# WPW7X:
# WP Organization and Programme Execution Plan (PEP 2022)

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The views and opinions expressed herein do not necessarily reflect those of the European Commission.

# WPW7X status: achievements FP8, 2021

FP8

- Coils for HELIAS can be built precisely ✓ [1]
- Bootstrap currents are small and controllable ✓ [2]
- Optimization reduces NC thermal transport ✓ [3]
- Viable detachment scenarios demonstrated ✓ [4]

FP9

- Stable high-beta operation ☐
- Good fast-ion confinement ☐
- Improved confinement regimes* ☐
- Integrated SOL/core high-performance* ☐
- Integrated high-performance steady-state optimized operation ☐

* new insights

mid-term Roadmap

- Same with metallic-wall operation ☐

→ **provision of an alternative line to fusion electricity (Mission 8)**


[1] Sunn-Pedersen et al. Nature Comm. (2015)
[2] Dinklage et al. Nature Phys. (2018)
[3] Beidler et al. Nature (2021)
[4] Jakubowski et al., Feng et al. Nucl. Fusion (2021)

# WPW7X status: change from FP8 to FP9, COVID, …

- Large planning delays 2021 and budgetary uncertainties
  - ➢ conduction of many tasks was (unacceptably long) in limbo

- Well established communication on the working level and mutual trust ensured that BENs conducted almost all of the planned tasks (shifts: 1,04%PM, unclear task 0,16%PM, formal iteration outstanding 23,43%PM – reporting deadline ~end of Nov.)

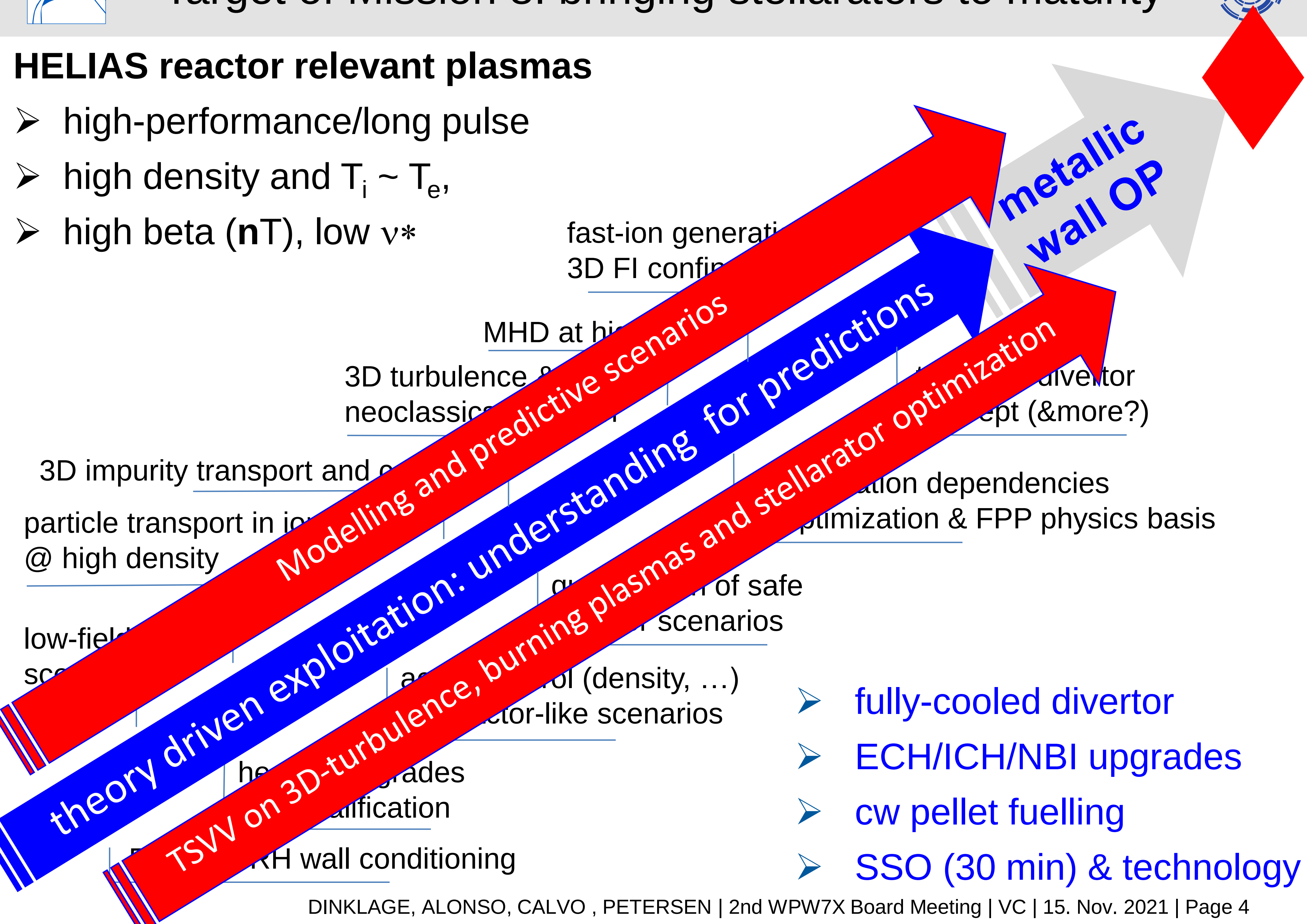
**The TFL and DTFLs are grateful to the WPW7X Team for their commitment and the good progress achieved under difficult circumstances. The interaction with the W7-X Team is outstanding.**

- **Lessons:**
  - ➢ *Management:* long-lead times led to uncertainties → working efficiency affected, (exponentially) increasing management effort, overload on working level → first priority of any time-line should be to make BENs able to conduct tasks from Jan. 1st.
  - ➢ *Budget:* BENs need to allocate their resources/know about expectable resources → clear commitments/communication on working level required (so-called level-3 tasks and their specifications, campaign allocations, special cases) by Jan. 1st (already impossible for 2022)

# Target of Mission 8: bringing stellarators to maturity

**HELIAS reactor relevant plasmas**

- high-performance/long pulse
- high density and $T_i \sim T_e$,
- high beta (**n**T), low $\nu*$

