Project Board Meeting, 01-02.04.2025 Garching

WP W7-X 2024 / 2025

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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.

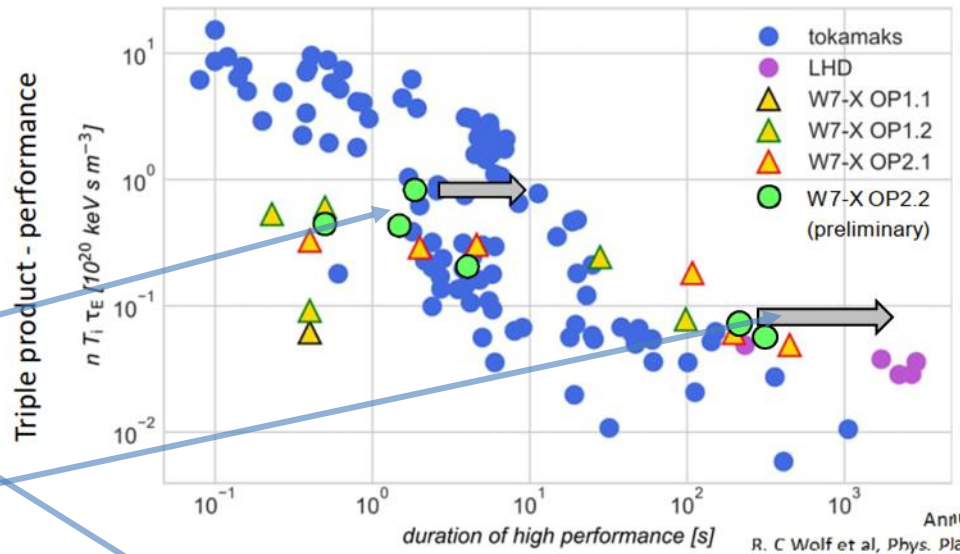
2024 high level objectives

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

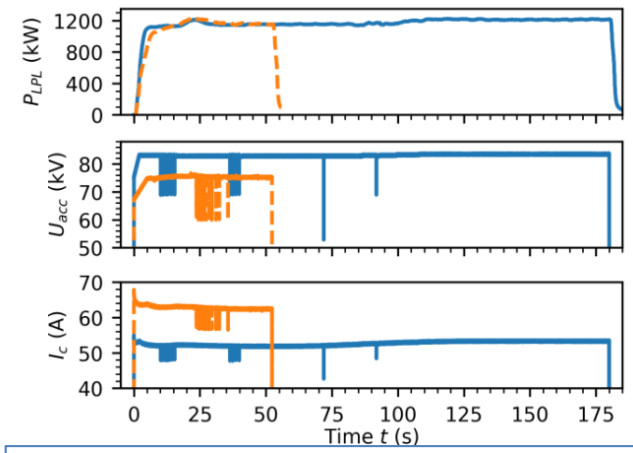
- The positive effects of optimization on plasma confinement, fast particle behavior, and MHD equilibrium and stability.

- Achieving good plasma confinement in the long-mean-free-path regime at elevated plasma beta.

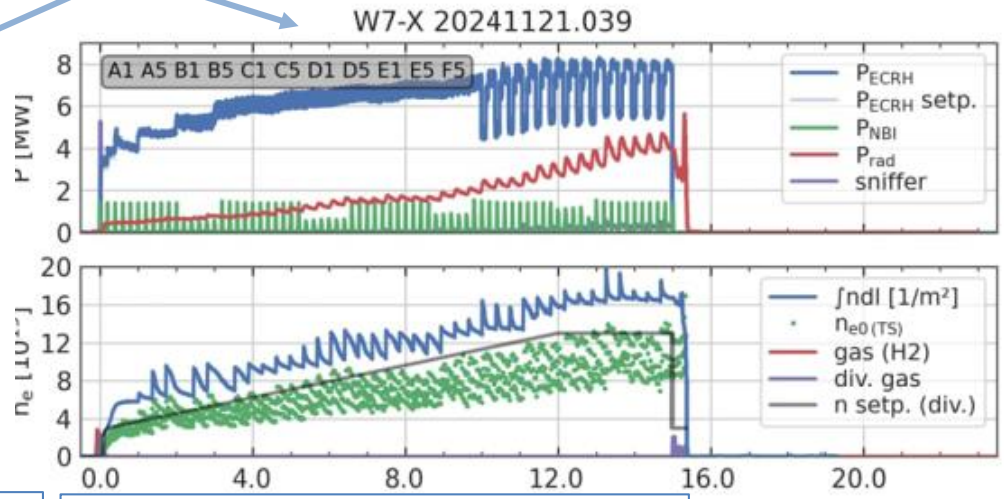
- Ensuring safe steady-state operation while exploring potential reactor scenarios.



