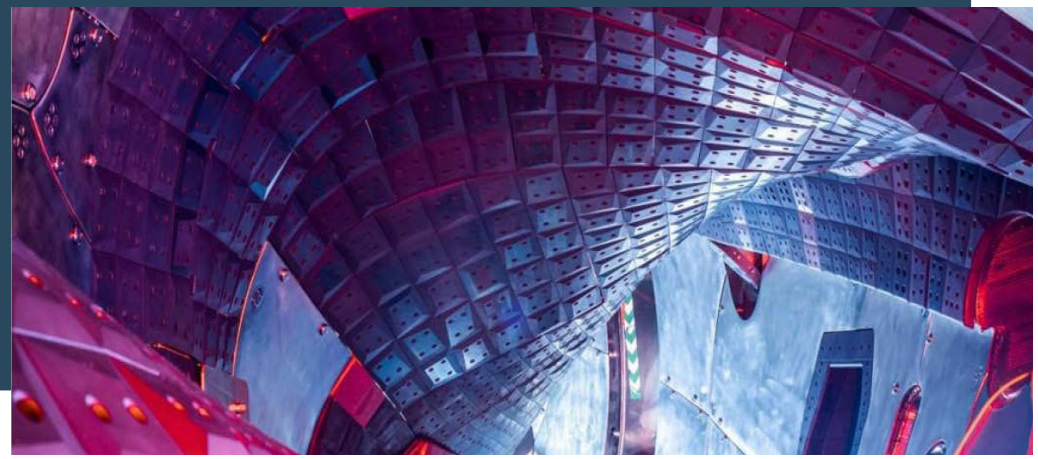
MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

The stellarator W7-X on the way to long pulse operation

Wendelstein 7-X



Hans-Stephan Bosch for the W7-X Team

EUROfusion

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.

content

1. Physics Results up to 2018

2. W7-X Completion up to 2021

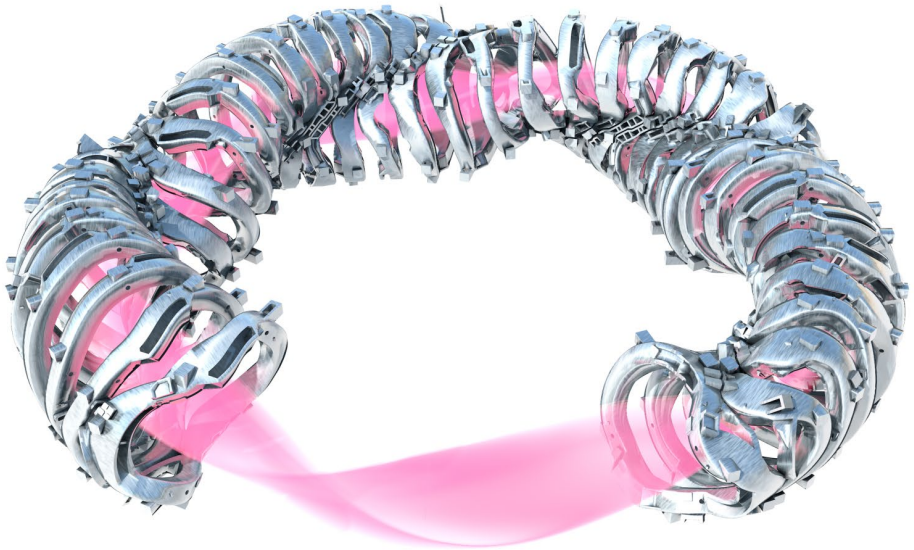
3. Commissioning 2022

Wendelstein 7-X

plasma volume 30 m^3

Wendelstein 7-X

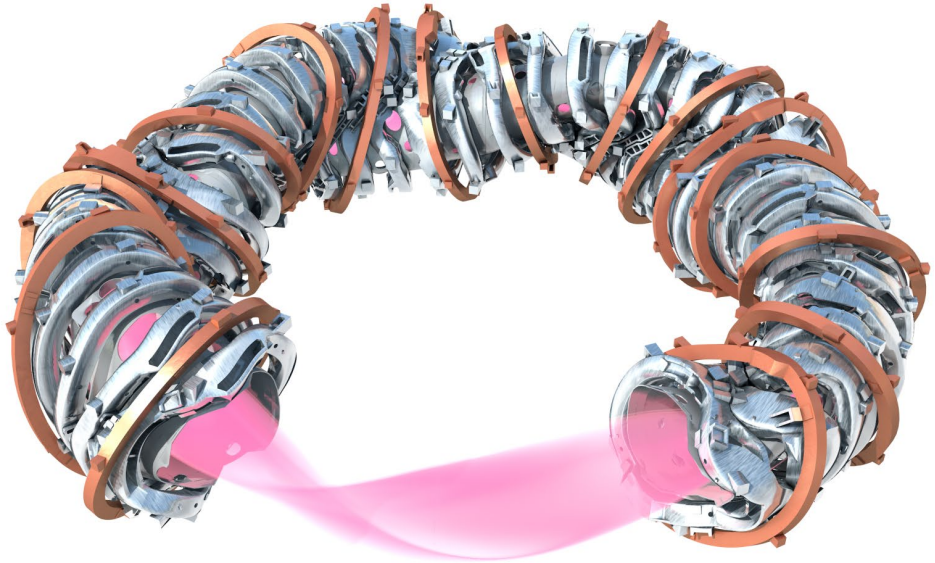
50 non-planar NbTi coils
5 types DC <18 kA



Wendelstein 7-X

50 non-planar NbTi coils
5 types DC <18 kA

20 planar NbTi coils
2 types DC <16 kA



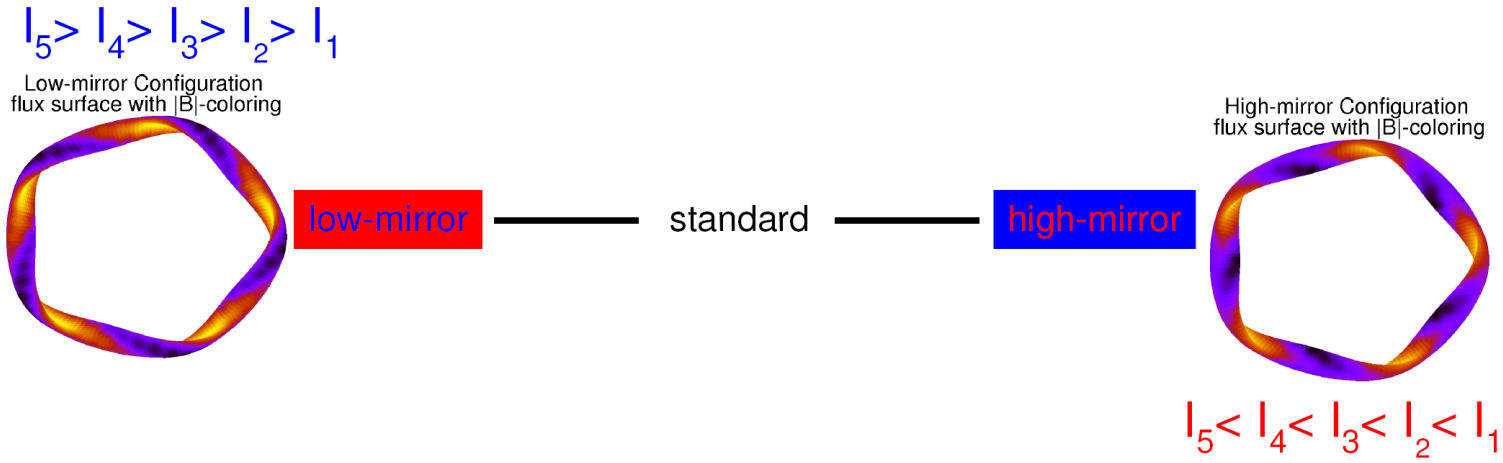
70 Coils in 7 types allow different magnetic configurations

Optimized magnetic field

In Stellarators the magnetic configuration is controlled by external currents only!

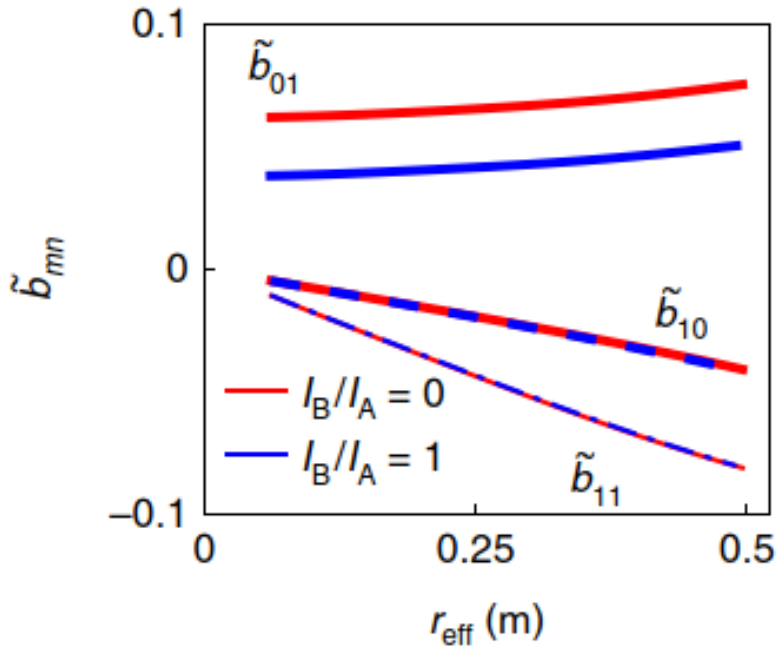
W7-X has 5 non-planar and 2 planar coils, which can be controlled separately, great flexibility!

