PSD Project Board Meeting
30.10.2024

For the W7-X team
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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

Research topics for experimental campaigns 2024/2025

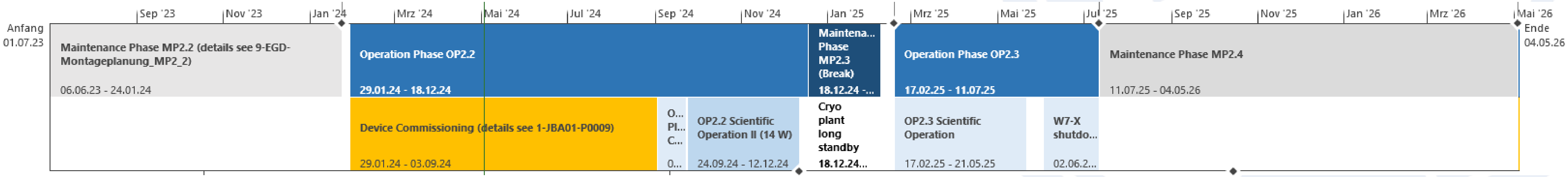
ID	Tag	Description
RT-01	High performance conditions	Exploration of reduced turbulence/ high-performance scenarios in view of stationary plasma conditions with temperature-, density and impurity-profile control.
RT-02	Heating scenarios	Exploration of heating scenarios using upgraded heating capabilities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

Status of Wendelstein 7-X

- Technical commissioning completed sucesfully ✓
- Plasma commissioning started 3 Sep 2024 ✓
- Plasma scientific operation OP2.2 – 01 Oct 2024 until 12 Dec 2024
- Plasma scientific operation OP2.3 – 17 Feb 2025 until 21 May 2025
- Program Workshop took place on 24-24 Apr 2024 ✓
- Campaign participation in OP2.2 assigned ✓
- Campaign participation in OP2.3 preliminary assigned. Announcement Nov 2024.



ECRH upgrades

- 1.5 MW successfully installed and commissioned for OP2.2

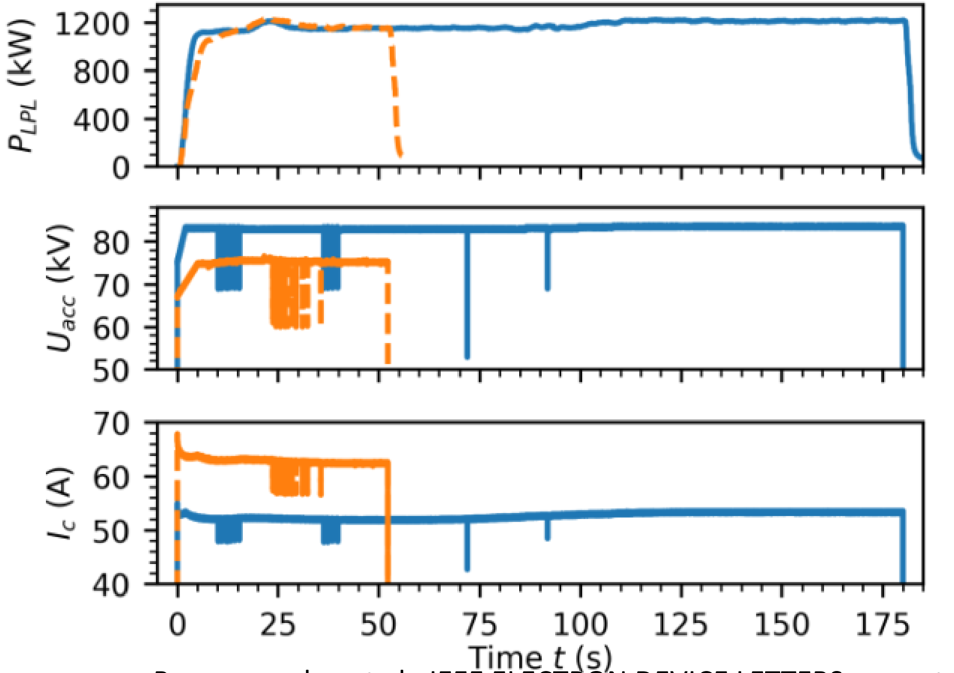
⇨ The 1-ms short-pulse tests confirmed the nominal output power of 1.5 MW