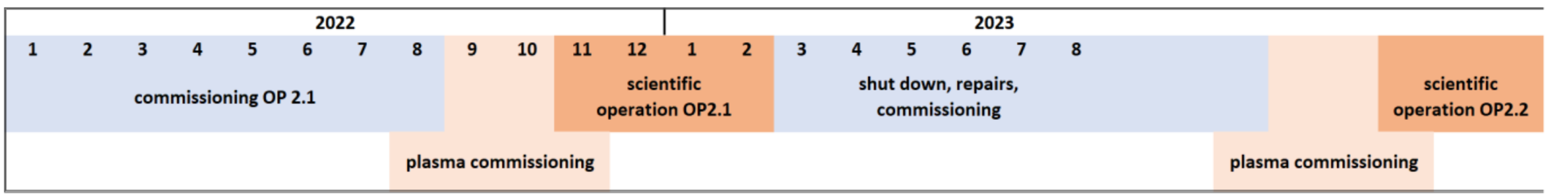


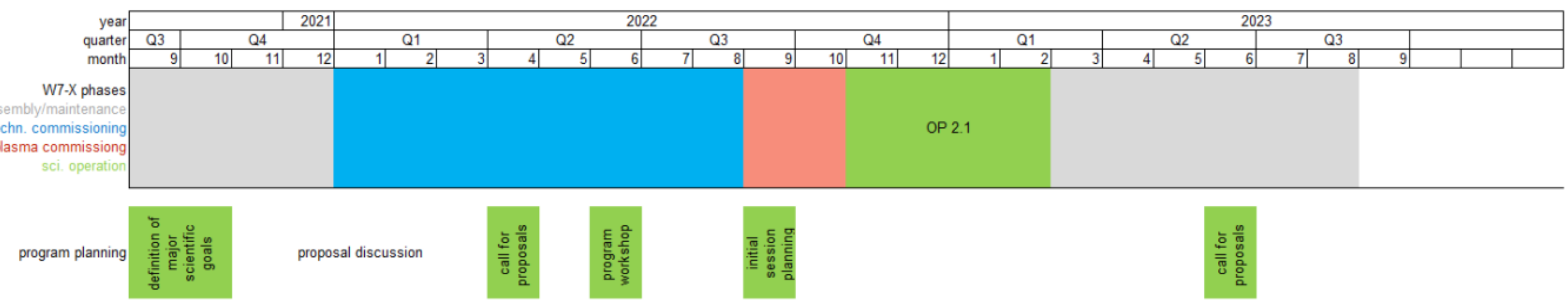

- fully-cooled divertor
- ECH/ICH/NBI upgrades
- cw pellet fuelling
- SSO (30 min) & technology

# Preparation, Conduction and Exploitation of OP2.1

| (MW) | ECRH | $NBI_{inj}$ | ICRH | $P_{tot}$ |
|---|---|---|---|---|
| OP1.2 | 7.8 | 3.2 | --- | **7.8** |
| 2022 | 9.3 | 6.4 | ~1.0 | **>10.8** |

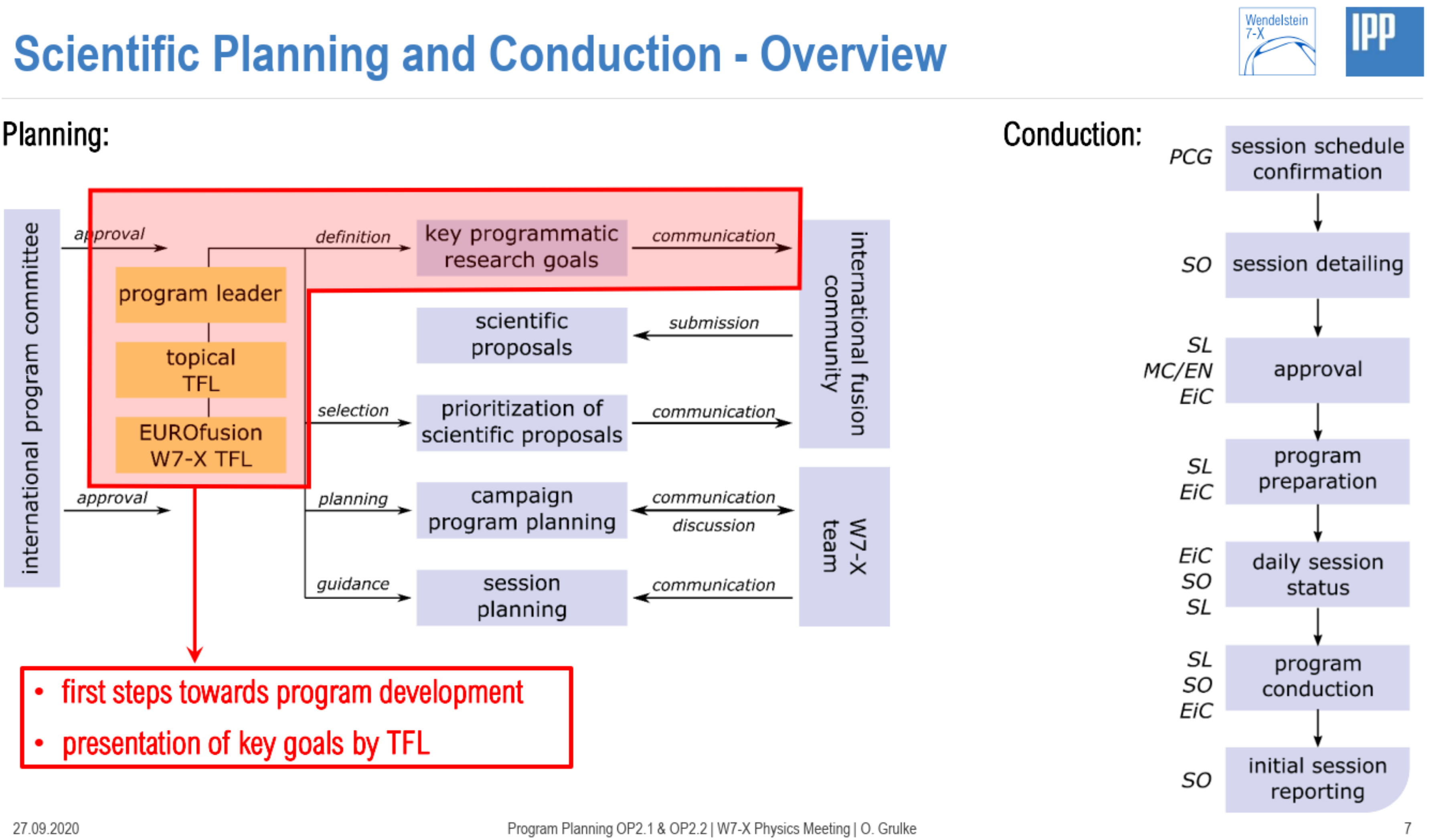
Water-cooled PFCs
Pellet injection
Cryo-pump
Diagnostics upgrades