- currents sequence in the TF Coils changes the mirror ratio
- current directions in both PC changes the edge iota
- different directions of the PC current flow determine the radial position

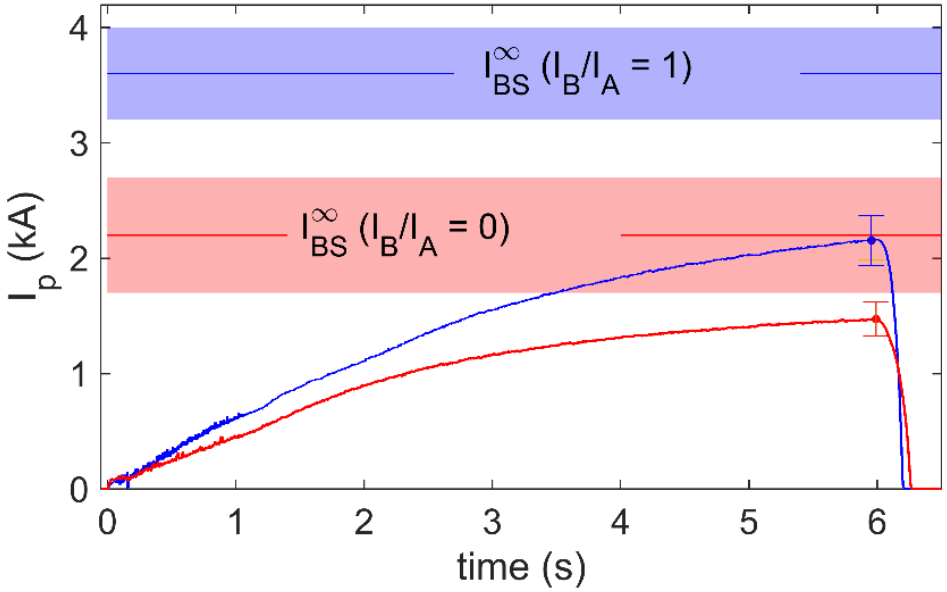


Optimized plasma confinement

- Plasma current (bootstrap) are small
- they depend on the magnetic configuration, here for a limiter configuration
- Switching one planar coil of, increases the Fourier-component b_{01}, decreasing the bootstrap current
- Measurement with Rogowski-coil confirms this part of the optimisation.



Dinklage, et al. Nature Phys. **14** (2018) 855



Record Discharge

W7-X 20181017.019

- high plasma density by fueling via pellet injection
- peak density $n=1\cdot10^{20}\ m^{-3}$
- temperatures equilibrated $T_i=T_e\sim3.8keV$
- exceptional energy confinement time transiently exceeding stellarator scaling

- record triple product for stellarators

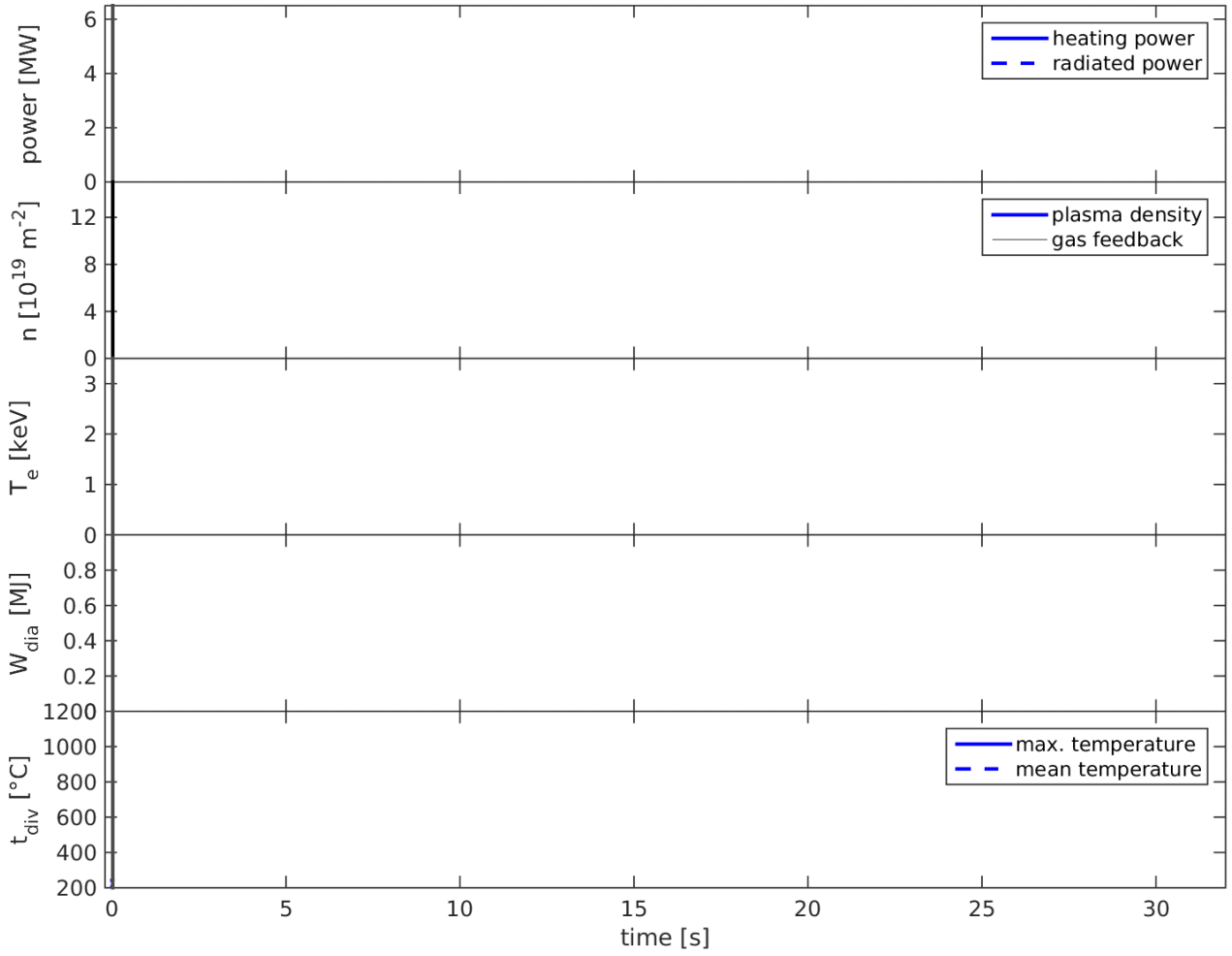
$$\tau_E = 220ms \approx 1.4\tau_{ISS04}$$

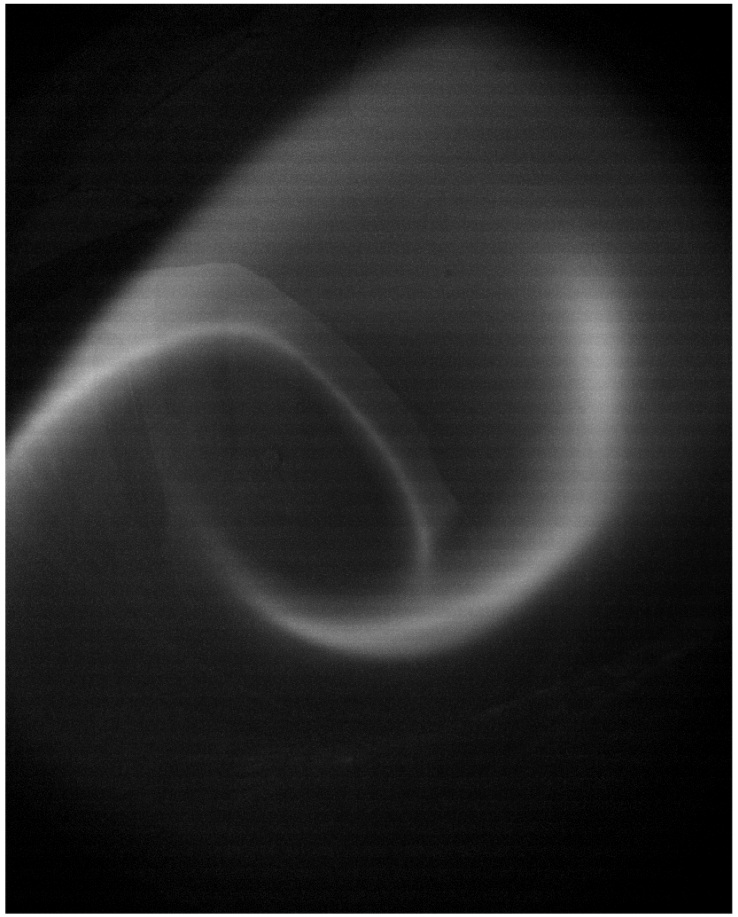
$$n\,T_i\,\tau_E = 6.8\cdot10^{19}\,\frac{keV\,s}{m^3}$$