⇨At 1.3 MW pulse lengths of 3 minutes achieved

⇨At 1.2 MW pulse length of 580 s demonstrated

⇨Thales will build 3 further 1.5 MW

- Contract to develop 2 MW gyrotron awarded to Kyoto Engineering



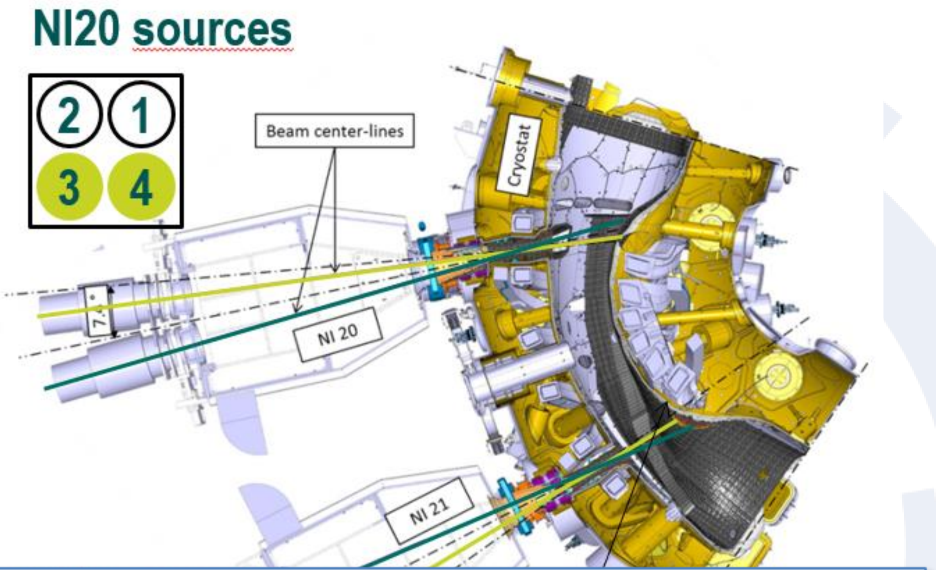
Ponomarenko, et al., IEEE ELECTRON DEVICE LETTERS, accepted

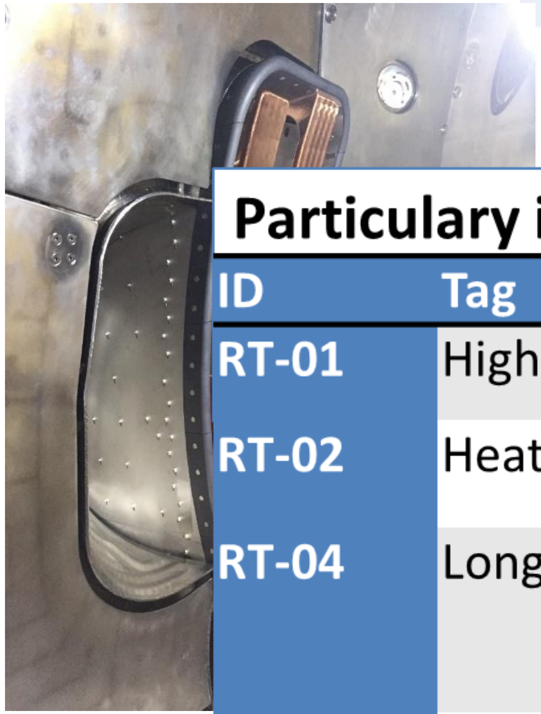
Particulary important for

ID	Tag
RT-01	High performance conditions
RT-02	Heating scenarios
RT-04	Long-pulse operation and wall conditioning
RT-05	Detachment

Enhancements to heating systems

- NBI 55 kV **H injection** with all 4 sources S3, S4, S7, S8
  - injected power approx. 2-2.2 MW
  - pulse length: max. 5 sec integral
- NBI 42 kV **^{4}He injection** with 4 sources S3, S4, S7, S8
  - injected power approx. 1.2 MW (tbc)
  - pulse length 5 sec (tbc)
- ICRH (with FZJ, ERM/KMS)
  - Power > 1 MW
    (400 kW in comissioning)
  - pulse length up to 10 s
  - Scenarios:
    - H minority in He plasmas
    - ^{3}He minority heating in ^{4}He or H
    - 3-ion-heating with ^{3}He, H, ^{4}He
    - Plasma start-up (at 1.7 T)