- ➢ 15.7.2022: Call for Participation
- ➢ 15.9.2022: deadline for manning decision (to be approved in Oct. 2022)

# Exploitation in the One-Team-Approach©



# Scientific Objectives W7X OP2.1/2.2

The scientific objectives of OP2.1 and OP2.2 are prioritizes along the needs to assess the stellarator line  and take into consideration the device capabilities in OP2.1 and 2.2

**TF1: Core Physics**
TF1.1: explore high-performance reduced transport regimes
TF1.2: implement and explore extended heating capabilities (ECH,NBI, ICH)
TF1.3: develop low field operation for high-beta scenarios

**TF2: Edge and Divertor Physics**
TF2.1: qualify long-pulse operation
TF2.2: qualify prolonged divertor detachment
TF2.3: prepare carbon-free operation
TF2.4: develop and optimize wall conditioning procedures
TF2.5: document the plasma performance with reference discharges

**TF3: Optimization**
TF3.1: complete the physics basis for core transport and stability
TF3.2: complete the physics basis for edge transport
TF3.3: complete the physics basis to high beta and low collisionality

**Status: communicated 27.10.21 (W7-X Team). Discussion about to be concluded.**

# Workplan Objectives AWP2022

| | |
|---|---|
| WPW7X-2022.O1 | Technical preparation and operation of EU components for W7-X experimental campaigns |
| WPW7X-2022.O2 | Task Force for OP2.1 |
| WPW7X-2022.O3 | Preparation of the scientific program for OP2.1 and OP2.2 |
| WPW7X-2022.O4 | Preparation of metallic walls for W7-X |
| WPW7X-2022.O5 | Support the preparation of the HELIAS physics basis, ITER first plasmas and ITER operation, ensure information exchange with WPPRD and continue international collaborations in support of the Mission 8 objectives. |
| WPW7X-2022.O6* | Continue the collaboration with TSVV-12 on stellarator optimization and lay out plans for the project with the goal of producing highly optimized designs by 2025. |
| WPW7X-2022.O7* | Continue the collaboration with TSVV-13 in order to enhance the capabilities of micro-turbulence modelling in W7-X via development of the currently available gyrokinetic codes, their verification and their application to specific transport problems. |

# 2022 Objective 1: Technical preparation

**Operate and exploit EU components in the W7-X experimental campaign OP2.1 and prepare OP2.2.**

objective

a. Conduct the scientific commissioning, operate and participate in experiments using video cameras, IR surveillance, AM Beam, PHA, Reflectometry, CO monitor, probes, pressure gauges, manipulators, spectroscopy and software/control systems

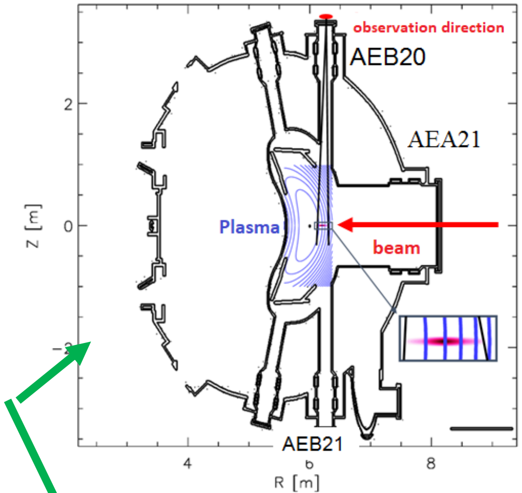
b. Prepare and conduct impurity transport studies with TESPEL and LBO

examples

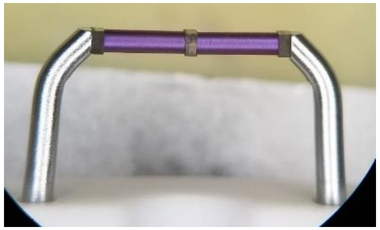
description of work

synergy potentials

Upgrade AM-Beam:
SOL/edge densities
→ integrated SSO scenarios




New design LaB6 pressure gauges
gas balance
→ divertor operation



# 2022 Objective 1: technical preparation OP2.1

**Technical preparation of OP2.1: finalize the development of heating and fueling system upgrades as well as diagnostics upgrades, prepare their installation on the device, conduct system qualification and technical commissioning**

a. Heating upgrades
b. Fueling systems and density control
c. Divertor and wall heat-load surveillance
d. Diagnostic commissioning (upgrades and enhancements, also from FP8)

| (MW) | ECRH | $NBI_{inj}$ | ICRH | $P_{tot}$ |
|---|---|---|---|---|
| OP1.2 | 7.8 | 3.2 | --- | **7.8** |
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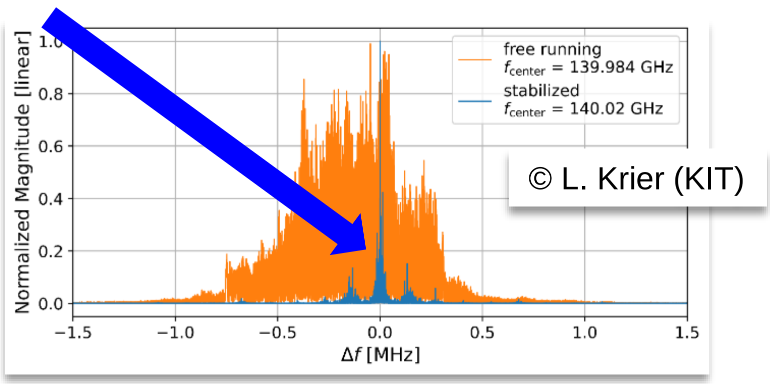
Heating upgrades: performance increase
→ high-β, low ν*, high $nT_i\tau_E$




ECRH frequency stabilization

# 2022 Objective 1: preparation of operation

**Preparation of operation: prepare safe long-pulse, high-power operation by implementing safety interlocks and develop strategies for wall conditioning**

a. wall conditioning schemes (incl. ICH, w/ WPPWIE).

b. safe operation schemes.

c. heating scenarios (ICH, ECH, NBI)

d. generation of fast ions (ICH, NBI).