Wolf, et al. Phys. Plasmas, **26** (2019) 082504

Detached Plasma

W7-X 20181017.016





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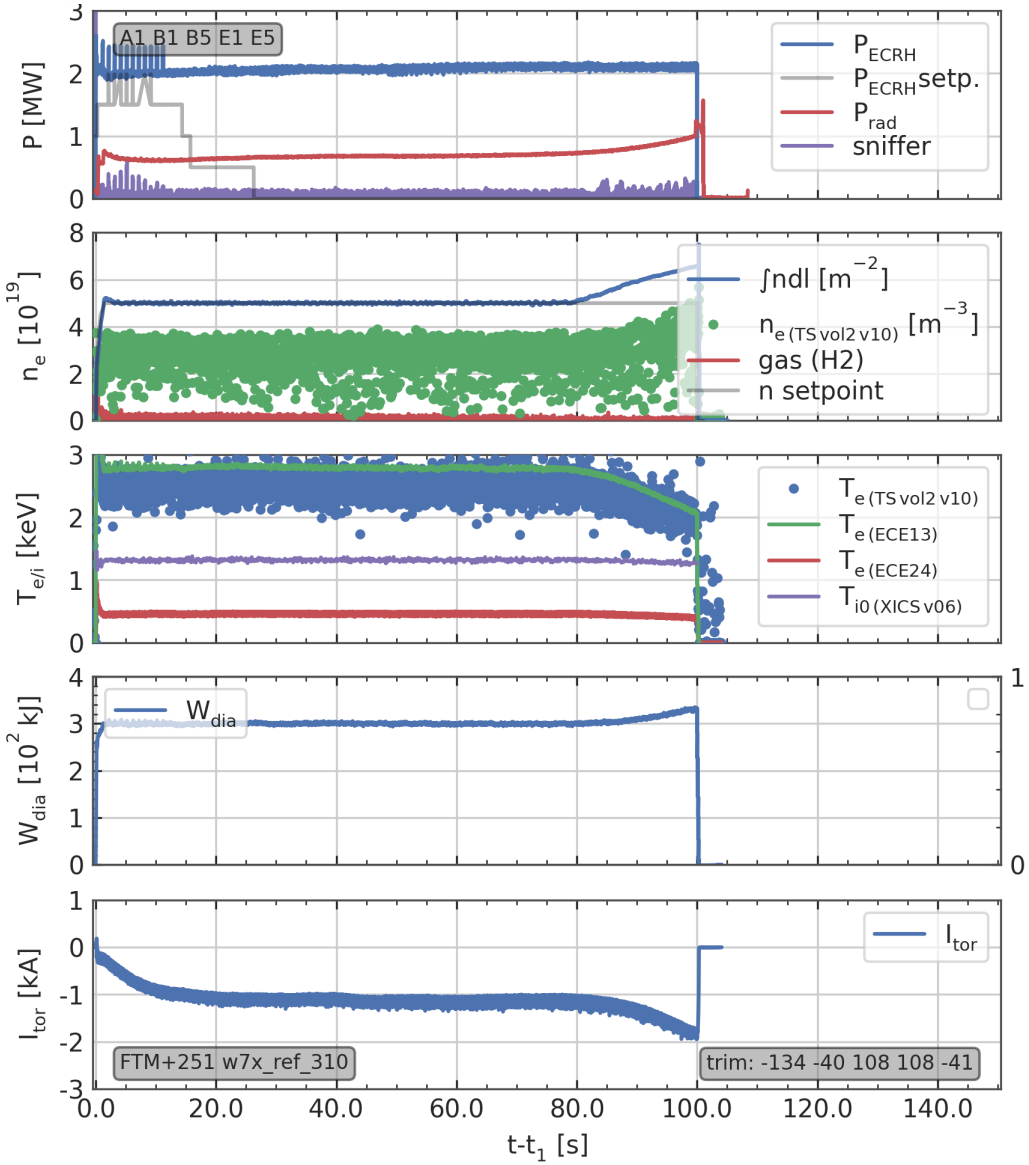
100 s Plasma

W7-X 20181017.019



Wolf, et al. Phys. Plasmas, 26 (2019) 082504

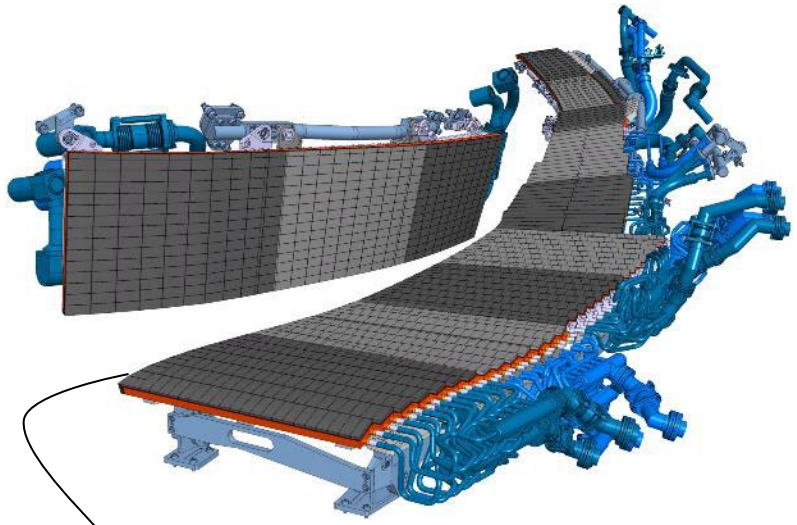
content

1. Physics Results up to 2018

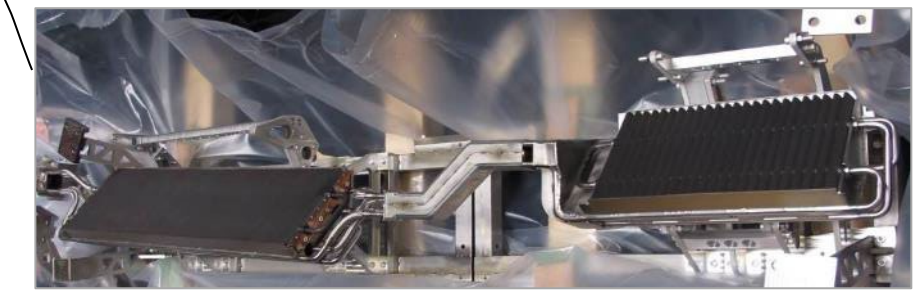
2. W7-X Completion up to 2021

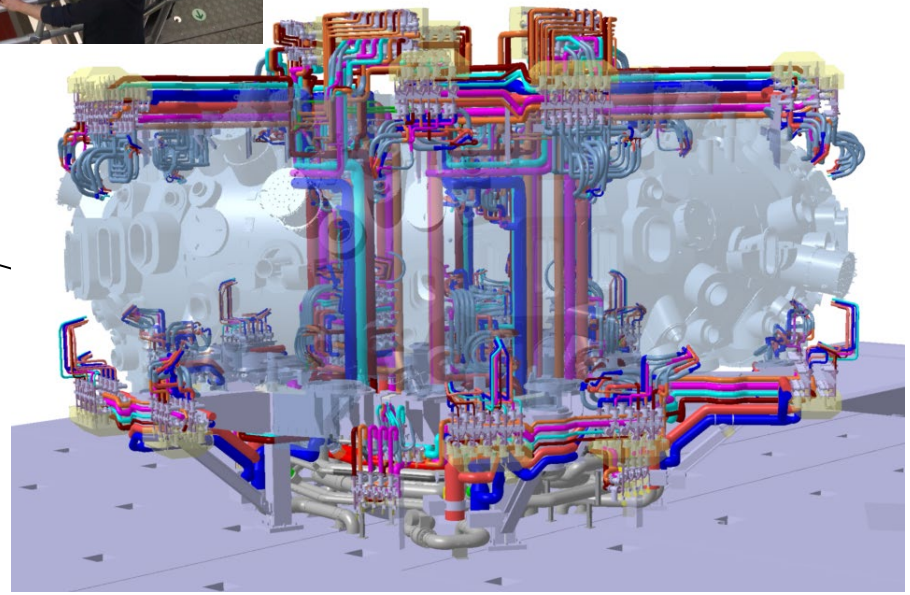
3. Commisssioning 2022

Completion Phase 2018-2021

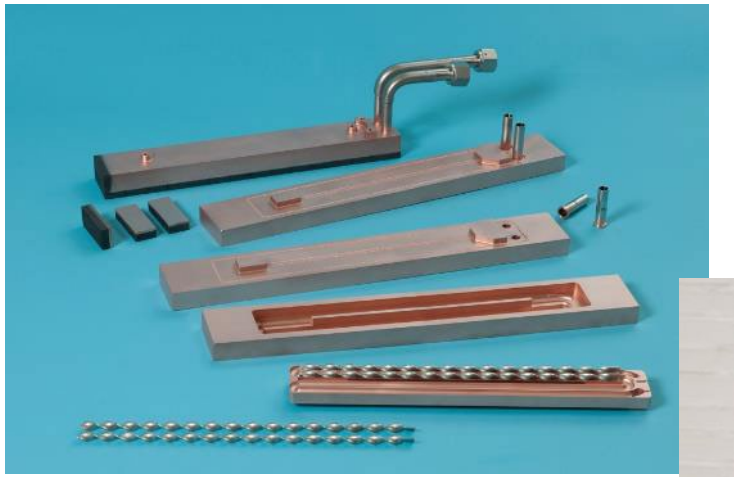


- 10 HHF Divertors
- 10 Cryo pumps with LHe
- Extension of cryo supply
- complex cooling water system

