Project Board 27.10.2025

WP W7-X – Status 2025

**Marcin Jakubowski (PL), Arturo Alonso (DTFL),
Iván Calvo (DTFL), Juliane Haese (PSO)**

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.

Initial information

- A new Task Force Leader (TFL) took over WP W7-X in May 2024.
- With the AWP 2025 presentation scheduled for June 2024, the plan largely continued WP W7-X's long-term objectives, with only a few modifications.
- 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 (e.g. 1.3 GJ energy turn-around)

- **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.

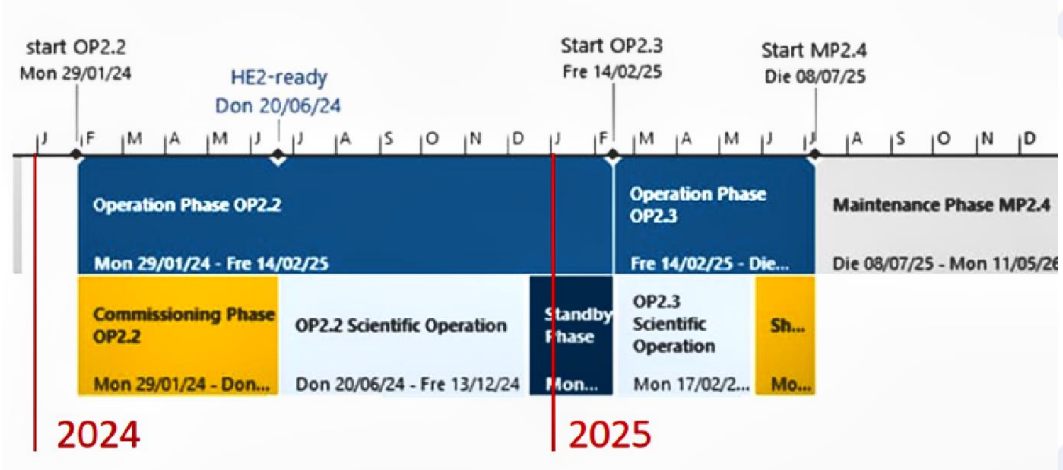
Research Topics include:

High performance conditions

High beta scenario development

Long-pulse operation and wall conditioning.

Low field operation



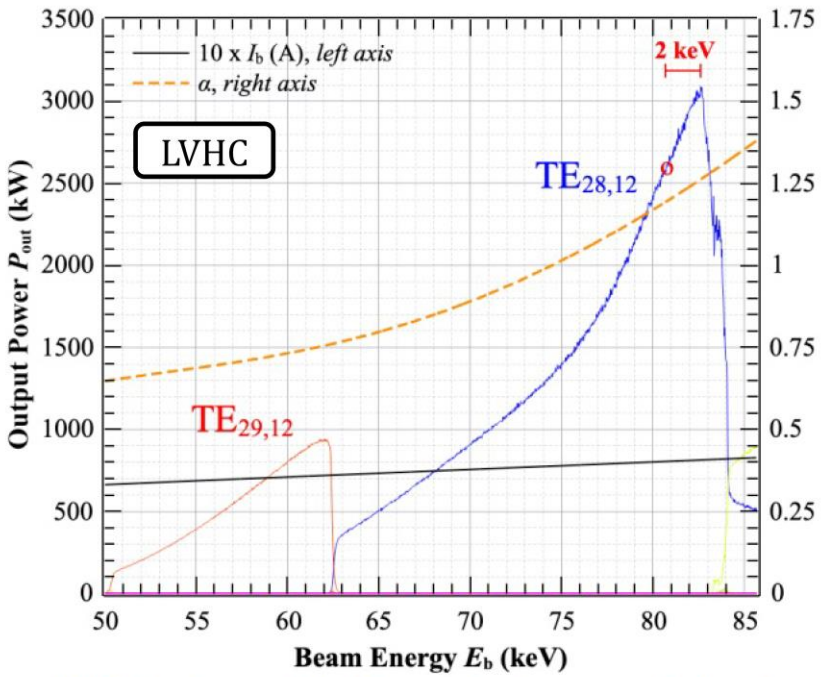
New activity launched within WP W7-X

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

- **<u>1.5 MW gyrotrons:</u>**
  - First 1.5 MW gyrotron routinely used in OP2.3 campaign, with the output up to 1.3 MW.
  - Saturation of output power at 1.3 MW a TH1507U gyrotron at IPP is accompanied by increasing parasitic mode emission at 122.5 GHz. New cavity shape was tested with short pulse gyrotron at KIT and has been implemented in the next 1.5 MW gyrotron.
- 2 MW gyrotrons:
  - Development is ongoing with tight collaboration between IPP, NKUA (NCSRD), KIT and PoliTo (ENEA).