Annual report CICLOP group
R. C Wolf et al, Phys. Plasmas 26 (2019) 082504
O. Grulke, IAEA Fusion Energy Conference 2023

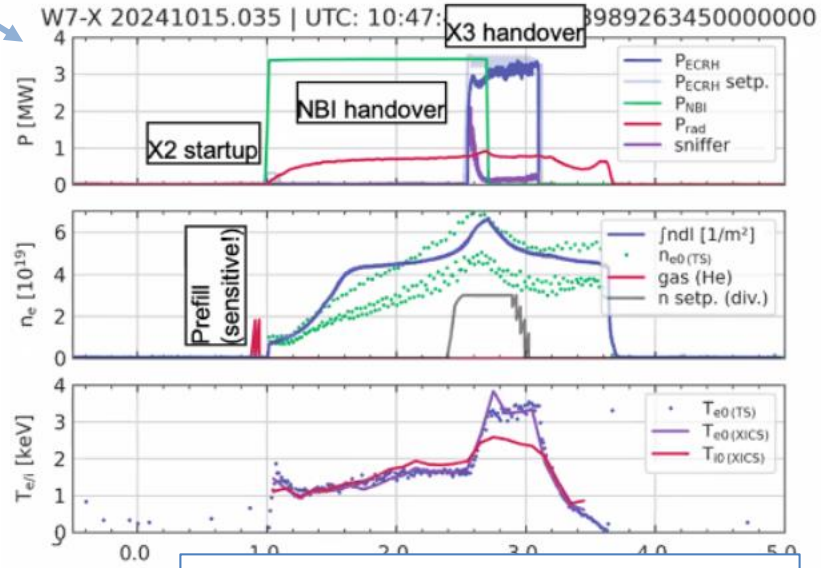


Successful operation of new 1.5 MW gyrotron (target: 30 min of operation)



Successful operation of steady-state pellet (target: 30 min of operation)

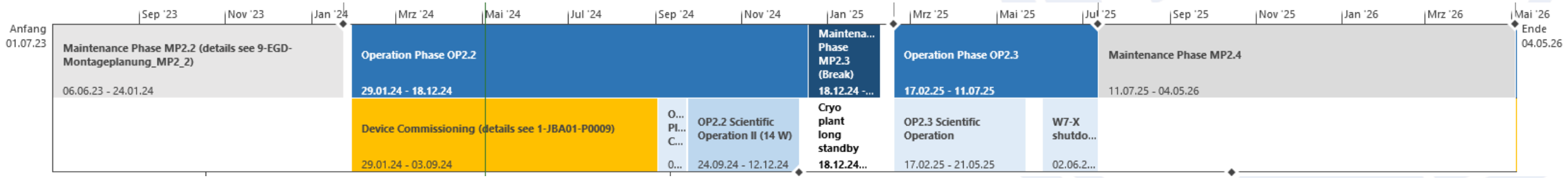
Courtesy J. Baldzuhn,
L. R. Baylor, W7-X Team



OP2.2 low field (1.8 T) plasma with high ion temperature

Status of Wendelstein 7-X

- Experimental campaign OP2.2 in 2024 peformed succesfully.
  Initial delay to repair of the faulty transformer fully compensated with additional experimental days in OP2.2 & OP2.3
- Experimental campaign OP2.3 planned for 2025 started as planned and ongoing.
- From mid-July longer mainatenance phase planned until mid of 2026.



