Preparation of Steady-State Operation of the

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Introduction

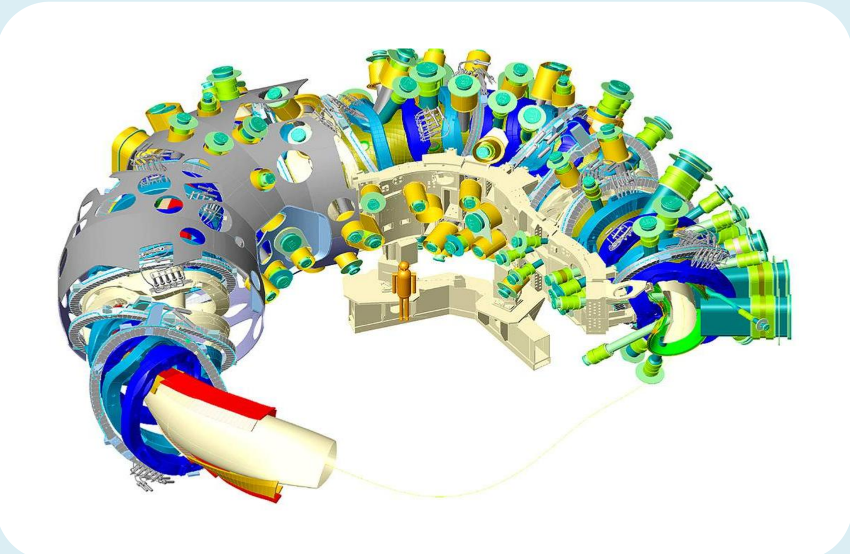
Optimized stellarator Wendelstein 7-X

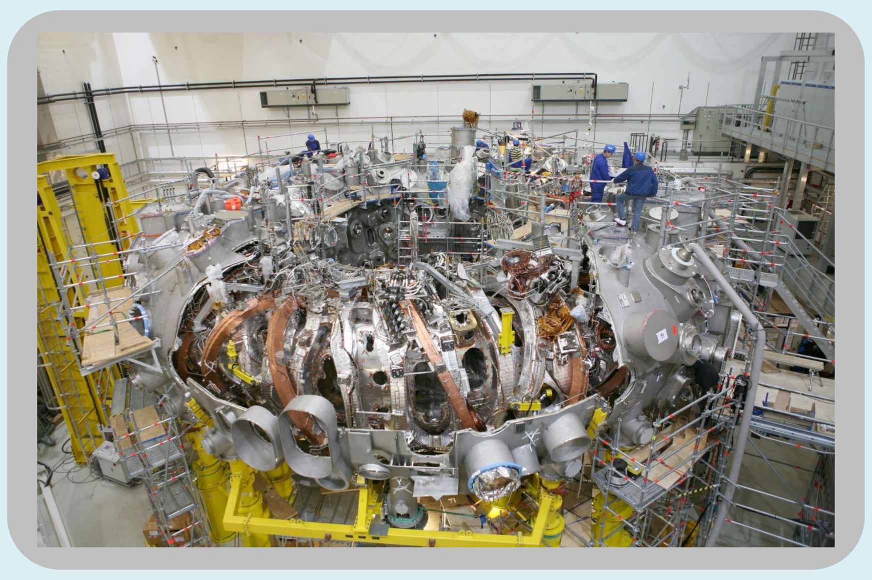
Drift-optimization for good fast ion confinement, improved neoclassical confinement

Minimized Pfirsch-Schlüter and bootstrap currents

Good equilibrium and stability properties at <β> = 5%

Low magnetic shear and ι = 1 at plasma boundary for resonant magnetic island divertor