NKUA simulation of TE28.12 mode at <2 MW



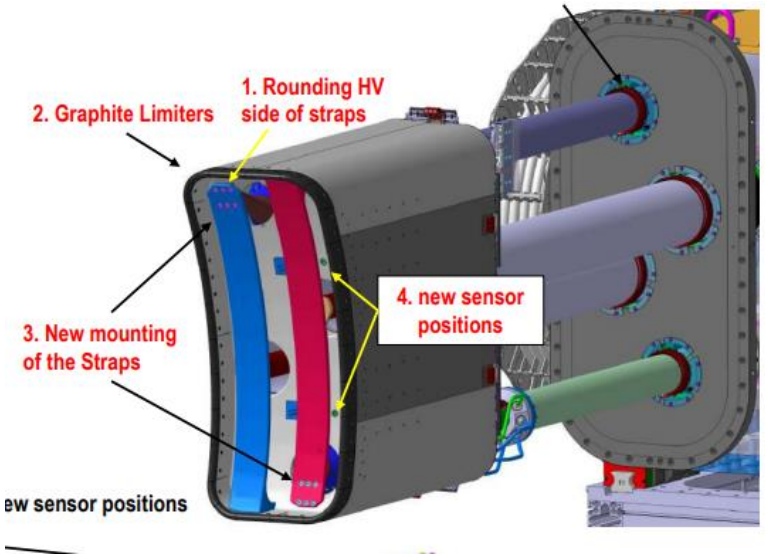
LVHC having a 2-keV margin from mode loss[1]

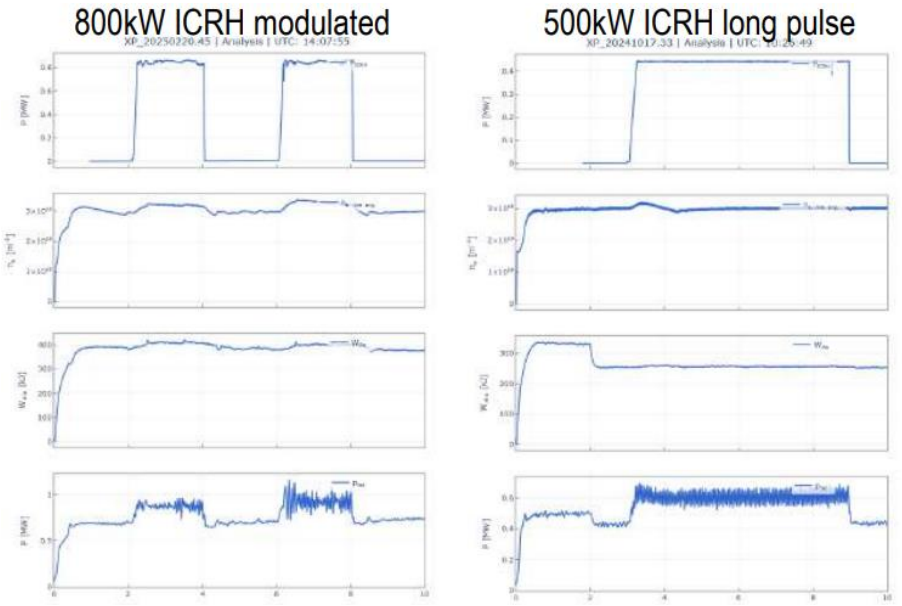
α	R_b (mm)	P_{out} (MW)	η_{elec} (%)	ρ_{out} (kW/cm²)
1.2	10.1	2.61	41.3	2.46