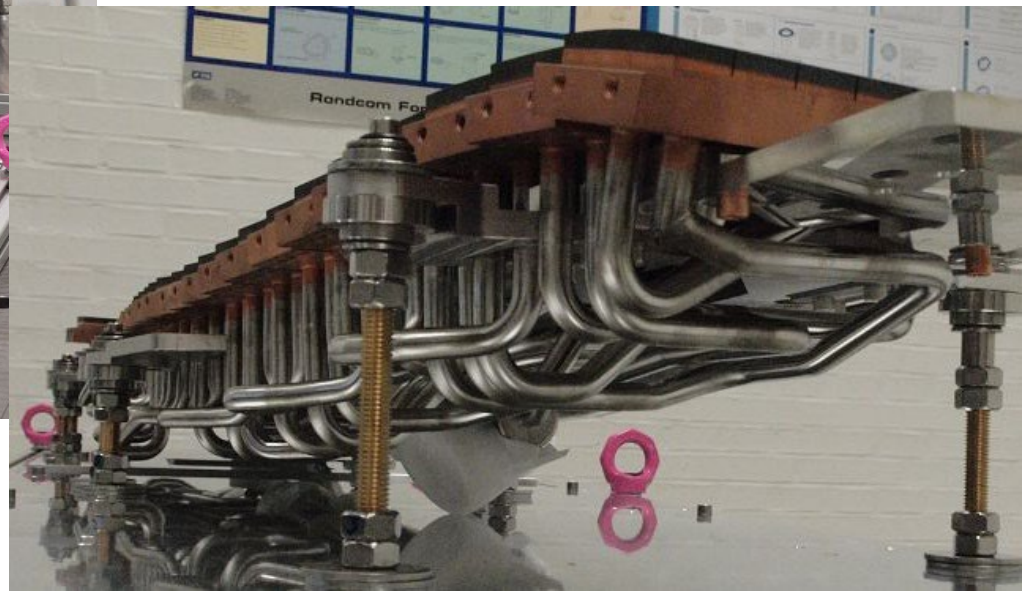




High Heat Flux (HHF) divertor

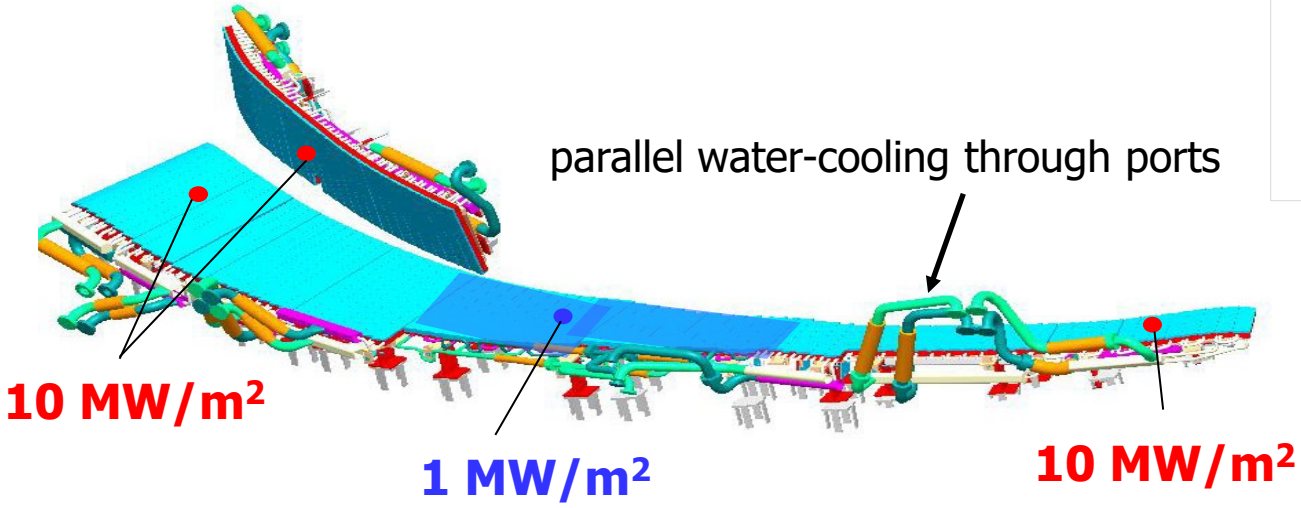


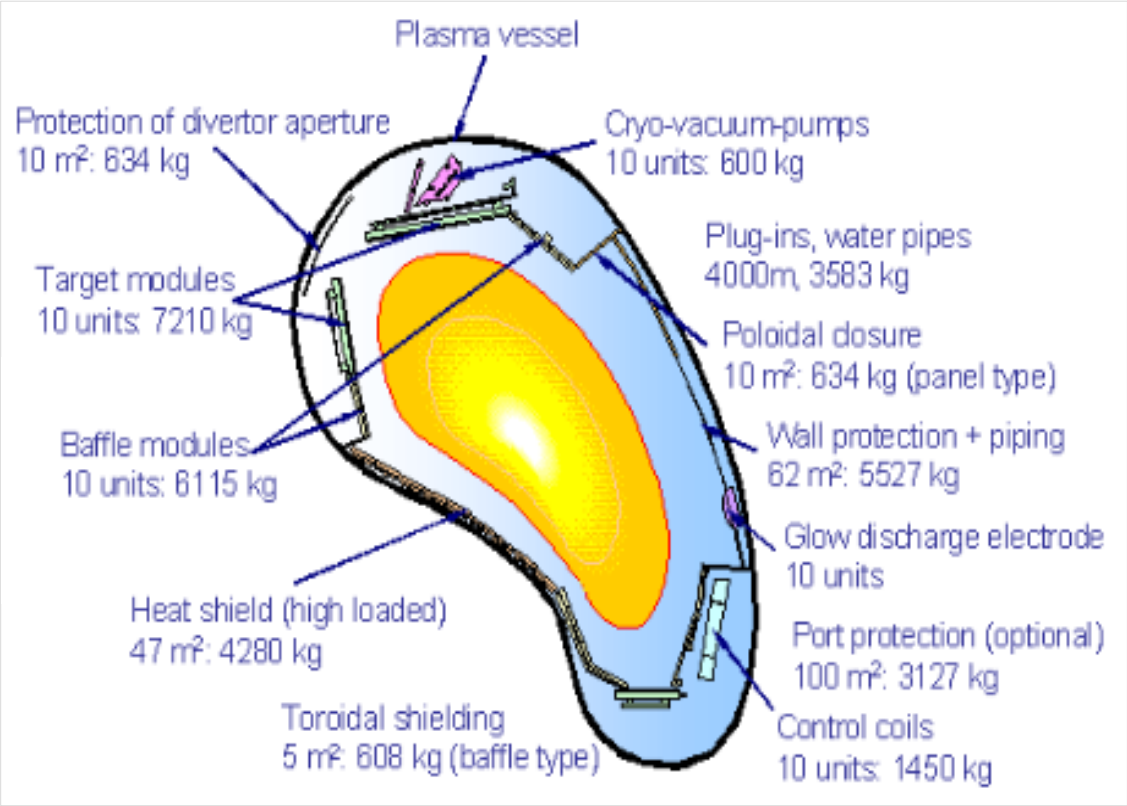
- pressure water cooled divertor targets
- CFC blocks welded on CuCrZr heat sinks
- Steady state cooling with water



In-vessel components

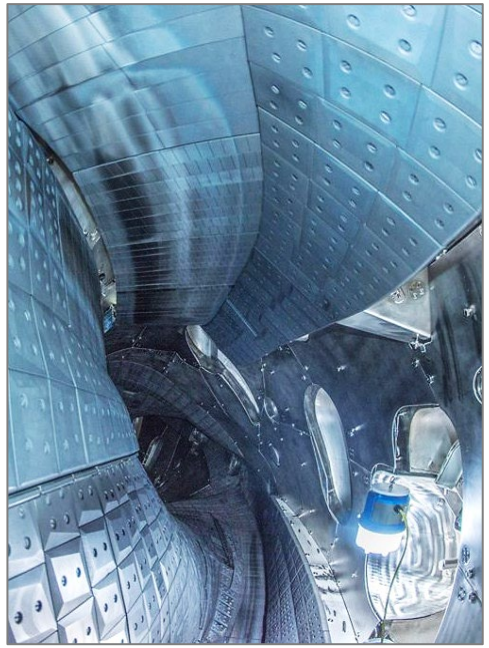
- All in-vessel are water-cooled
- 10 divertor units, 5 below the plasma, 5 on top
- All in-vessel are water-cooled
- Baffle modules from graphite
- Wall protection from steel