Research topics for experimental campaigns 2024/2025

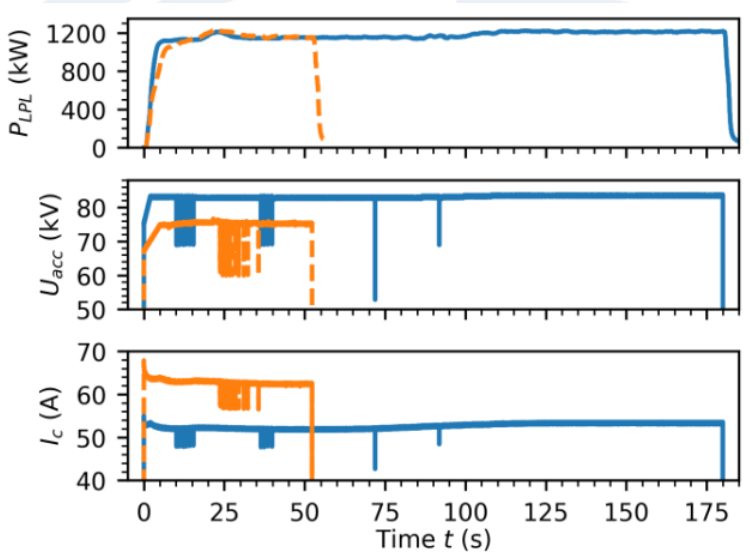
ID	Tag	Description
RT-01	High performance conditions	Exploration of reduced turbulence/ high-performance scenarios in view of stationary plasma conditions with temperature-, density and impurity-profile control.
RT-02	Heating scenarios	Exploration of heating scenarios using upgraded heating capabilities (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.

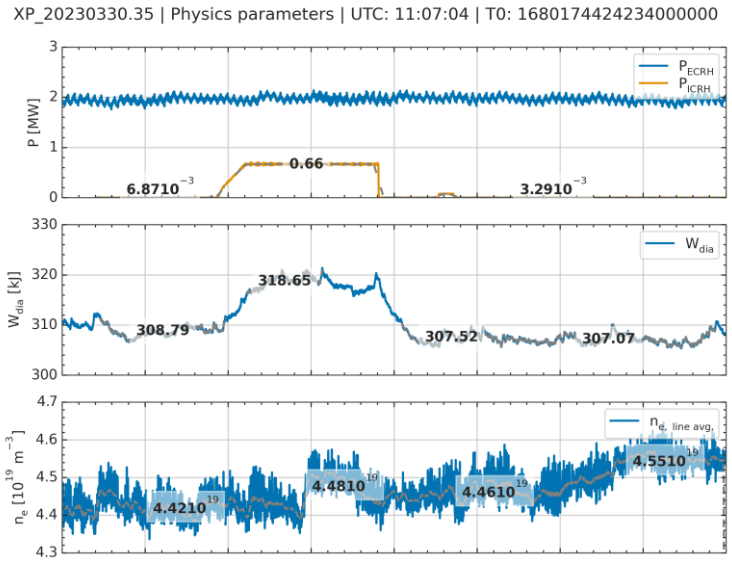
Research topics for experimental campaigns 2024/2025

ID	Tag	Description
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.

Heating systems (ECRH, ICRH)

- The first 1.5 MW/140 GHz gyrotron (TH1507U) was developed and successfully tested, making it the most powerful W7-X gyrotron to date, setting the stage for further upgrades.
- 1.5 MW is being routinely used during the campaign
- Investigations at KIT and NKAU led to modifications in cavity design and beam tunnel structures to suppress parasitic modes, significantly improving gyrotron performance.
- Simulations and design optimizations indicate progress toward achieving a 2 MW-class gyrotron, with new strategies being explored to overcome operational challenges.
- Two-strap ICRH antenna has been routinely operated in OP2.2 focusing on plasma heating, fast ion generation and start-up at low field.





Enhancements (diagnostics)

- The design and optimization of the Scintillator-based Fast Ion Loss Detector (sFILD) progressed in 2024, incorporating an upgraded ASCOT model that accounts for non-hydrogenic species and refined wall geometry for improved fast-ion loss estimation.

- Key steps toward manufacturing were taken, including optical performance analysis, identifying potential manufacturers, and initiating the manufacturing procedure for 2025.

- The MATEO development in 2024 included finalizing the endurance test, customizing and completing the detailed design, initiating production and procurement, creating control system documentation, and developing a new isolation amplifier prototype for data acquisition.

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)**
    Project progresses well
  - **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.