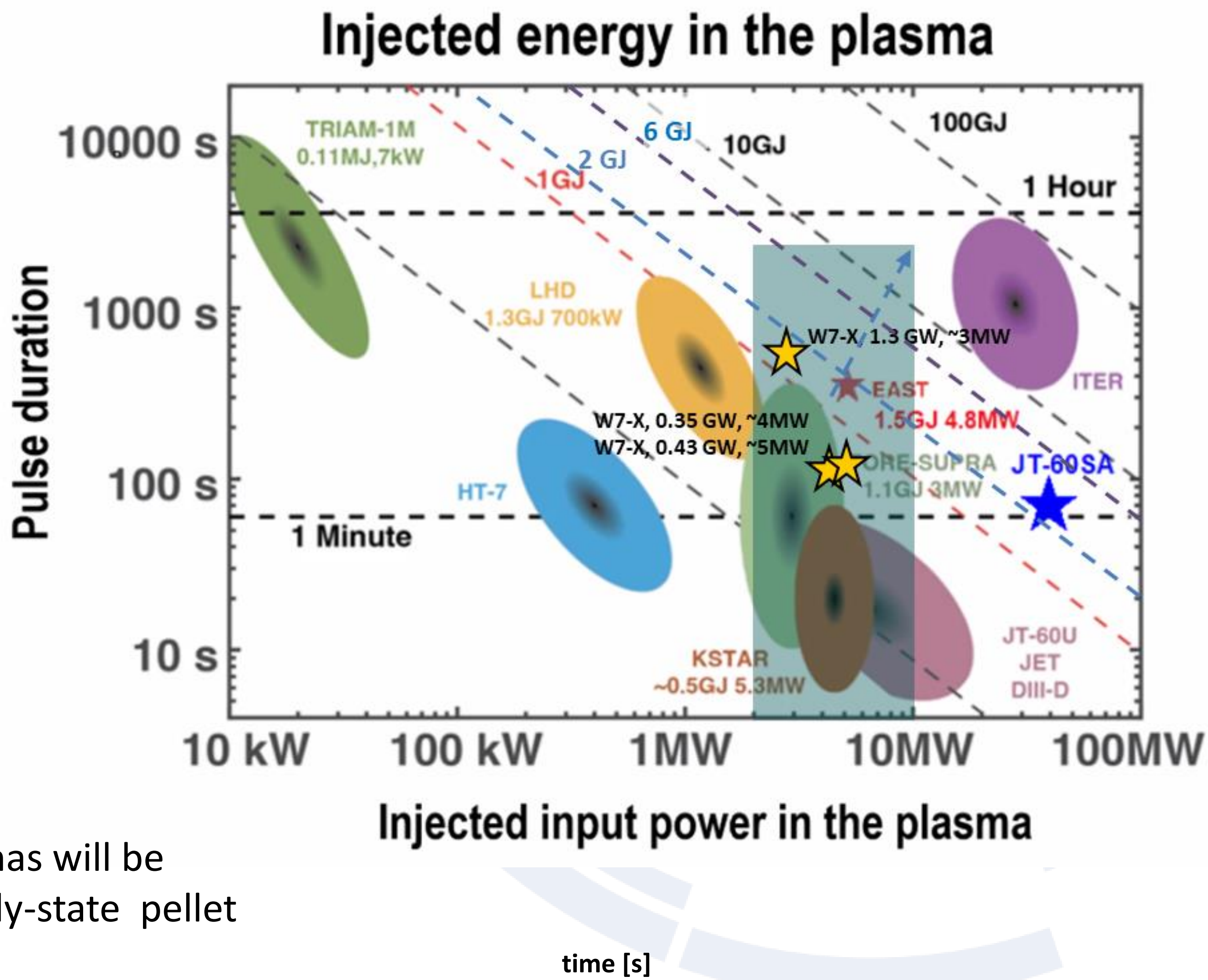


Particulary important for

ID	Tag
RT-01	High performance conditions
RT-02	Heating scenarios
RT-04	Long-pulse operation and wall conditioning
RT-08	Core physics studies