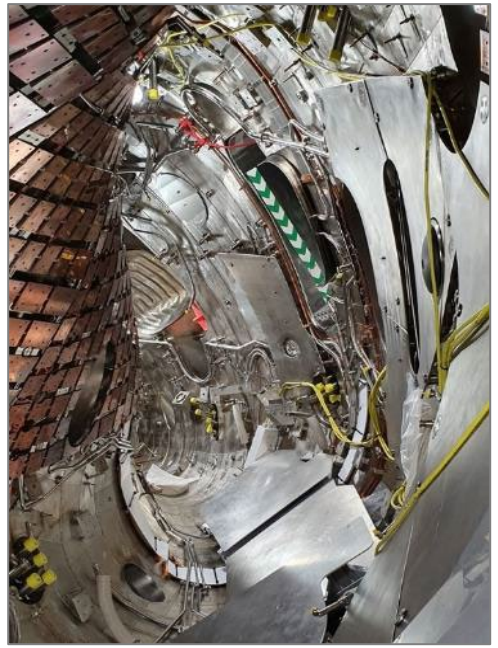


Stadler, et al., Fus. Eng. Design. **84** (2009) 305

Assembly of the in-vessel components

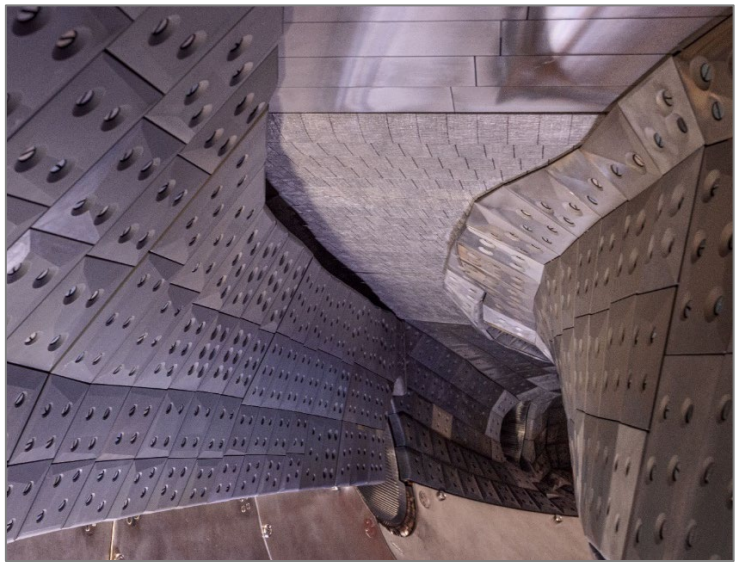


December, 2018



fall 2019

Corona break,
measures implemented, June 20



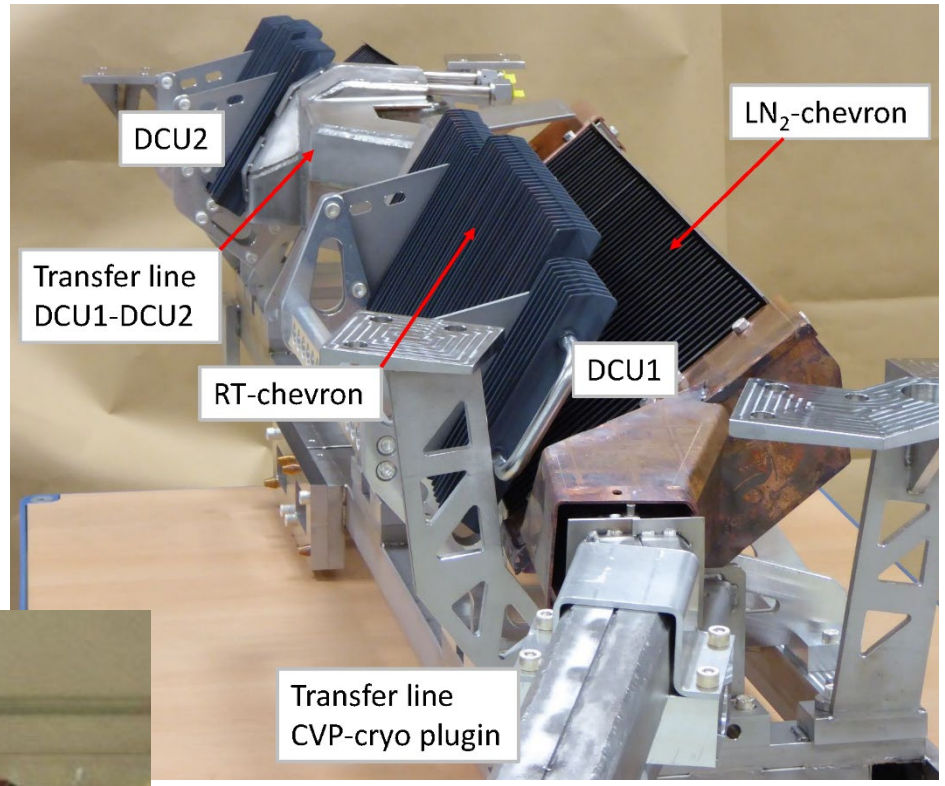
December, 2021

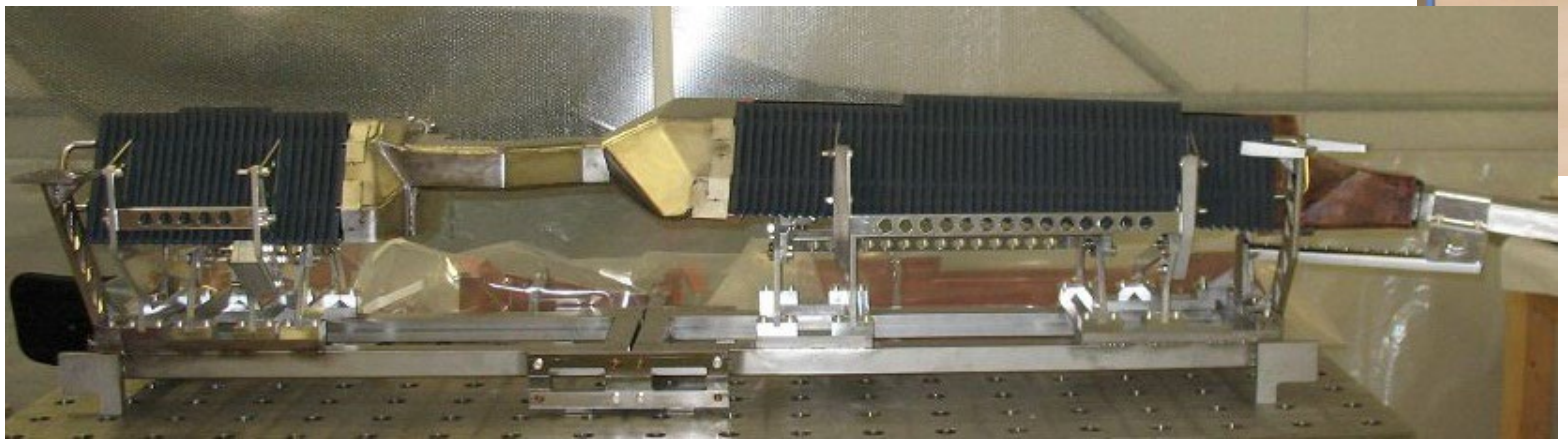
In-vessel assembly:

- 10 HHF-divertors
- Water-cooled targets, baffles and port protection
- 10 Cryo-pumps
- 7 km water cooling pipes
- Diagnostic systems

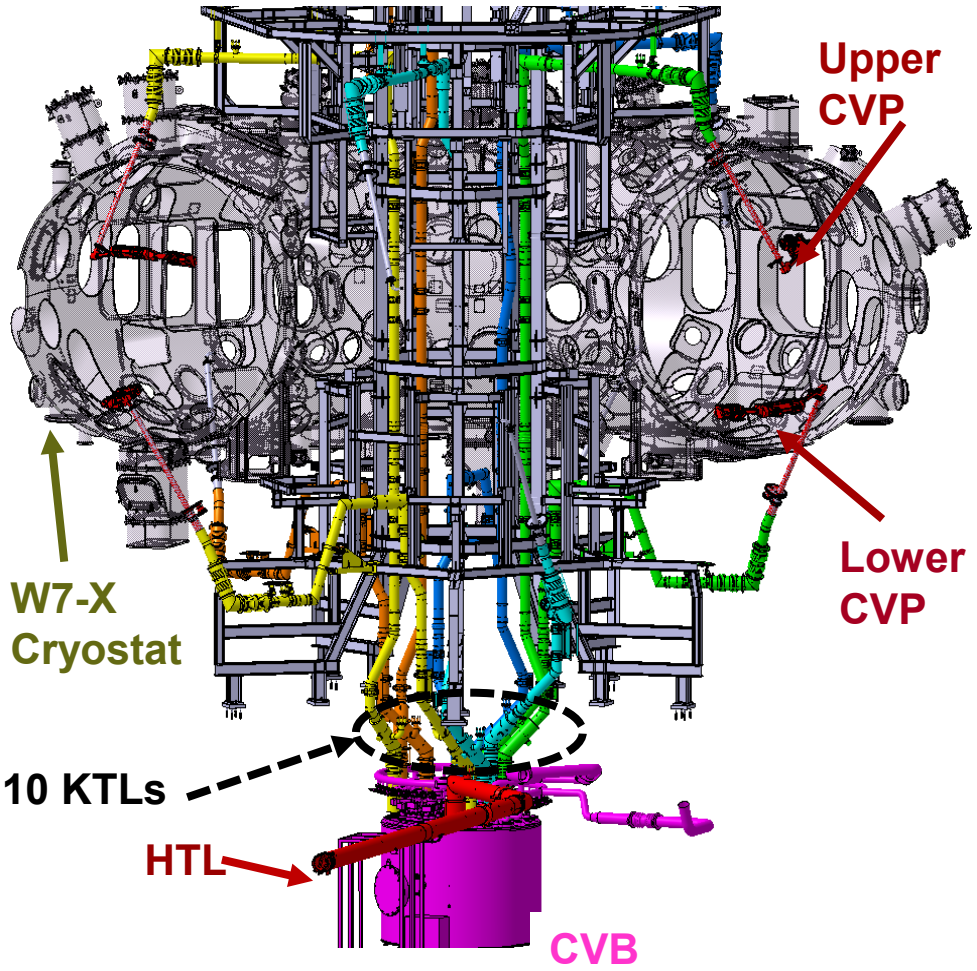
Cryo pumps behind the divertor

- 10 pumps, separated into 2 sections
- 80 K and LN_2 chevrons to protect the pumping pipes (LHe)
- Water-cooled shield against stray radiation (not shown here)