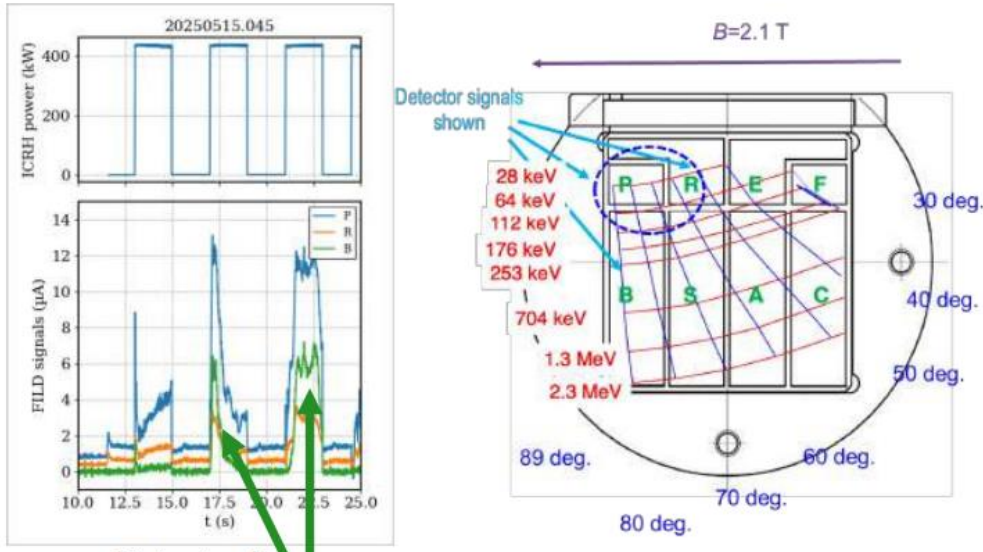
[1]*Use of the TH1507U diode gun*

Status of heating systems: ICRH

1. First real campaign use of ICRH in 2025 with so notable results:
   1. High power (800kW) and long pulse (~5s) operation with breakdowns
   2. First production of 64keV 3He++ particles with 3-ion scheme 4He-(3He)-H
   3. ICRH wall cleaning and plasma start-up.
2. Technological improvements by LPP-ERM-KMS team







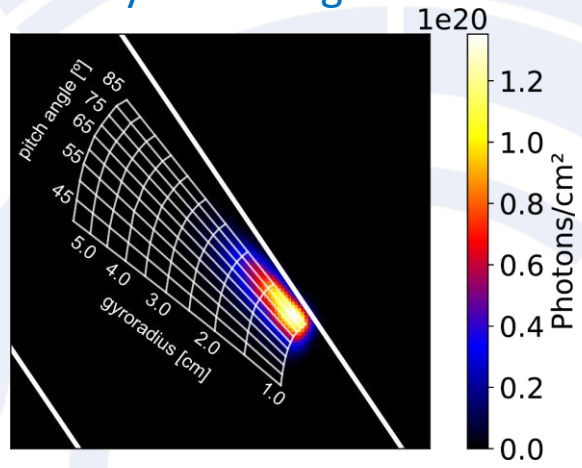
Detector B
Fast particles E > 64kev
at pitch angle 80-90 degrees

Status of major enhancements projects within WP W7-X

SFILD

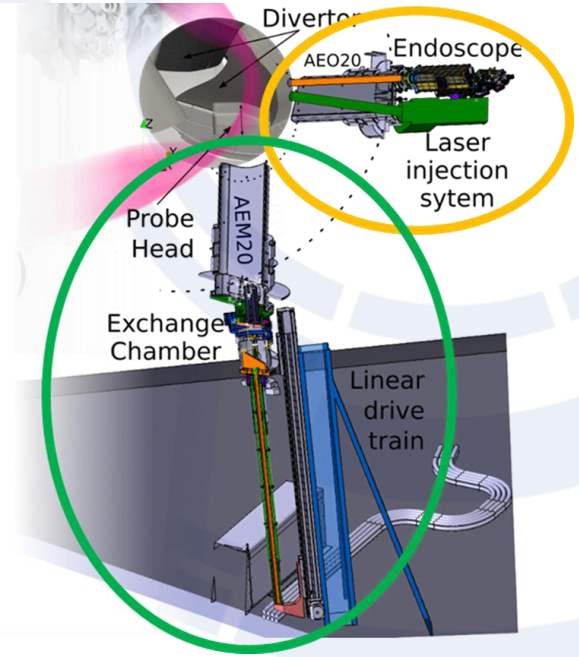
Topic	Activities in 2025
Modelling	• sFILD synthetic signal from ASCOT+FILDSIM to characterise H and He beams signal including a realistic collimator and noise
Optics	• A conceptual design of the optical system already exists • Design of the clamping system for the in-vessel installation • Performance lab testing
Scintillator	• 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