Development of long pulse

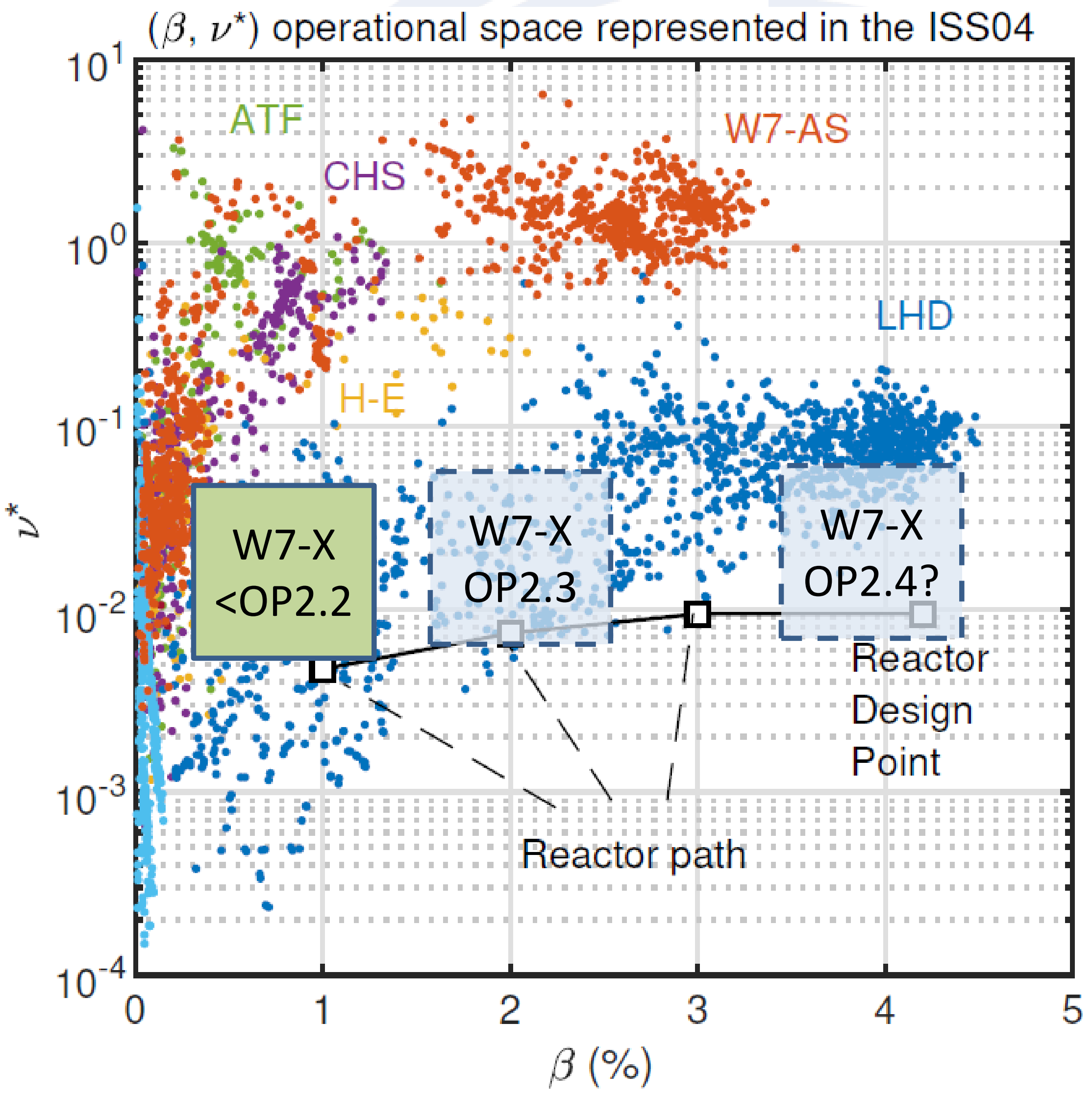
- In OP2.2/2.3 the next milestone of LPO will be reached
  - 2 GJ attached discharge:
    - test scenarios to accomodate low plasma current
    - Operate at power fluxes close to reactor design point
    - Monitor impurities in steady-state (incl. tungsten)
  - 2 GJ detached, if feedback on plasma radiation will be implemented.
    - Based on mixture of intrinsic and seeded impurities
    - Move to higher P_{SOL}
- Additionally scenarios with high performance plasmas will be developed to prolong their duration, e.g. with steady-state pellet injector/NBI.