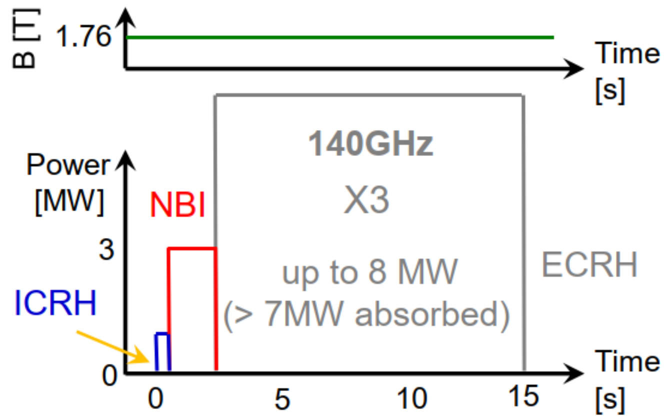
e. Low-B start-up (ICH, NBI, ECRH) and X3 plasma heating

f. long pulse operation

g. pellet injection, gas puff scenarios

h. steady-state detachment (seeding)

X3 heating and ICH/NI startup:
high-β operation
→ stellarator optimization




T. Stange et al

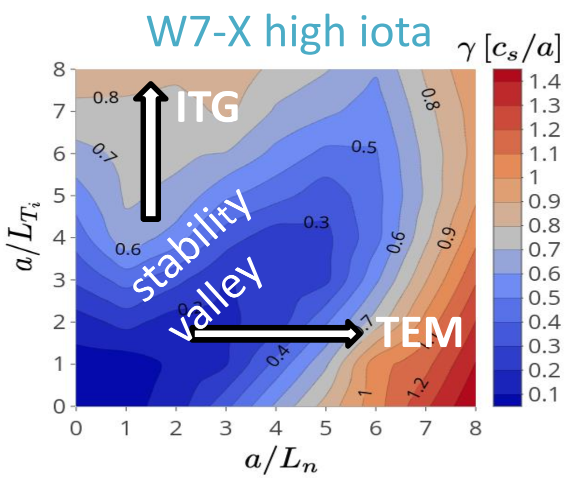
WPPWIE TSVV 12 TSVV 13

# 2022 Objective 2: Experiments in Campaign OP2.1

**Prepare and conduct experiments along the high-level objectives of WPW7-X**

a. neoclassical optimization at high-β
b. turbulence mechanisms (fluctuations, zonal flows)
c. transport reduction in high-performance regimes
d. H-mode, HDH-mode, …
e. detachment (exploration of the accessible operation range, active cooling, seeding, pumping)
f. confinement in the extended configuration space
g. SOL transport & wetted areas (in view of potential reactor scenarios).
h. MHD optimization: low-B, high-beta and configuration variation.
i. qualification of fast-ion confinement
j. impurity transport
k. particle transport for scenarios (density peaking)

Taming 3D turbulence: Improve confinement → high-performance




Alcusson et al., PPCF (2020)

WPPRD TSW 12 TSW 13

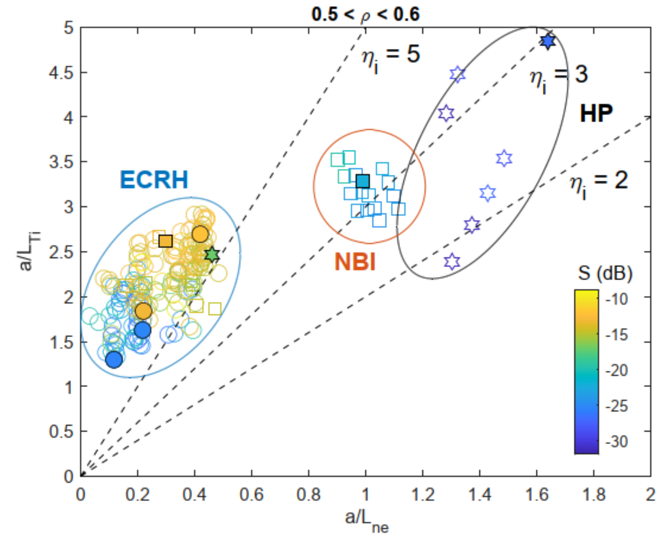
# 2022 Objective 3: scientific preparation

**Scientific preparation of OP2.1: Advance the analysis of OP1 experimental data to develop and validate physics models and codes to prepare OP2 experimental scenarios, experiment proposals and to construct the physics basis and the design and simulation tools for next-step devices.**

a. Exploit OP1 data for OP2 operation

b. Integrate validation activities from the associated TSVV tasks

Fluctuation reduction in different OP1.2 scenarios:
Expectations for OP2.1
→ swift qualification of upgrades




Carralero et al., submitted (2021)