Technical parameters

Magnetic field (superconducting):
3 T

Magnetic field energy:
900 MJ

Plasma volume:
30 m³

Pulse duration:
30 minutes

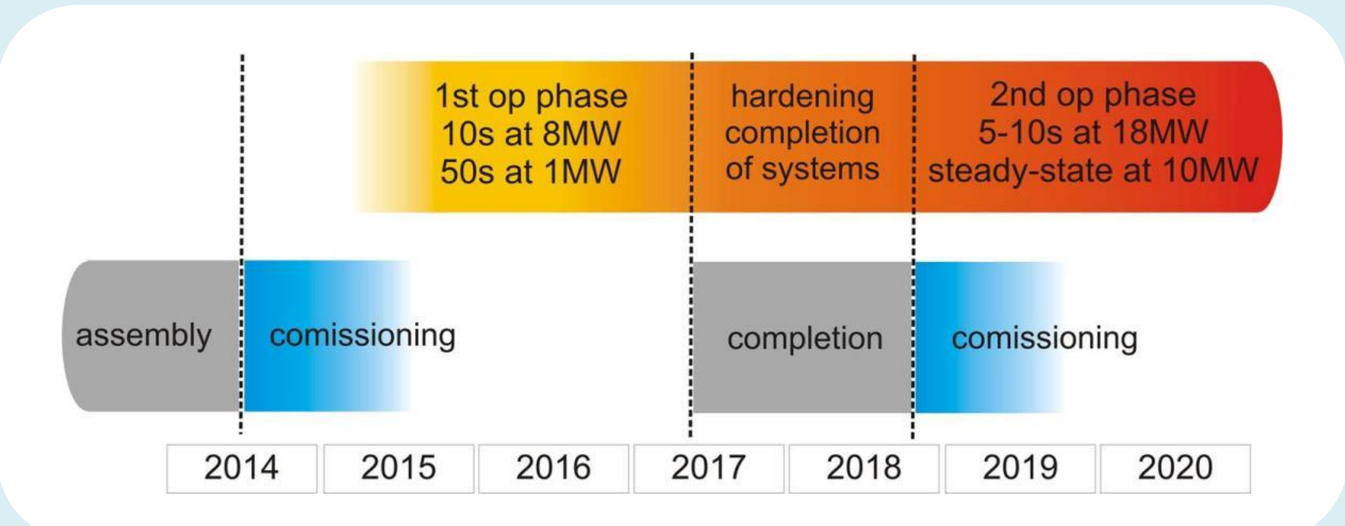
Heating power:
10 MW (30 MW)

Maximum heat load:
10 MW/m²

Characteristic time scales

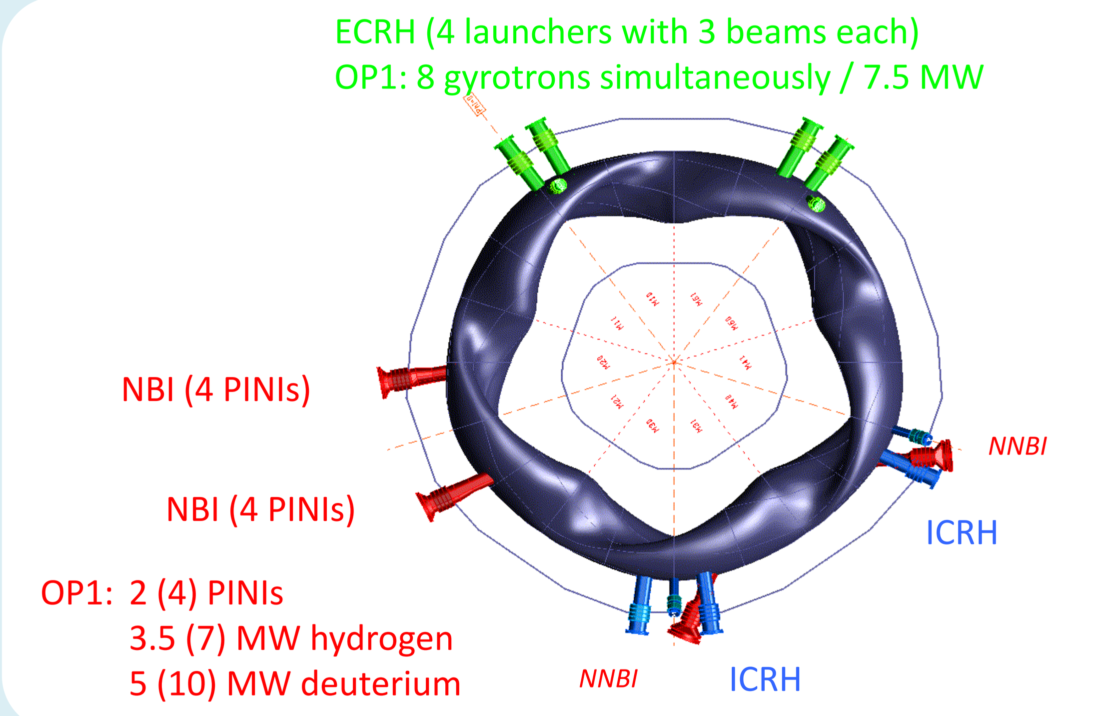
1st wall cooling equilibrium	1s
Gas inventory	seconds – hours
Erosion	months
Energy / particle confinement	100 ms
Fast ion slowing down time	100 ms
Establishment of a stationary equilibrium: L/R time	30 s