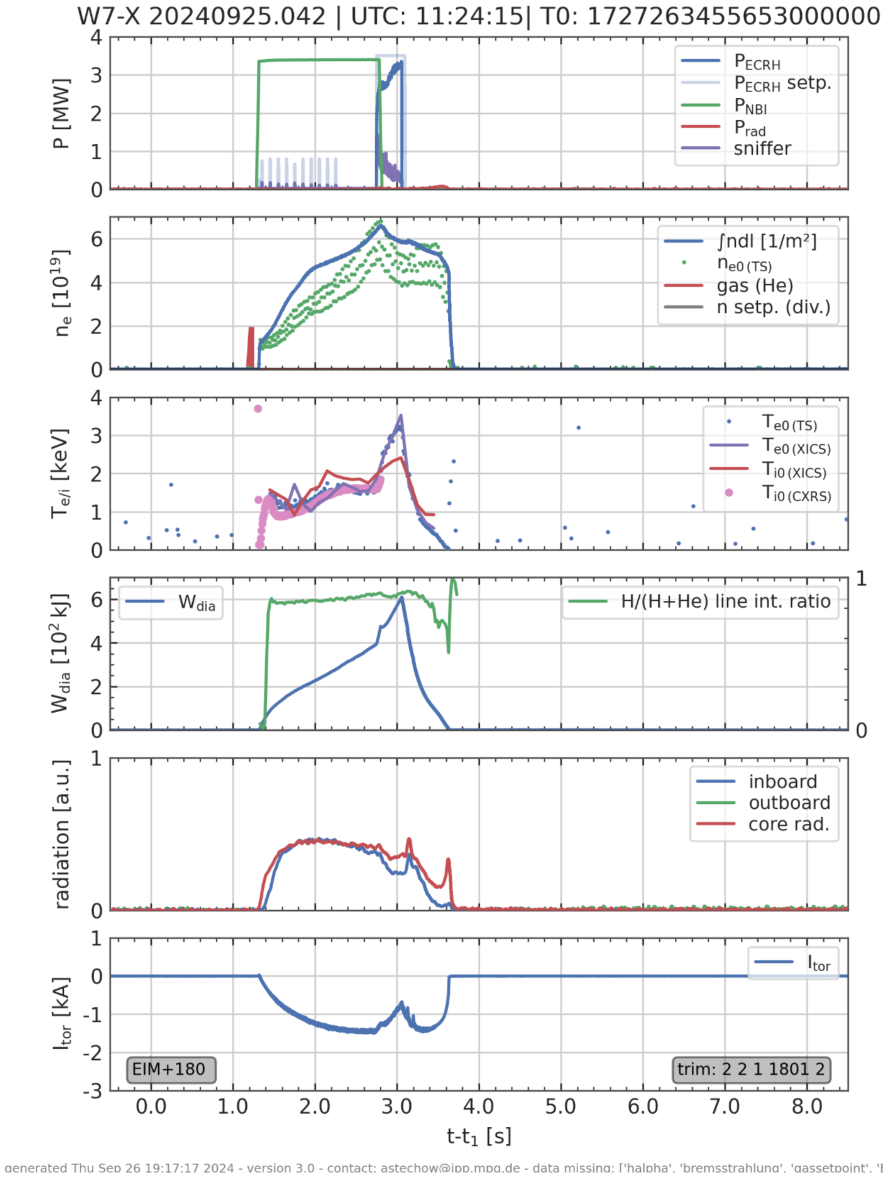
Importance of developing low-B scenarios at W7-X

The development of low-B scenarios at W7-X (namely, 1.7 T for X3-ECH heating) is programatically important beacause:

1. **Plasma start-up not based on X2-ECH will be required in a reactor.** At W7-X, also the combination of ICH and NBI is being pursued.
2. **Low-B operation at W7-X allows an easier access to high-β, low-ν* operation**, potentially close to reactor design values (see next slide).
3. **Investigate B transport dependencies for reactor projections.** Notably, there is no stellarator scaling of the SOL e-folding length.