TSVV 12 TSVV 13

# 2022 Objective 4: long-term developments

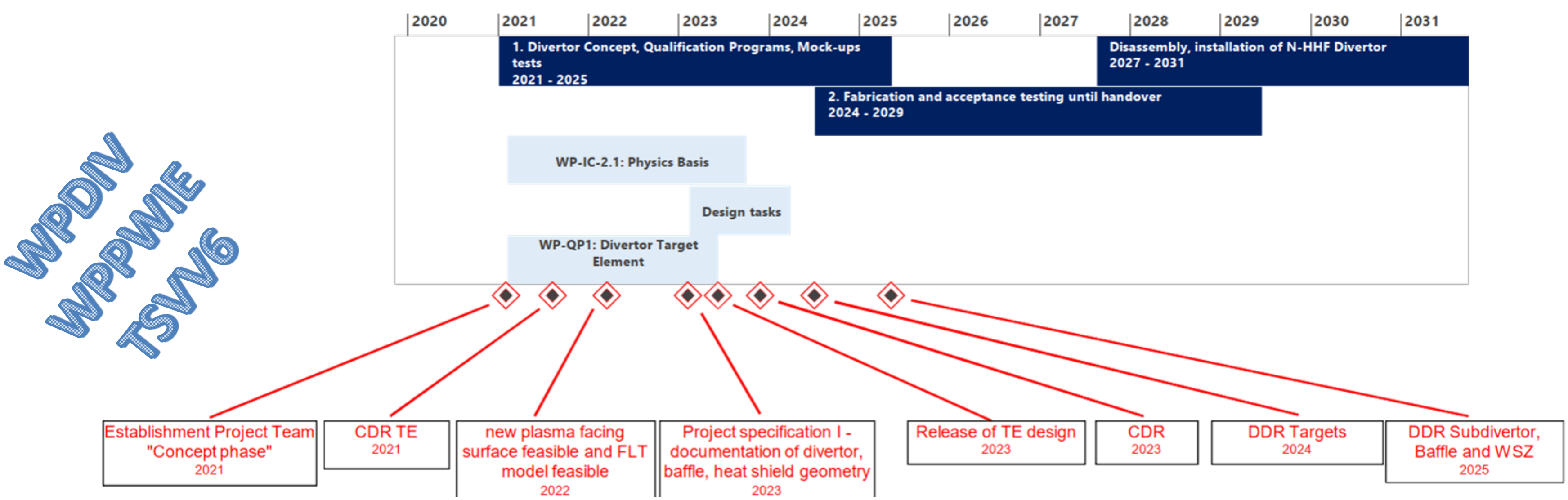
**Preparation of longer-term upgrades of the W7-X divertor and plasma facing components in collaboration with other EUROfusion work packages (w/ WPPWIE, WPDIV).**

a. EMC3/EIRENE/ERO2.0 validation

b. Develop metallic wall operation and divertor concepts.

c. Experiments for metallic wall operation & validation of material migration

W-divertor project
prepare metallic W7-X:
→ HELIAS reactor



# 2022 Objective 5: HELIAS basis, ITER support

**Support the preparation of the HELIAS physics basis, ITER first plasmas, ensure information exchange with WPPRD and continue international collaborations in support of the Mission 8 objectives.**

a. International collaborations (IEA Technology Collaboration Programme on Stellarators and Heliotrons)

b. Integration of stellarator databases into the EUROfusion database

c. Specific support actions (e.g. ITER ECRH stray radiation model and material testing) and ITPA contributions.

Mistral stray-radiation test facility: material/component test
→ hardening, safe operation

# TSVV 12: Stellarator Optimization

| GA Deliverable no. | Title | Due Date (mm/yyyy) |
|---|---|---|
| **D03.04** | Stellarator optimization code including algorithms with reduced sensitivity to local minima in parameter space | 12/2022 |

**Other specific objectives for 2022 (selection)**

- Evaluation of improvement on ideal MHD stability using **CAS3D** within optimization framework.
- Interface between the neoclassical code **KNOSOS** and optimization code.
- Interface between the gyrokinetic code **`stella`** and optimization code.
- Benchmark and early estimate of the accuracy and speed of bootstrap codes.
- Benchmark of existing fast ion codes – validation of existing features.
- Application of new diagnostics in the MHD code **SPEC** to assess magnetic topology and robustness of stellarator equilibria against pressure and current perturbations.

Developments in this TSVV are not only relevant for the **design of next-generation stellarators**, but also for their **application to W7-X campaigns** (e.g. assessment of fast ion confinement, assessment of robustness of magnetic configuration, efficient evaluation of neoclassical transport, etc.).

# TSVV 13: Stellarator Turbulence Simulation

| GA Deliverable no. | Title | Due Date (mm/yyyy) |
|---|---|---|
| **D03.02** | Non-linear stellarator gyrokinetic code(s) treating at least entire flux surfaces (not limited to single flux tubes) | 12/2022 |

**Other specific objectives for 2022 (selection)**

- Benchmark of the full flux surface version of **`stella`** vs GENE-3D run in full flux surface mode.
- Interface between **KNOSOS** and gyrokinetic codes.
- Development of **synthetic diagnostics** that provide meaningful numerical input for the interpretation of OP2 turbulence data.
- Assessment of the turbulent transport of the different species, with emphasis on impurities. Assessment of the relative weight of turbulent to neoclassical transport.
- Development of adjoint methods for linear gyrokinetics to be applied to turbulence optimization.

Developments in this TSVV are of the utmost importance for W7-X campaigns. The **calculation of turbulent transport** is essential to interpret, predict and, hopefully, control total transport in W7-X.

# Synergies within EUROfusion

| | |
|---|---|
| • FTD.WPPRD: | reactor relevant proposals |
| • FSD.WPPrIO: | EU imaging initiative?<br>Database (IMAS), specific support actions, ITPA coordination? |
| • FTD.WPDIV: | coordination W7-X, WPDIV, WPPW |
| • FSD.WPPWIE: | EU wall conditioning initiative?,<br>TG PWI @ W7-X |

| | |
|---|---|
| • TSVV6: | W7-X validation cases being discussed |
| • TSVV12: | tools ↔ validation ↔ proposals |
| • TSVV13: | tools ↔ validation ↔ proposals |
| • … | thrust meetings underway |