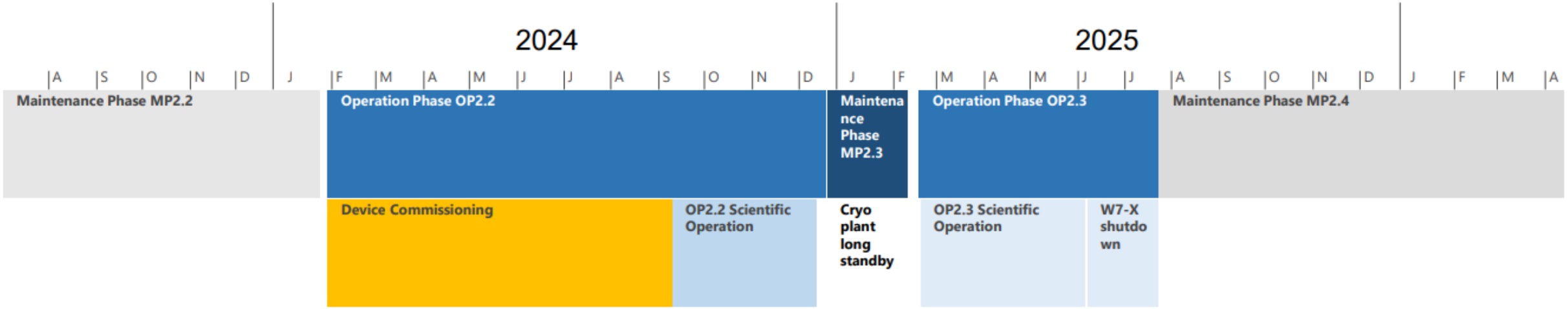


MATEO

- New DO for MATEO due to retirement of Olaf Neubauer (→ Wolfgang Bie
- Preparation of documentation for MATEO in advance to the DDR
- Provision of MATEO handling prototype completed, assembly of MATEO b system ongoing.
- Concept development for the MATEO observation system



Campaign in 2025



- Experimental campaign OP2.3 in 2025 peformed succesfully.
  Initial delay to repair of the faulty transformer fully compensated with additional experimental days in OP2.2 & OP2.3
- From mid-July longer mainatenance phase planned until mid of 2026.
- 17 Beneficiaries involved in exploitation of W7-X
- EUROfusion proposals in the campaign > 30%

Main scientific results of 2025 campaign

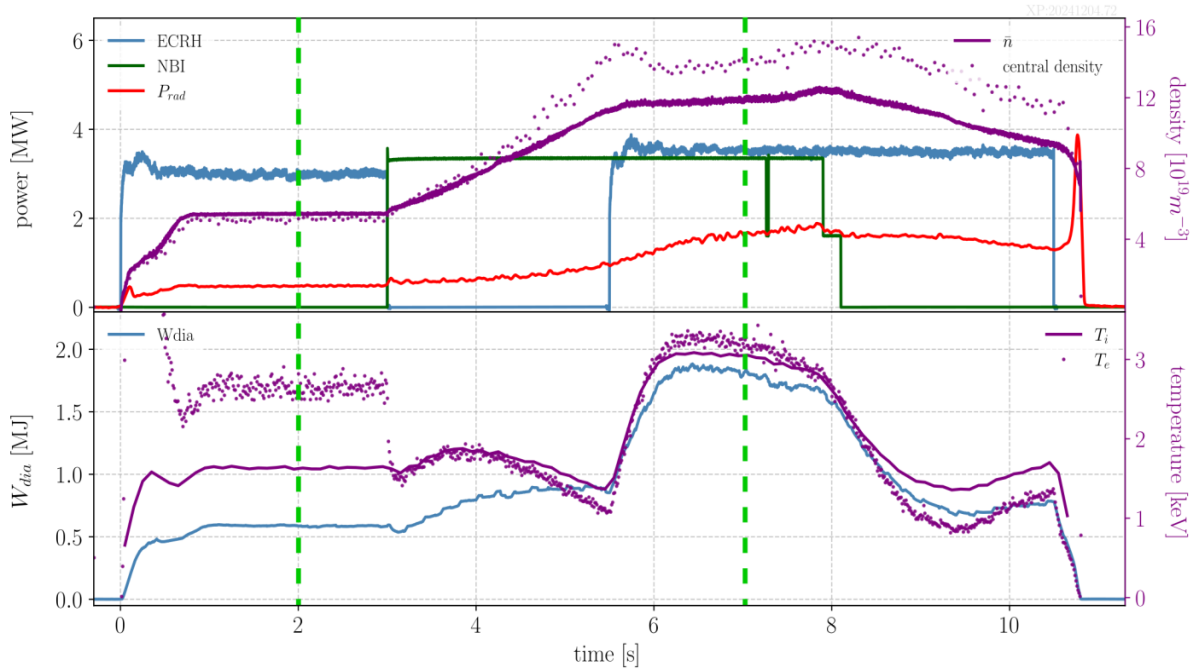
S. Bannmann, et al., IAEA-FEC 2025

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

- 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.