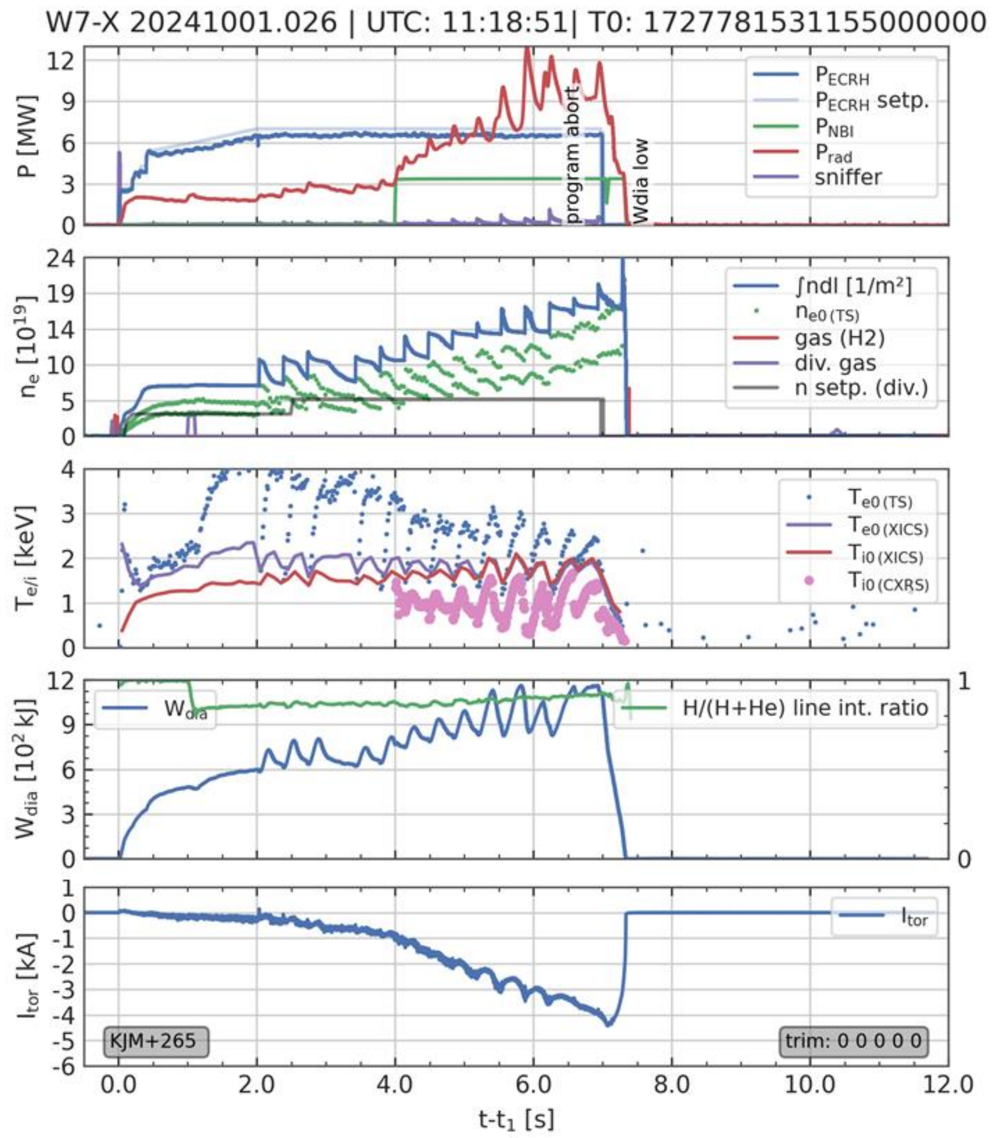


Plasma start-up at 1.8 T with ECRH & ICRH



- A full plasma start up in the core could be achieved with a combination of X2 ECRH (101GHz, 250 kW, 40ms duration) and NBI (2 sources).
- IRCH was sucesfully taken into operation. Power deposition within the SOL island and at the separatrix. Further optimization required.
- Operation at lower field provides easier route towards high beta plasma → closer to reactor design point.

Steady-state pellet injector goes into operation OP2.2



pellet material	H_2 or D_2
pellet size	2mm – 3mm (adjustable)
pellet speed	250 – 1000 m/s
repetition frequency	single on demand, continuous up to 10 Hz
injection duration	up to 30min tested
injection modes	feed-forward, density feedback control foreseen beyond OP 2.3