**The synergy potentials are difficult to exploit due to other workload**

# Opportunities for industrial collaborations

THALES



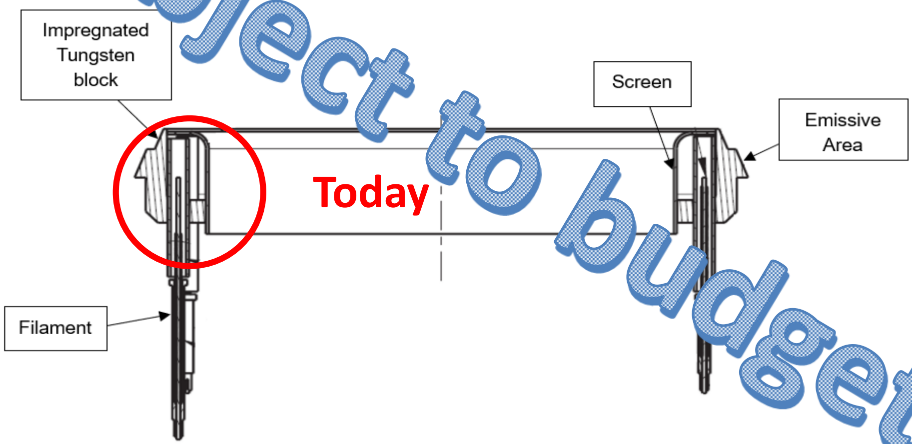



Figure 1 : TH1507 Gyrotron Cathode

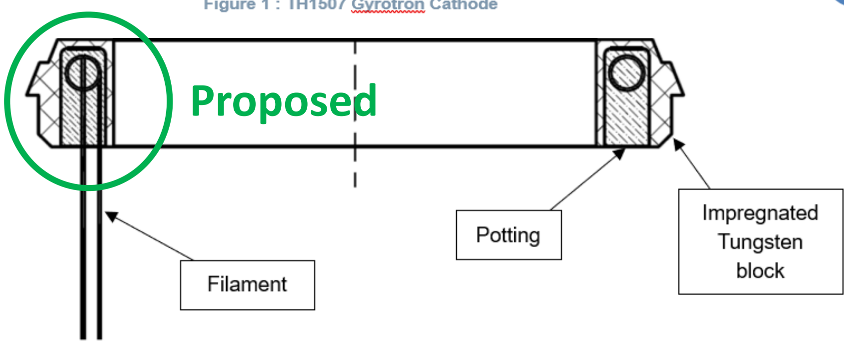



Figure 2 : Example of a potted gyrotron cathode

**Present technology:**

- heating is based on confined radiation from heated filament
- isolation by the ceramic beads.

**New proposal (Thales):**

back of emissive area in potting of alumina.

Advantages:

- enhanced heat transfer to emissive area
- overall electrical isolation
- better thermal homogeneity

→ enhanced longevity & robustness

→ RAMI

**Enable a leading European technology for production of thermal emitters for MW-class gyrotrons by introduction of potted emitter technology.**

**Lack of resources hampers long-lead time development and reduces scope**

# Grant Deliverables & Milestones 2022

| | Description | Due date | Type | Dissemination |
|---|---|---|---|---|
| W7X.M.02 | Commissioning of W7-X enhancements incl. Commissioning w/ plasma **OP2.1. 1st operation** of W7-X w/o use of water-cooled PFCs | Dec. 2022 | Data | Sensitive |
| W7X.D.03 | Report on conducted **scenario & campaign preparation OP2.1** (focus: wall conditioning, divertor exhaust and core heating/fast-ion confinement, preparation of steady-state scenarios, preparation of exhaust scenarios with divertor heat load control) | Dec. 2022 | Report | Public |
| W7X.D.02 *TSVV* | Non-linear stellarator gyrokinetic code treating at least entire flux surfaces (not limited to flux tubes) | Dec. 2022 | Other | Sensitive |
| W7X.D.04 *TSVV* | Stellarator optimization code including algorithms with reduced sensitivity to local minima in parameter space | Dec. 2022 | Other | Sensitive |

# AWP 2022: Milestones

SMART WPW7X Milestones 2022

- WPW7X-2022-M.1: Program meeting
  *Physics program (aligned with Mission 8 objectives) ready*
- WPW7X-2022-M.2: CfP evaluated
  *Manning for campaign OP2.1 organized*
- WPW7X-2022-M.3: Plasma commissioning phase conducted
  *ICRH antenna in operation*
- WPW7X-2002-M.4: Scientific operation
  *First plasma (w/ water-cooled PFCs installed, not operating) in campaign OP2.1*

# WP Organization and Activities in 2022

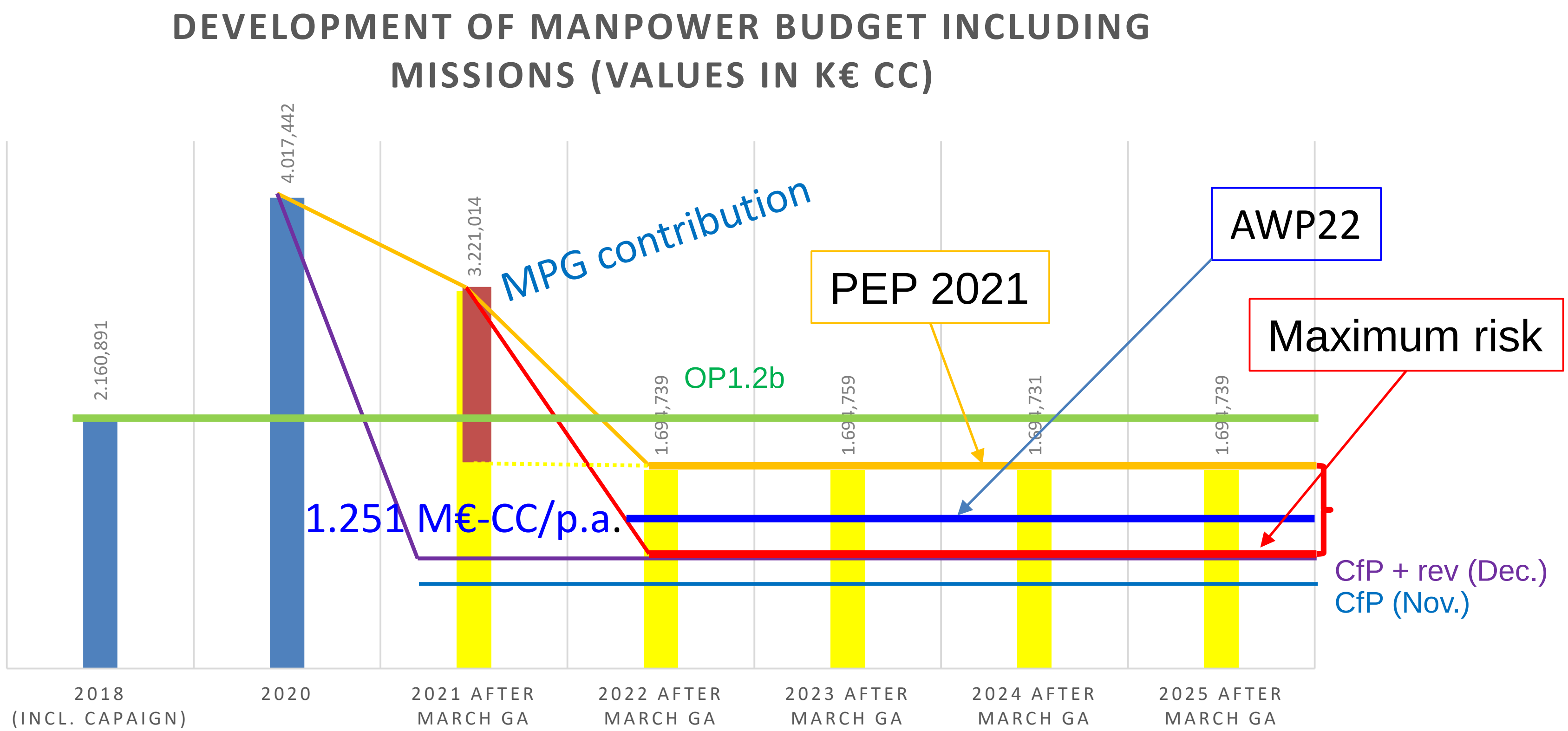
- Preparation of OP2.1
  - preparation of experiments and scenarios
  - preparation of components and diagnostics
  - commissioning of components and diagnostics