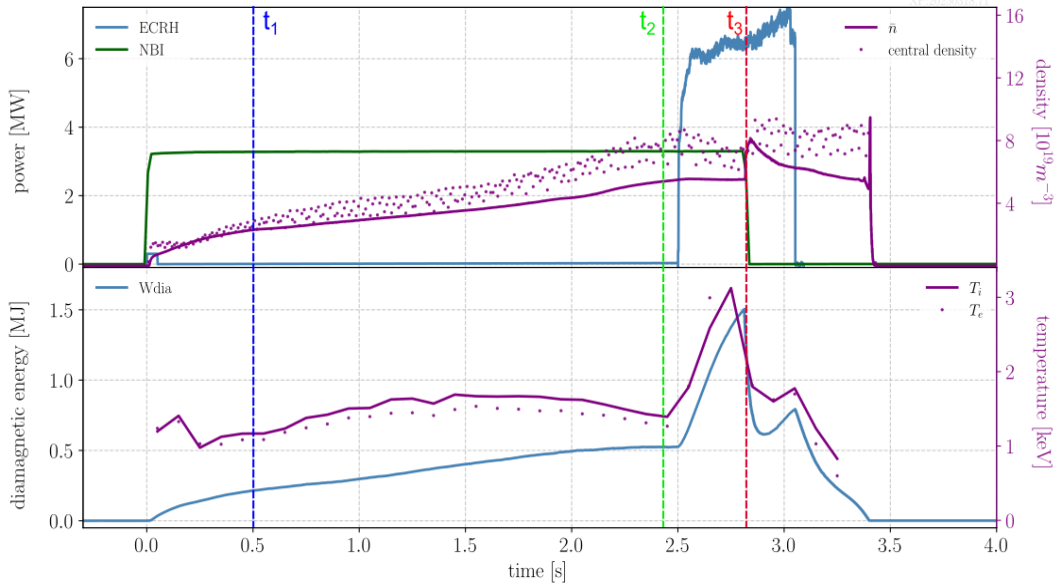


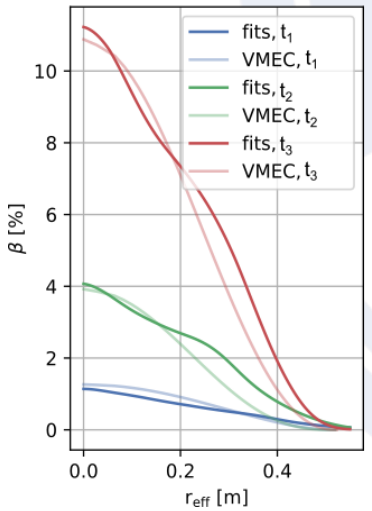
Main scientific results of 2025 campaign

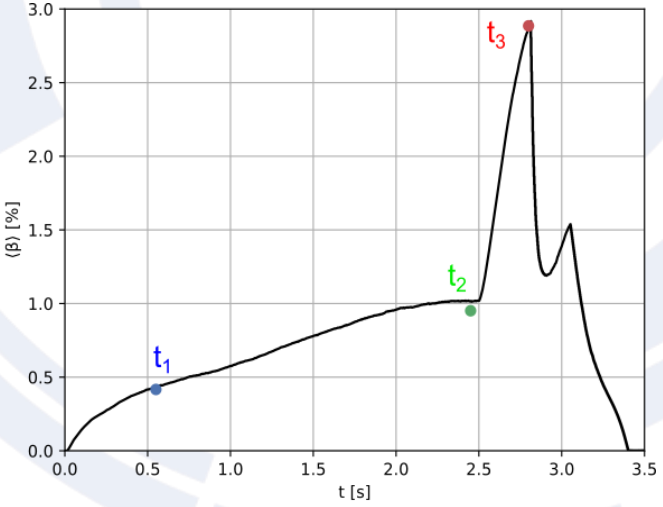
WP W7-X focuses on contributing to and **leveraging W7-X** to demonstrate physics questions related to HELIAS line towards fusion reactor:
- The positive effects of optimization on plasma confinement, fast particle behavior, and MHD equilibrium and stability.

- **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.





