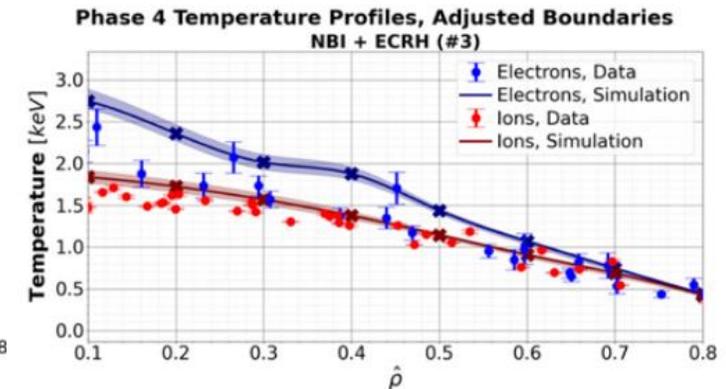
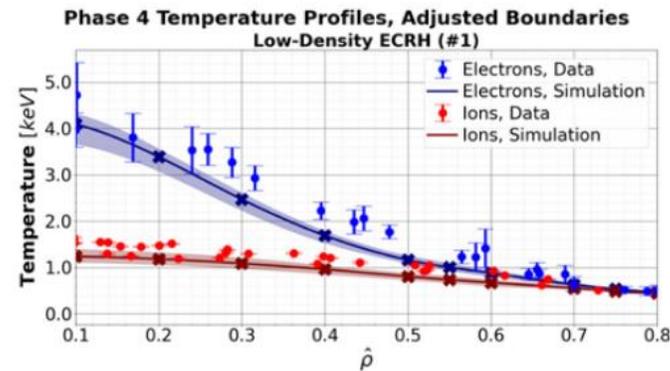
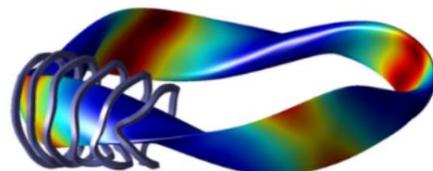
- ❑ **TSVV12:** developed **state-of-the-art stellarator optimization tools** with fast numerical capabilities integrated into **open-source suites**.
- ❑ Achievements:
 - ❑ New designs show **improved reactor performance without increased complexity**
 - ❑ Foundation established for **next-generation stellarator concepts** with enhanced 3D magnetic insights

- ❑ **TSVV13:** Suite of **stellarator gyrokinetic codes** (GENE, stella, GENE-3D, EUTERPE) cross-verified and **validated against W7-X experimental data**
- ❑ Achievements:
 - ❑ Established first **comprehensive stellarator benchmark case** enabling unprecedented collaborative code development
 - ❑ **Verified predictions across multiple domains:** turbulent transport, impurity behavior, zonal flows, and electromagnetic instabilities

SQUID family



CIEMAT-QI family





AI/ML Projects

- Three projects within WP W7X:
 - **Testing cutting-edge AI research to increase pattern recognition and image classification in nuclear fusion databases (CIEMAT)**
Successfully finalized
 - **AI based surrogate forward and inverse models for the TRAVIS ray-tracing code (DTU/IPP) –**
Personnel shifts required and synergies with two further fusion related projects motivated adaptation of the project plan. Nonetheless, the personnel shortage, while relieved, resulted in delays. With greater human resources in place and good progress on training a more fine-grained project plan has been developed.
Request to shift 11.5 PM from 2025 to 2026 rejected by PMU. Report still pending
 - **Development of machine learning (ML) based inference methods for complex diagnostics (EK-CER) -**
progresses well, although first application not at W7-X and MASTU, but AUG
Successfully finalized



Summary

- The campaign was completed successfully, achieving major progress across key physics milestones with active contributions from EUROfusion partners.
- A 1.5 MW gyrotron was routinely operated, with additional gyrotrons currently under development and ongoing improvements to the cavity design. Initiated design of 2 MW gyrotrons.
- ICRH was applied in multiple scenarios, including the initial operation of three-ion heating and wall conditioning, with further enhancements underway.
- Addressing key physics gaps enabled more science-based discussions on future stellarator requirements. The final report published in IDM, EPS Plenary talk and paper in preparation
- All milestones and General Deliverables achieved.



Research topics for experimental campaigns 2024/2025

ID	Tag	Description
RT-01	High performance conditions	Exploration of reduced turbulence/ high-performance scenarios in view of stationary plasma conditions with temperature-, density and impurity-profile control.
RT-02	Heating scenarios	Exploration of heating scenarios using upgraded heating capabilities (ECRH, NBI, ICRH).
RT-03	High beta scenario development	Development of high plasma beta scenario by low field operation.
RT-04	Long-pulse operation and wall conditioning	Development of integrated scenarios for long-pulse operation with PFC heat-load control, efficient particle exhaust and impurity screening; Development of wall conditioning procedures.
RT-05	Detachment	Development of long and stationary divertor detachment scenarios with and without impurity seeding.



RT-06	Tungsten PFCs (together with WP PWIE)	Exploration of scenarios compatible with carbon free operation and tungsten PFCs.
RT-07	Documentation of physics basis	Physics basis (core, edge) and reference discharges.
RT-08	Core physics studies	Completion of the core transport and stability physics basis in the extended operational space.
RT-09	Edge physics studies	Completion of the edge and SOL physics basis in the magnetic configuration space of W7-X.

- **Preparation of MATEO documentation for the detailed design review (DDR)**
 - Project specification sheet **completed and approved**
 - CODAC specification sheet **completed**
 - Safety analysis document **in review procedure**
- **Provision of the MATEO handling prototype, begin assembly of the MATEO base system**
 - Prototype testing (fast motion) **successfully completed**
 - Handling prototype **prepared**
 - Manufacturing of mechanical parts **in progress**
 - Supply systems (electricity, media, gases) **in progress**
 - Manufacturing and test of BIAS modules for probe supply **completed**
 - Assembly start of base system scheduled end 2025
- **Concept development for the MATEO observation system**
 - Conceptual studies are continued, hardware development has been **postponed to prioritise base system**