- Conduction of OP2.1
  - manning in three W7-X TFs
    (priorities along the EUROfusion EPs and developments)

- HELIAS physics basis, ITER and DEMO
  - HELIAS: INCO, EUROfusion databases
  - ITER: specific support actions
  - DEMO: to be iterated – 3D physics

- WP Management

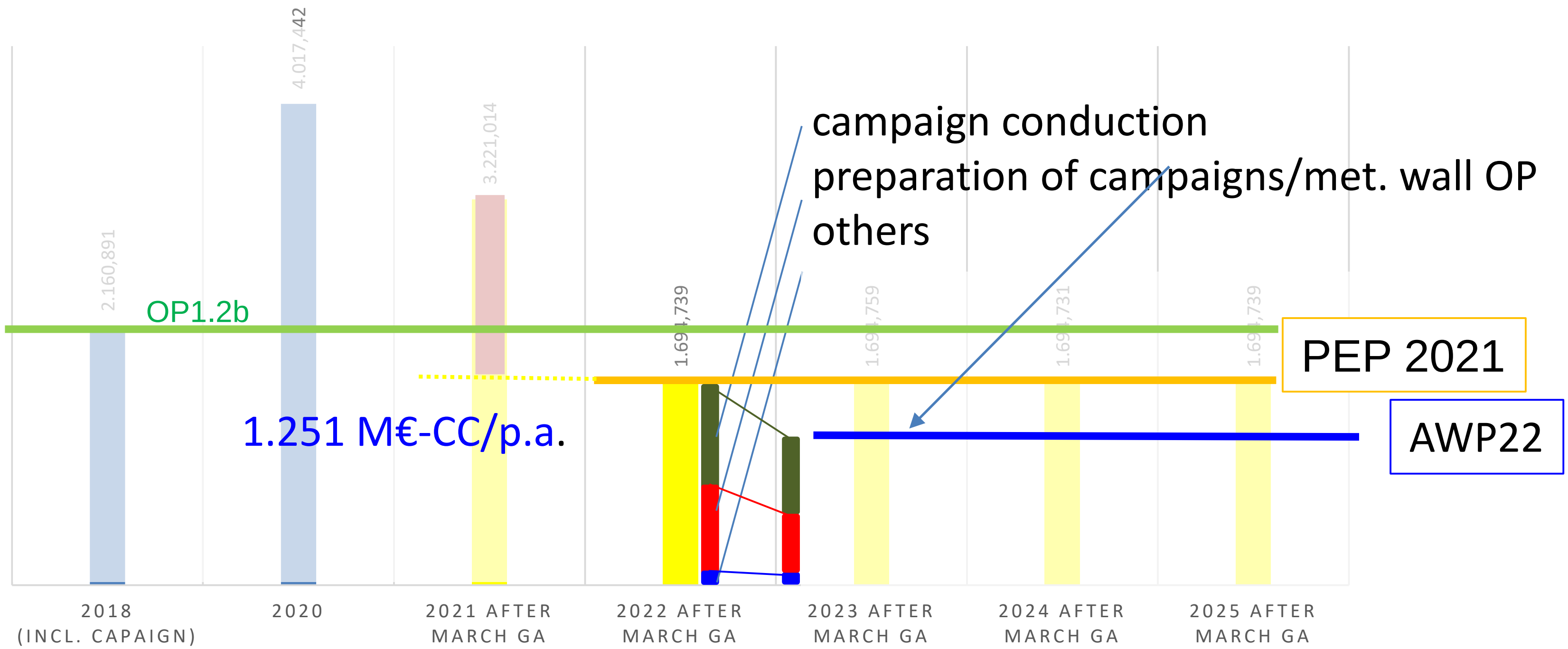
# HR (incl. missions/unit costs) budget options/risks




My understanding: if UK gets associated and EUROTOM adds it to the grant, we recover to PEP2021, planning is made with option AWP22
-> Emilia

# Resource allocation

DEVELOPMENT OF MANPOWER BUDGET INCLUDING MISSIONS (VALUES IN K€ CC)




- ➢ Keep activities balanced over 2022-25 (flat spending)
- ➢ Priorities on campaigns and exploitation of EU components.
- ➢ 2022: substantial part (~50%) allocated only after summer.
- ➢ **No allocation on task level (lvel-3) yet – resources in IMS are indicative.**

# Reactions: lack of resource allocations (level-3)

I think that, in spite of all the uncertainties to be clarified, the PMU should be able to present a preliminary distribution of resources per beneficiary, having in mind that this initial assignment will be subject to subsequent refinements and amendments along the year 2022. I do not see any good reason not to proceed in this way… Anyway, let us have this discussion in the Board meeting.