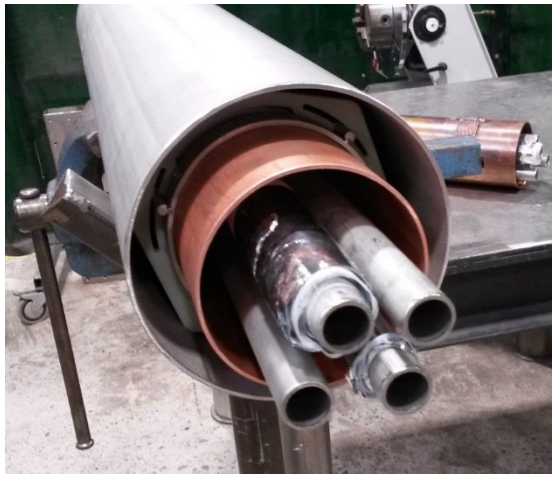


Cryo supply for the cryo pumps



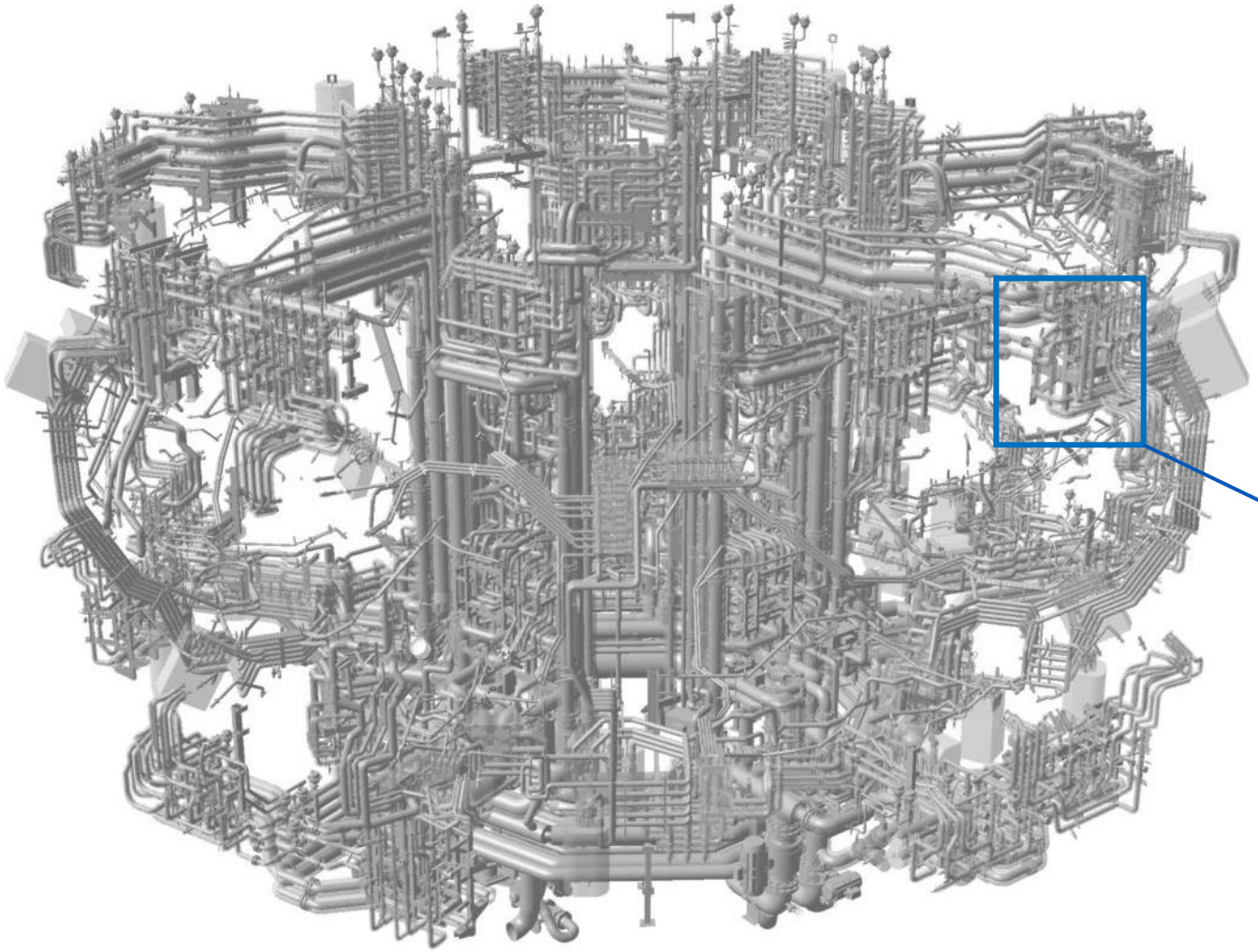
Main components

- HTL: Transfer line from CryoSupply → CVB
- CVB: cryo valve box
- KTL: 10 transfer lines (He, LN2) between CVB → CVP
- CVP: cryo vacuum pumps (10)



Transfer line (KTL)

Water cooling system (outside vessel)



- Pipework accuracy +/-5mm (to avoid clashes)
- Previously: 54 water circuit in PV
- Now: about 657 water circuits in PV!!

Trial assembly of one manifold-unit (out of 44)

Wendelstein 7-X
in December 2021

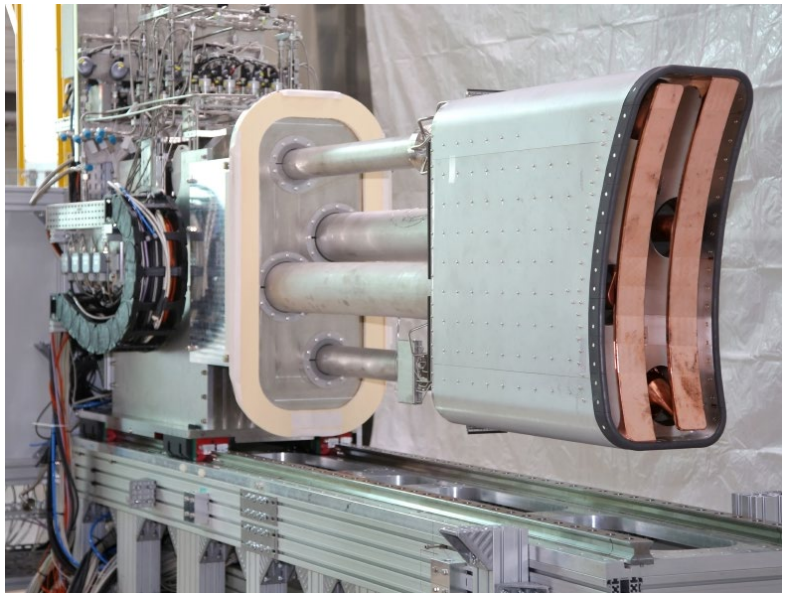
Heating systems enhancement

NBI

- Additional 2 ion sources being commissioned
- Total nominal power ~ 7 MW (55 kV, H2, for > 5s)

ICRH

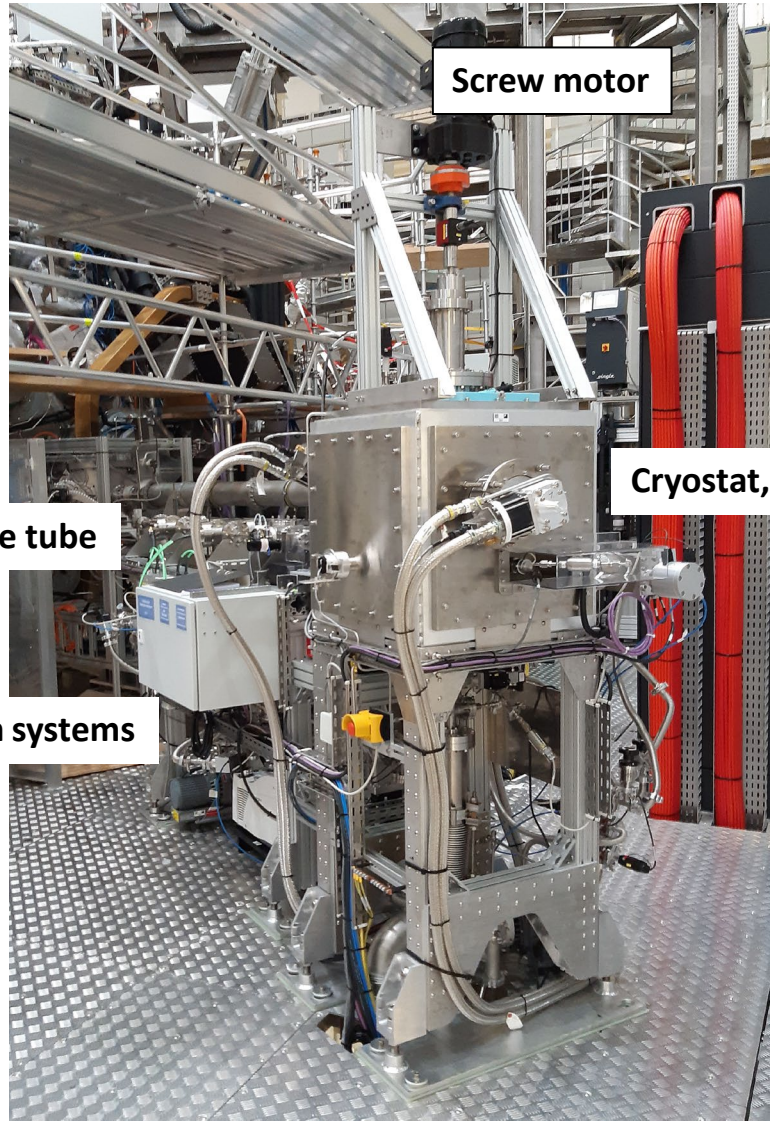
- New ICRH single star antenna from FZJ/ERM
- Frequency range 25-38 MHz, P > 1.5 MW
- Devoted to fast ion generation via 3-ion schemes



ECRH

- 10 gyrotron at 140 GHz delivering ~ 8 MW to the plasma
- New 1.5 MW gyroton prototype is in test at IPP Greifswald
- New microwave design using TE28.10 mode

Fueling Enhancement



- Continuous injection, up to 30 min.
- 250-100 m/s, helium propelled
- Built by ORNL with contributions of PPPL (US) and NIFS (Japan)
- The injector is installed at W7-X, control systems are still in work