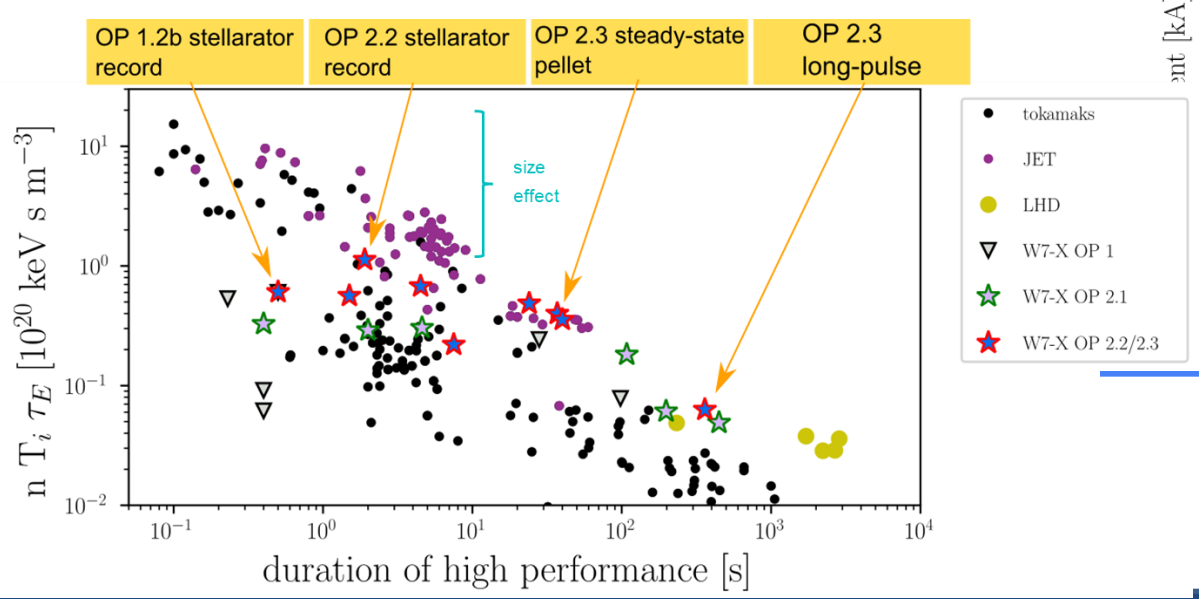


Main scientific results of 2025 campaign

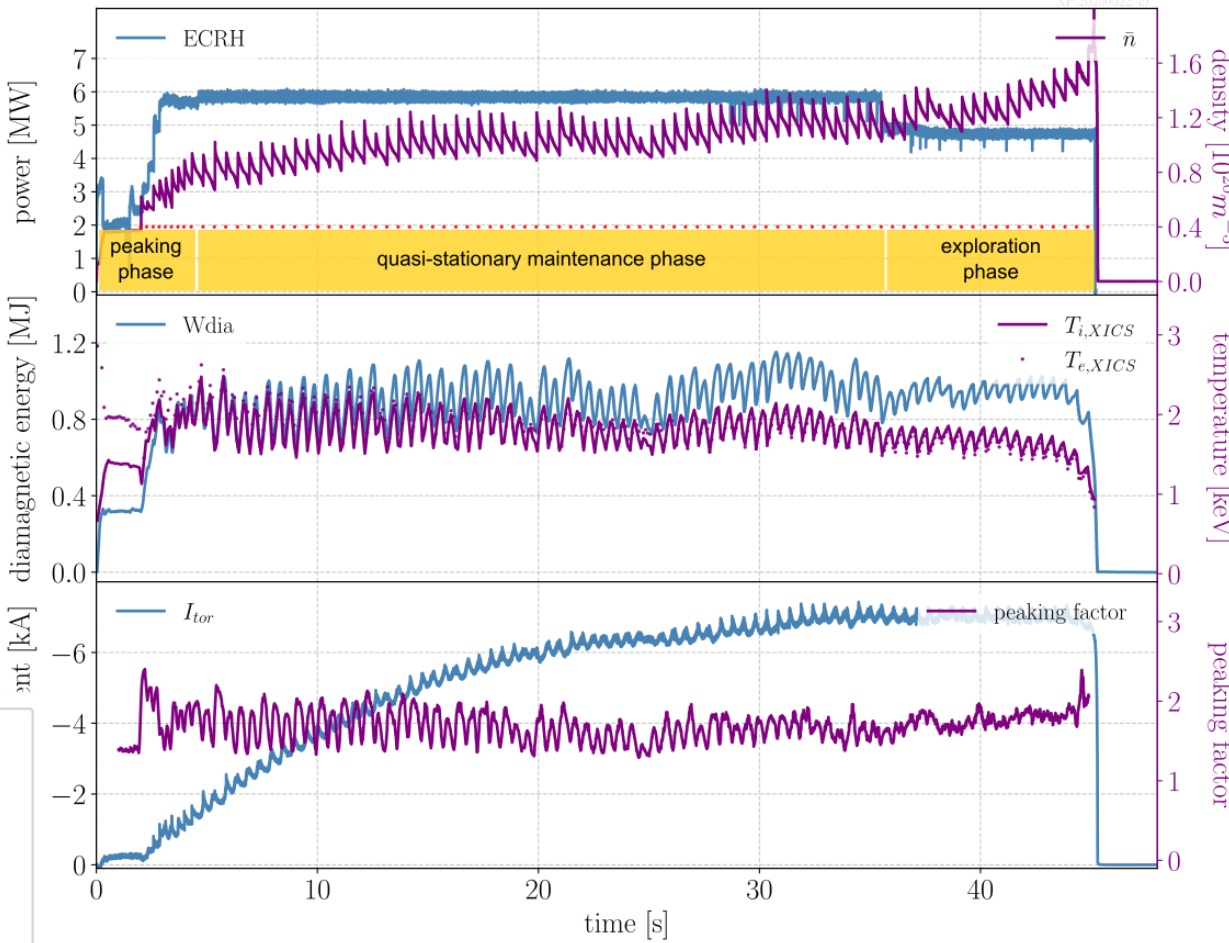
WP W7-X focuses on contributing to and **leveraging W7-X** to demonstrate physics questions related to HELIAS line towards fusion reactor:
- The positive effects of optimization on plasma confinement, fast particle behavior, and MHD equilibrium and stability.