Deliverables and milestones for 2024/2025

W7X.D.07	D03.07	Deliverable	Report on the modelling of plasma heating schemes, plasmas with fast-ions and transport regimes for long steady-state high-beta operation (energy limit 6 GJ) - **modification requested**	31.12.2024
W7X.D.08	D03.08	Deliverable	Report on conducted Scenario & campaign preparation (focus: turbulent and neoclassical transport, high-power steady-state operation) **– on track**	31.12.2024
W7X.D.09	D03.09	Deliverable	Assessment report on scenarios with optimized transport and high-beta operation (energy limit 6 GJ) – **modification requested**	31.12.2024
W7X.D.10	D03.10	Deliverable	Verified and validated stellarator gyrokinetic codes for the calculation of turbulent transport (TSVV-13) – **on track**	31.12.2025
W7X.D.11	D03.11	Deliverable	Report on conducted scenario & campaign preparation (focus: high-power steady-state operation) – **on track**	31.12.2025
W7X.D.12	D03.12	Deliverable	Assessment report on HELIAS optimization (with data from carbon PFC operation) (energy limit 18 GJ) – **modification requested**	31.12.2025
W7X.D.13	D03.13	Deliverable	Report on conducted scenario & campaign preparation (focus: PFC upgrades) **– on track**	31.12.2025
W7X.D.14	D03.14	Deliverable	Comparative assessment of the HELIAS reactor physics basis with respect to other stellarator concepts (with International Collaborations). **– on track**	31.12.2025

Change of deliverabls and milestones

FSD	W7X	D3.9	W7X.D.09	D03.09	Deliverable	Assessment report on scenarios with optimized transport and high-beta operation (energy limit 6 GJ)	31.12.2024	48	
Should be									
FSD	W7X	D3.9	W7X.D.09	D03.09	Deliverable	Assessment report on scenarios with optimized transport and high-beta operation (energy limit 2 GJ)	31.12.2024	48	on track
FSD	W7X	M20	W7X.M.06	M03.06	Milestone	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	60	Unknown
Should be									
FSD	W7X	M20	W7X.M.06	M03.06	Milestone	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	60	Unknown
FSD	W7X	D3.12	W7X.D.12	D03.12	Deliverable	Assessment report on HELIAS optimization (with data from carbon PFC operation) (energy limit 18 GJ)	31.12.2025	60	Unknown
Should be									
FSD	W7X	D3.12	W7X.D.12	D03.12	Deliverable	Assessment report on HELIAS optimization (with data from carbon PFC operation) ~~(energy limit 18 GJ)~~	31.12.2025	60	Unknown

PCR 2025

ID	Proposal description	Justification	PM @ 50%	BEN	CC [k€]
W7X-1	Complete the HELIAS physics basis and develop high performance scenarios for W7-X - validation of physics models and codes (fast ions, turbulence characterization, enhanced confinement regimes)	Enhance the involvement of the CIEMAT team in studies related to HELIAS physics to expedite progress and ensure timely readiness for the decision point regarding the HELIAS-based reactor.	**24**	CIEMAT	**81.80**
W7X-2	Increase the efforts on the analysis and modelling for OP2.2 & OP2.3:	Increased expenditures driven by the emphasis on 'high beta' and 'long pulse' research in OP2.3, aimed at studying divertor physics in high-beta discharges, as well as the behavior of impurities and filaments at the plasma boundary.	**42**		**112.66**
	- EMC3-Eirene modelling of high β plasmas, incl. synthetic diagnostics, AI to provide quick assessments - analysis of divertor plasmas with four endoscopes		12	FZJ	56.79
	- Validation of PHA and C/O monitor experimental data for long pulses using modelling; - Development of scripts for fast data processing;		12	IPPLM	23.81
	- fast cameras data: fueling (pellets), high performance, impurity transport (TESPEL) - filaments at the plasma boundary and alkali beam: density profiles, CXRS		18	EK-CER	32.06

PCR 2025

ID	Proposal description	Justification	PM @ 50%	BEN	CC [k€]
W7X-3	Insufficient missions budget in 2025. Funding source: unused 2024 secondment budget of 63k€ (not allocated)	Bringing mission budget to the level of 2024 is essential; otherwise, participation in the campaign could prove inadequate, significantly increasing the risk of not achieving the 2025 objectives and overall deliverables.			63 k€

Evaluate critical physics uncertainties associated with a Stellarator DEMO

- **Timeline:** Establish high-level objectives by June 2025, followed by an in-depth analysis to be concluded by the end of 2025.

- **Approach:** The assessment will concentrate on six key areas, with each area led by two experts specializing in the respective field of focus.
  - **Heat and particle exhaust in the island divertor**
  - **MHD equilibrium and stability**
  - **Core transport and confinement**
  - **Fast particle confinement and interaction with Alfvén waves**
  - **Plasma-wall interaction**
  - **Scenario integration**

- **Deliverables:** A document with a summary of high-level objectives will be completed by the end of June 2025, followed by a comprehensive analysis report, including references to relevant publications, to be finalized by the end of 2025.

Reaching goals of W7-X within FP9