content

1. **Physics Results up to 2018**

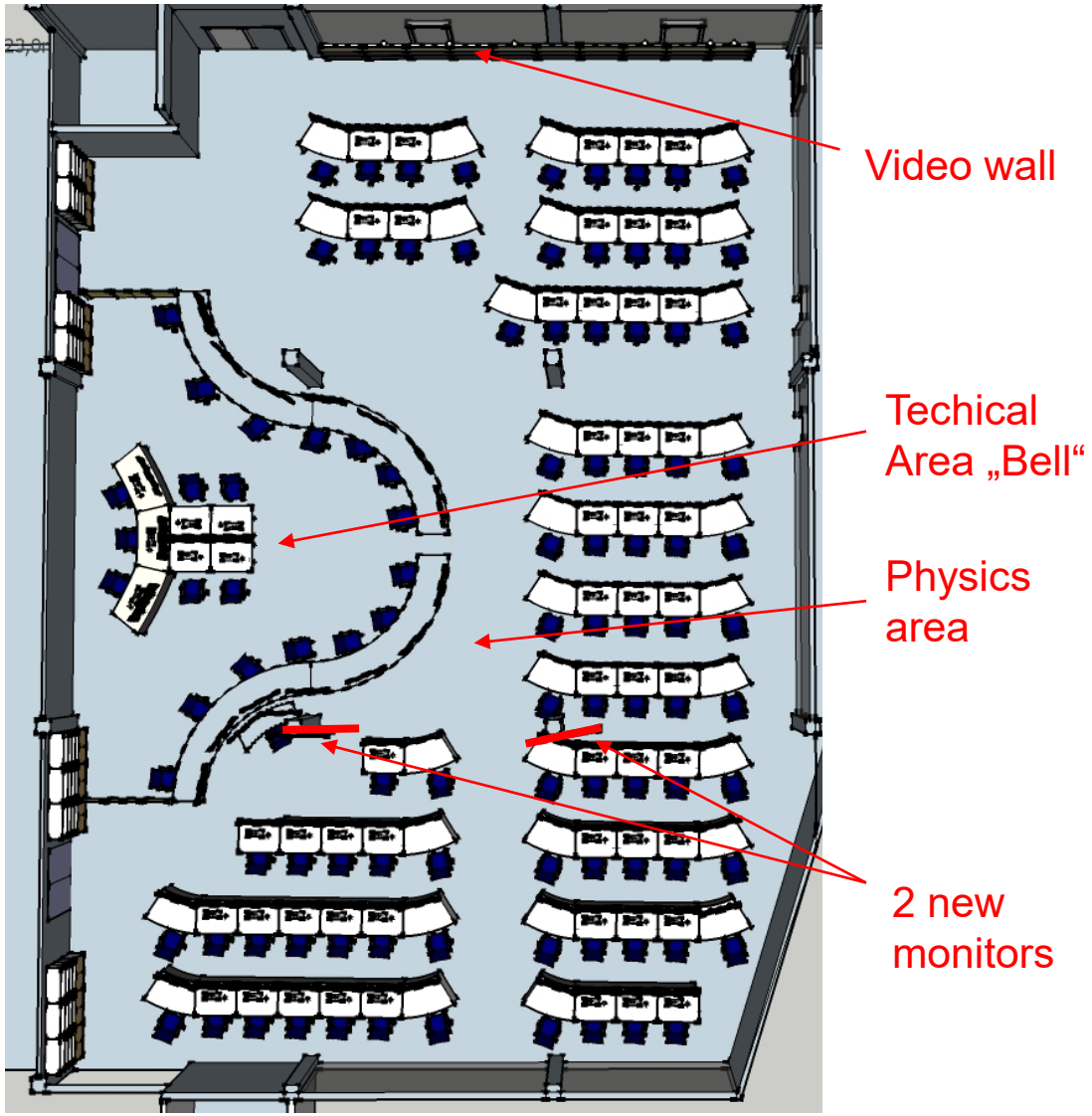
2. **W7-X Completion up to 2021**

3. **Commissioning 2022**

   Preparations

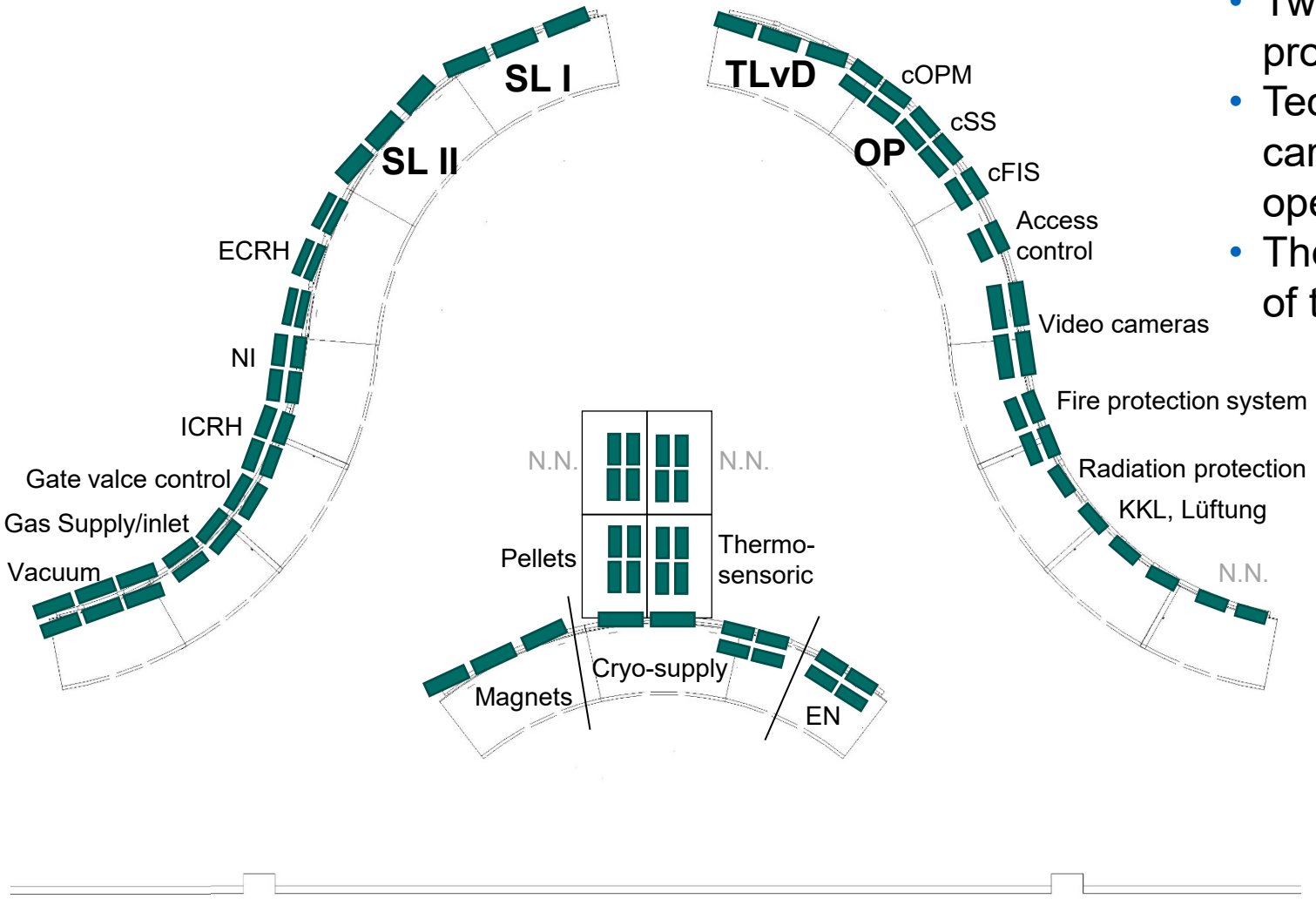
   commissioning

Control room



- Expansion to 96 places for scientists from previously 60
- But limitations due to Corona
  - Max. 54 scientists,
  - reduced number of operation staff
  - IT Safety
  - IT networks for machine and office are segregated
  - Exceptionally due to Corona, access to machines in the experimental network is possible from site offices
  - Access to numerous services is possible for W7-X team members also from external via VPN
    - Experiment Data
    - Real-time monitoring of discharges
    - Databases for proposal planning
    - Equilibrium databases
    - Logbook
    - etc.

Control room, technical area („bell“)

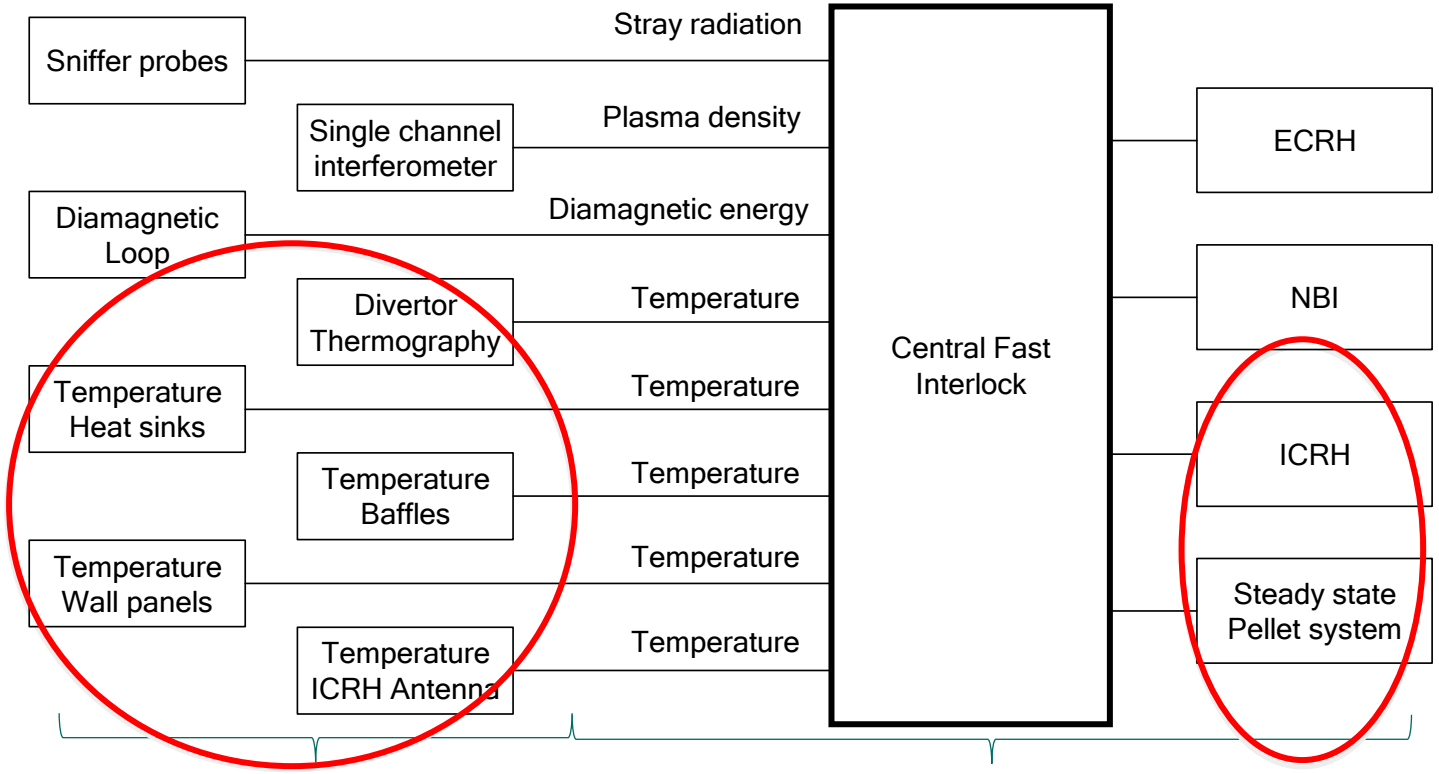


- Two **S**ession **L**eader lead the physics program
- Technical Leader in Charge (**TLvD**) takes care of the technical subsystems during operation
- The Codac-**Op**erator handles the operation of the device

Central Fast Interlock System

The CFIS is a system of safety-related diagnostics and the plasma heating systems to realize a fast shut off