- 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.



O. Grulke, IAEA-FEC 2025



Wendelstein 7-X sets World record for long plasma triple product

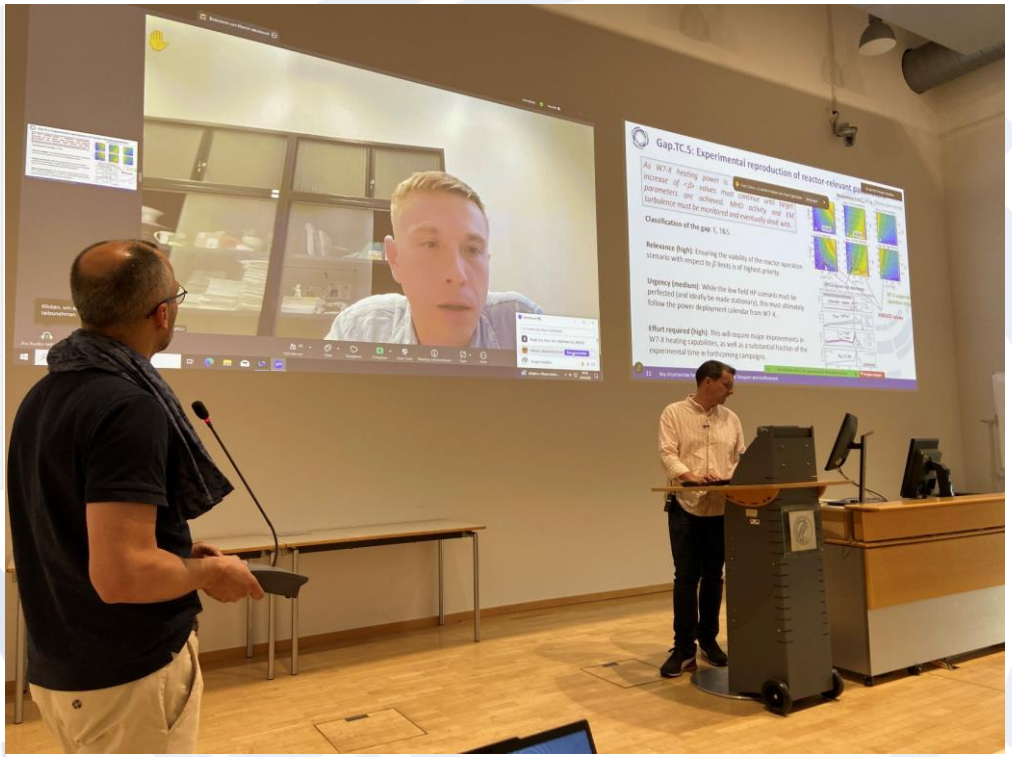
June 4, 2025 | EUROfusion News, Member News, IPP (Germany)