  - **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

Status of Grand Deliverables

ID.	Deliverable title	Delivery due date	Date of completion	Delayed	Status	Comments
D03.05	Assessment report on fast-ion generation and divertor exhaust (energy limit 1 GJ)	31/12/2023	27/02/2024		100%	
D03.06	Report on conducted scenario & campaign preparation (focus: preparation of steady-state scenarios turbulent and core neoclassical transport)	31/12/2023	23/02/2024		100%	
D03.07	Report on the modelling of plasma heating schemes, plasmas with fast-ions and transport regimes for long steady-state high-beta operation (energy limit 2 GJ)	31/12/2024	25/02/2025		100%	
D03.08	Report on conducted Scenario & campaign preparation (focus: turbulent and neoclassical transport, high-power steady-state operation)	31/12/2024	25/02/2025		100%	
D03.09	Assessment report on scenarios with optimized transport and high-beta operation (energy limit ~~6 GJ~~ 2 GJ)	31/12/2024		31/12/25	50%	

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)

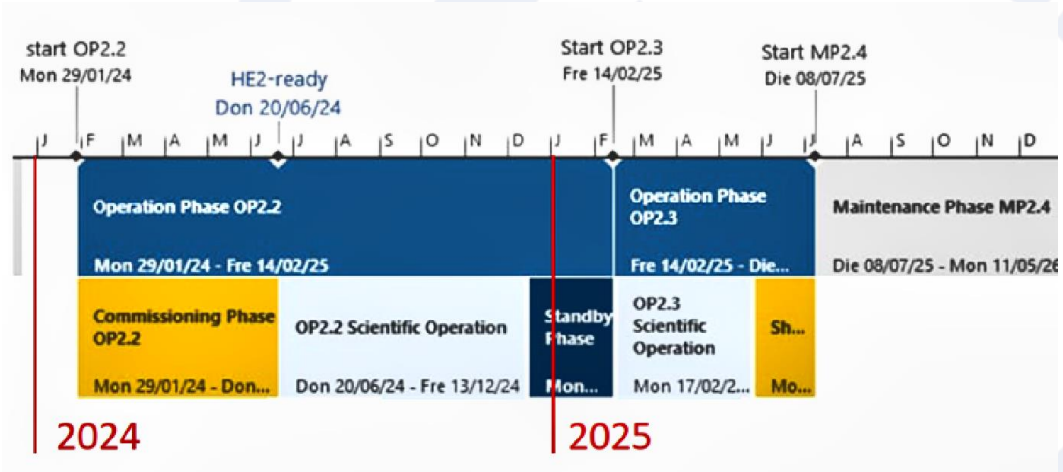
- **Main objective 2025: conduction of campaign W7-X** (heating upgrades, pellet injection, low field operation, wall conditioning/metallic wall, other RTs)
- EU contributions to upgrades in FP9
- Exploitation of 2024/25 campaign
- Physics basis & ITER support

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

2025 Description of Work

- *Focus of WPW7X-2025 Work Program:*
  - *Execution of the 2025 campaign (OP2.3) for W7-X, with data analysis and exploitation.*
  - *Integration of data evaluation from the 2024 campaign (OP2.2).*
- *Long-Term Developments:*
  - *Advancing diagnostics for steady-state operation, divertor studies and fast ion physics.*
  - *Enhancements and upgrades to heating power.*
- *Key Support Actions:*
  - *Leveraging specific European expertise.*
  - *Accelerating preparations for metallic wall operation, including tungsten divertor target design (in collaboration with WPDIV and WPPWIE).*
- *Targeted Initiatives:*
  - *Supporting the physics basis for ITER and HELIAS.*
  - *Experimental collaborations in non-HELIAS configurations within international partnerships.*
  - *A working group, which defines key physics gaps towards HELIAS reactor (June 2025)*

2025 Grant milestones

ID	GD-ID	Title in CWP	Due Date
W7X.M.06	M03.06	Operation with High power and long-pulse Completed ~~and 6 GJ energy turn-around achieved~~ (pulse lengths up to 600 s, long-pulse detachment).	31.12.2025
W7X.M.05	M03.05	High-beta HELIAS operation at low collisionalities	31.12.2025

2025 Grant deliverables

WP ID	GD-ID	Title in CWP	Due Date
W7X.D.12	D03.12	Assessment report on HELIAS optimization (with data from carbon PFC operation) (~~energy limit 18 GJ~~)	31.12.2025
W7X.D.10	D03.10	Verified and validated stellarator gyrokinetic codes for the calculation of turbulent transport (TSVV-13)	31.12.2025
W7X.D.11	D03.11	Report on conducted scenario & campaign preparation (focus: high-power steady-state operation)	31.12.2025
W7X.D.13	D03.13	Report on conducted scenario & campaign preparation (focus: PFC upgrades)	31.12.2025
W7X.D.14	D03.14	Comparative assessment of the HELIAS reactor physics basis with respect to other stellarator concepts (with International Collaborations).	31.12.2025
W7X.D.15	D03.15	Modern European stellarator optimization code and its use to determine options for next-generation devices.	31.12.2025