Many temperature sensors have been installed to monitor the Plasma vessel inside



Two more Heating and fuelling Systems are shut of to minize danger for W7-X

Reaction time: Max 100 ms Max 10 ms

Software for the operation

Experiment Organization

ProposalDB – physics proposals submission and evaluation

MFC-DB – magnetic field configuration assessment database

Session Detailing – experiment session preparation

… div. other databases

Experiment Configuration

ConfigDB – Configuration database and DevOps tools

ConfiX – component configuration editor

Xedit – experiment program editor

Experiment Control and Data Acquisition

End systems – hardware integration

CoDaStation – continuous data acquisition framework

FastControlStation – real time and feedback control

TTE – central timing and event system

Xcontrol – experiment control interface, status and progress monitor

DataMonitor – online data monitoring

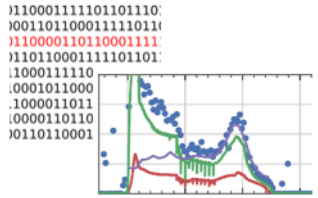
Data Archiving

ArchiveDB – longterm data storage and management

W7-X Logbook – central team logbook

DataBrowser – archive data browser and viewer

Data Analysis



JavaAPI – signal access interface

WebAPI – REST based data interface

LogbookAPI – REST based logbook interface

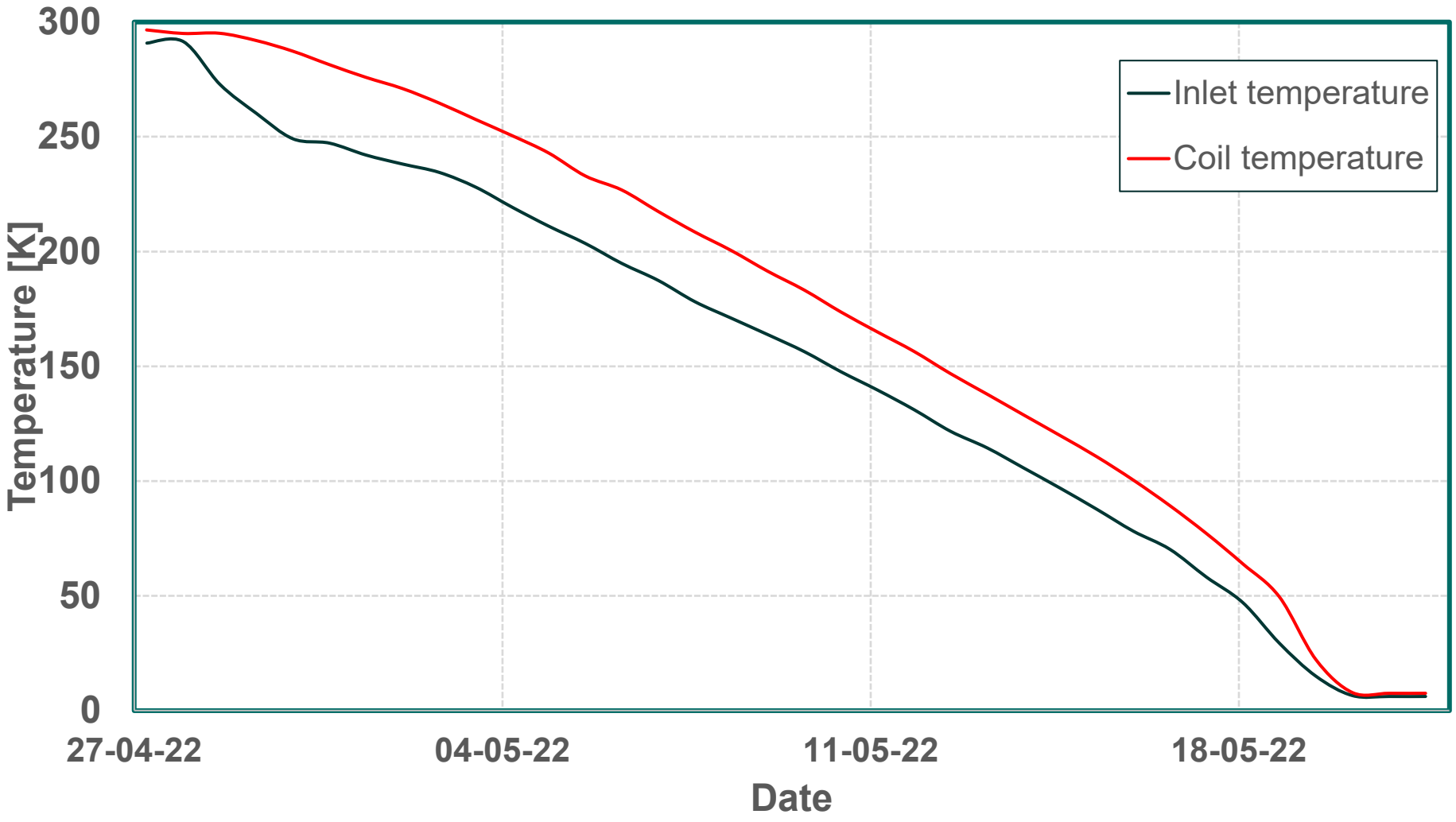
Physics Services – service oriented infrastructure for several physics computations

Foundation
Applications
Interfaces

Commissioning, overview

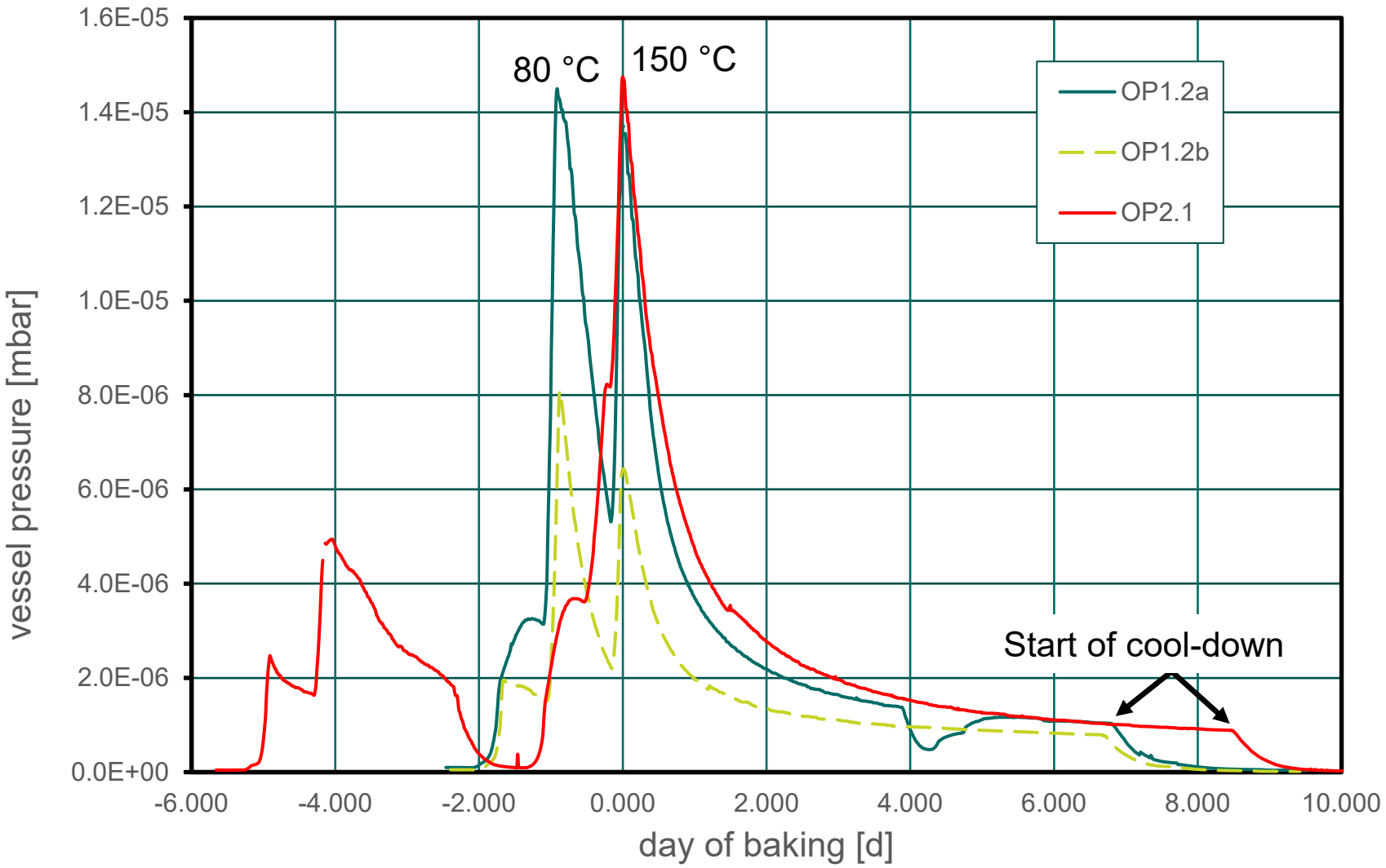
- Safety system (lSS and cSS) have been validated according to DIN/ISO 16511
- Cryostat and plasma vessel were pumped, some leaks on Cryostat vessel were repaired
- The Water cooling system (~580 circuits, 6800 m, 450 welding seams, 1500 screw joints) was checked for leaks, filled and adjusted for the required flow rates
- The cryo device was taken into operation again, all pipes were cleaned, before we cooled down the device to 4 K
- The divertor cryo pump has been cooled to 4K and tested with gas
- The magnet system has been tested, further configurations have been commissioned
- Baking of the plasma vessel to 150° C was successfull
- The boron cleaning system has been extended with a third cleaning system to improve the performance
- Last Saturday we have boronised the plasma vessel

Commissioning, Cryosupply



- 3 weeks cooling down
- temperature controlled
- Cryo supply also feeds the divertor cryo pump

Commissioning, baking the plasma vessel



- Baking in two steps to 80°/150 °C
- Mechanical measurement of the vessel and the basis
- For OP 2.1 baking has been extended by two days
- Volume pumped out during the baking: 1,8 X compared to OP 1.1

Conclusions

- W7-X is now ready for long discharges with high power heating,
- using many highly sophisticated diagnostic systems
- The device has been commissioned successfully.
- Physic preparation 27.09 – 17.11.
- The experimental programme will start 22.11.2022
- **Heating power will start cautiously, but the way is free!**

X. Litaudon et al., SOFT 2022