Status Grand Deliverables & Milestones

ID	Title in CWP	Due Date	Status
W7X.D.10	Verified and validated stellarator gyrokinetic codes for the calculation of turbulent transport (TSVV-13)	31.12.2025	on track
W7X.D.11	Report on conducted scenario & campaign preparation (focus: high-power steady-state operation)	31.12.2025	on track
W7X.D.12	Assessment report on HELIAS optimization (with data from carbon PFC operation)	31.12.2025	on track
W7X.D.13	Report on conducted scenario & campaign preparation (focus: PFC upgrades)	31.12.2025	on track
W7X.D.14	Comparative assessment of the HELIAS reactor physics basis with respect to other stellarator concepts (with International Collaborations).	31.12.2025	on track
W7X.D.15	Modern European stellarator optimization code and its use to determine options for next-generation devices. (TSVV-12)	31.12.2025	on track
W7X.M.05	High-beta HELIAS operation at low collisionalities	31.12.2025	Achieved, to be reported
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, to be reported

Key Physics Gaps towards HELIAS reactor

1. Heat and particle exhaust	2 events
2. MHD equlibrium and stability	2 events
3. Core Transport & Confinement	3 events
4. Fast particle confinement and interaction with Alfven waves	7 events
5. Plasma-wall interaction and PFCs	1 event
6. Scenario integration	1 event
General Meetings	7 events



IPP Greifswald, 24 June 2025

Key Physics Uncertainties and Research Needs for Stellarator DEMO Development

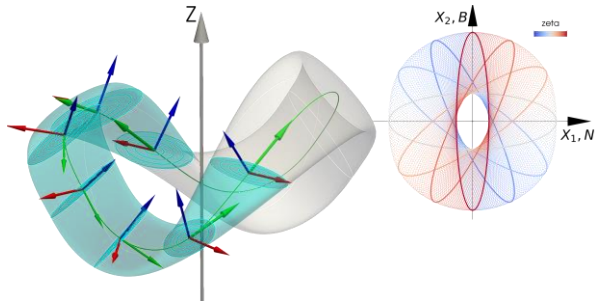
M. Jakubowski, A. Alonso, I. Calvo

https://indico.euro-fusion.org/e/HELIAS_gaps

- Working Meeting in Greifswald with > 140 participants incl. PMU, start-up representatives
- Individual reports delivered. Served as an input for analysis
- Joint report planned mid of November 2025.
- Joint publication in preparation planned to be published in 2026.

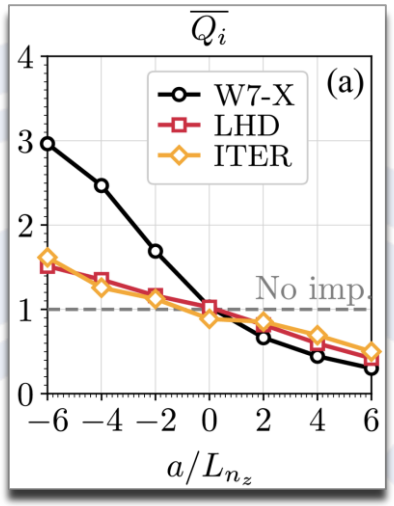
TSVV12

- **PI change (Joaquium Loizu (EPFL)**
- **Global fluid turbulence simulations** have been performed in the edge and scrape-off-layer of stellarators using the BOUT++ framework. **[Shanahan, JPP 2024]**
- **Semi-automated divertor plate design algorithm for low target heat loads. [Davies, NF 2024]**
- **Generalized Frenet frame for MHD equilibrium solver GVEC. [Hindenlang, PPCF 2025]**

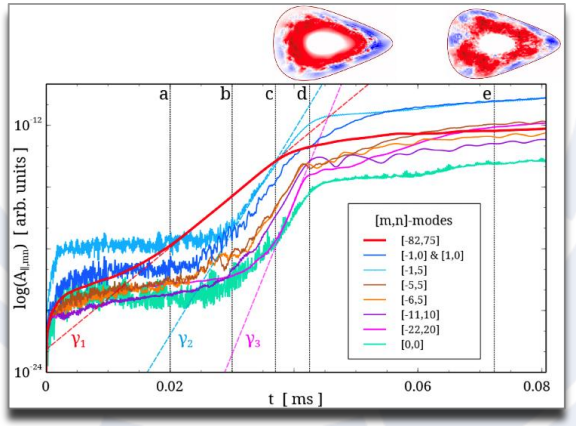


TSVV13

- The **effect of impurities on reducing or enhancing turbulence** has comprehensively been characterized for W7-X and other configurations (LHD and ITER) **[García-Regaña, PRL 2024]**



- **Long wavelength Alfvénic modes driven by ITG turbulence** have been studied in W7-X using global nonlinear electromagnetic simulations **[Riemann, PRL 2025]** (Sinergy with TSVV#10)



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.
- 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 is scheduled for publication later this year.
- All milestones and General Deliverables are on track or have already been 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.

MATEO project status Oct 2025

- **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**