… since we are approaching to the end of 2021 and I have to inform my …
I was wondering whether there is an updated decision on the distribution of funds for the W7X activities, especially for the technological part.

„In case we want a result (… on a task involving resources beyond WPW7X), any delayed decision will add at least one morer year of development time.“

# Risks (register to be updated)

- Scientific resources too low: critical reduction of scope
- Planning time-lines too slow and unclear assignments: critical reduction of scope
- Management resources too low (absorption in meetings, workload): delays, reduction of scope
- Lack of manning, lack of specialists: critical reduction of scope
- Machine delayed: delays
- COVID: delays
- Resources for HELIAS reactor studies  too small: Mission milestones cannot be achieved
- Depreciation costs for FP-8 EP.A (FZJ) not clarified: critical reduction of expected resources

- Pace of energy increase too low: delayed program
- PI not available: reordering of program required
- Heating ICRH coupling: reduction of scope
- NBI: lack of ion heating
- ECRH incl. development deleays: lack of cw heating/SSO performance

# INCO

- Due to COVID restrictions, travelling to the main cooperation partners (Japan, US) is much restricted

- A recent enquiry (still open responses) resulted in requests of

  - 195 travel days, ~60k€ travel cost estimates

  with large uncertainties.

- More INCOs continued by remote participation but at lower pace and efficacy

- Propose to go forward with INCOs on the low-level as requested for the beginning of 2022, define a ceiling for WPs when a broader planning is required and re-address the matter in spring/summer

# IO's (edited) laundry list

## Conclusions

- **W-7X can contribute to support R&D for IRP on areas with specific features and/or expertise of the team associated with H&CD, diagnostics, 3-D fields and long pulse features of the device**
  - Diagnostics (high $T_e$ and neutral pressure) WP -> formulate Level-3 tasks ✓
  - 3-D field impact on divertor power fluxes Arturo, Jakubowski check w/ TGE&D -> not followed up in Kalupin meeting???
  - ECWC conditioning WP –> formulate Level-3 task ✓
  - Fast Particle losses with 3-D fields Ivan/ Lazerson, CIEMAT check w/TGFI -> not followed up in Kalupin meeting
  - 3rd harmonic ECH heating physics AD /Thomsen, Stange, (TGMHD) -> w/ TF-I?
  - 3-D field equilibrium reconstruction and stability analysis Ivan TSVV, Joachim Jorge, Knieps? (is organized by Kalupin, PMU)
  - Imaging: discussion within FSD – science meeting …
  - Stray-radiation – MISTRAL -> ask AL for needs
  - Pressure gauges: organized by Figureido -> PMU needs to come up with a plan for hardware and feed-back
  - ITPA support – AA to check w/ CH
- **These issues are highlighted as high priority for IRP in next ~3 years. Priorities for 2022 need to be discussed in view of W-7X programme**

iter china eu india japan korea russia usa


WP-7X EUROfusion planning meeting - 9th September 2021

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+ IMAS discussion (AD w/ Hoehnen, Schneider, Pinches)
DEMO requirements to be addressed in meeting organozed by Kalupin

# News, updates, remarks

- Three (outstanding) EEG candidates for WPW7X related proposals, understood panel has identified a rare opportunity
- ERG proposals not assessed for feasibility within WPW7X (if any)
- LHD campaign in full swing with good participation of WPW7X (two scientific advisors, ~ dozen proposals assigned with machine time, LHD Team is open to conduct important R&D, e.g. ICH plasma start-up, installation of pressure gauges, etc.)
- The present overall management workload is too high (repetitively reported in the FSD meeting) to keep a science-oriented WP management style as in FP8.
- The present management of missions does not allow for a planning (costs fluctuate) and result large but ineffective workload. A serious issue for 2022 (campaign) is expected.

# Summary and conclusion

- Programme 2022: OP2.1, its preparation and strategic topics

Focus on campaign oriented work 2022-25

| EUROfusion Machine Time W7-X | | | | |
|---|---|---|---|---|
| 2021 | 2022 | 2023 | 2024 | 2025 |
| 0% | 18% | 23% | 30% | 30% |

- make enhancements (FP8-EP etc.) ready for OP2
- exploitation prioritized along high-level objectives of M8
- INCO, HELIAS physics basis, TSVV, ITER support
- synergy potentials (FSD, FTD, etc.) worked out and exposed

# Change requests and comments

- P. 24, Tab. 8-3: The consortium contribution in line „W7X-5“ includes resources attributed to deliverables from KIPT and CIEMAT. Therefore both need to be included in the column „involved Beneficiaries“ (currently missing).
- P. 27, Tab. 1 and the preceding paragraph are currently not matching in values regarding heating power. We requested a revision and plan on correcting the values accordingly.
- Minor correction on P. 7, Figure 1: PSO to be changed from „SM“ to „CP“.
- Minor correction on P. 15 (WBS): The abbreviation „IC“ in several tasks to be changed to „INCO“.

# Change requests and comments

Question from stakeholder (P. 33 Tab. 22D-1):

„Why are most Beneficiaries missing in lines W7X-2 & W7X-3 and where is line W7X-5?"

Clarification:

The Human Resources for 2022 are still *fully indicative*. Therefore all HR are currently listed under „W7X", reflecting their unallocated state. As soon as the 2022 Deliverables are defined the HR will be allocated to their respective WBS-Levels and appear in W7X-2/3/5.

- The line „W7X-2" currently *only* contains the Operation & Maintenance budget of MPG.
- The line „W7X-3" currently *only* contains Enhancement Depreciation of FZJ.
- „W7X-5" will hold resources once the Deliverables are defined.

# Complaints: lack of resource allocations (level-3)

I think that, in spite of all the uncertainties to be clarified, the PMU should be able to present a preliminary distribution of resources per beneficiary, having in mind that this initial assignment will be subject to subsequent refinements and amendments along the year 2022. I do not see any good reason not to proceed in this way… Anyway, let us have this discussion in the Board meeting.

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