Assembly, 1st operation phase, 2nd operational phase



For "Technical Challenges in the Construction of the Steady-State Stellarator Wendelsetin 7-X" see talk by Bosch et al. Thursday, Oct 11th, FTP/3-1

Steady state heating



Steady-state (30 minutes)
ECRH /ECCD (10 MW)
140 GHz, 2.5 T

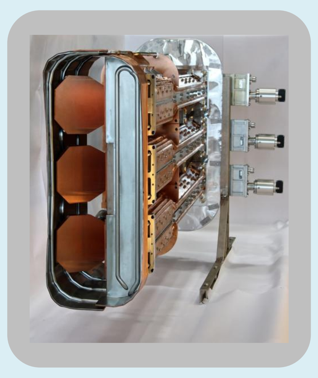
Pulsed (~ 10 s)
NBI (≤ 20 MW)
ICRH (~ 4 MW)

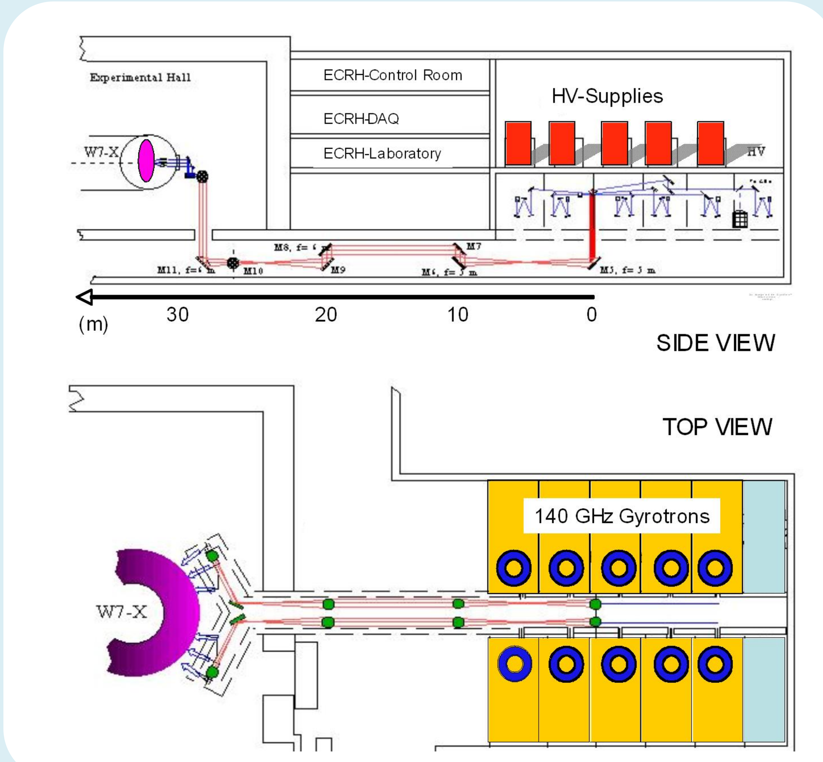
ECRH facility

Quasi-optical transmission line

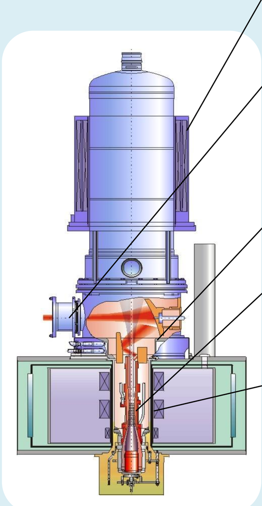
Overall losses ~ 7%

Front steering launcher





Improvement of gyrotrons

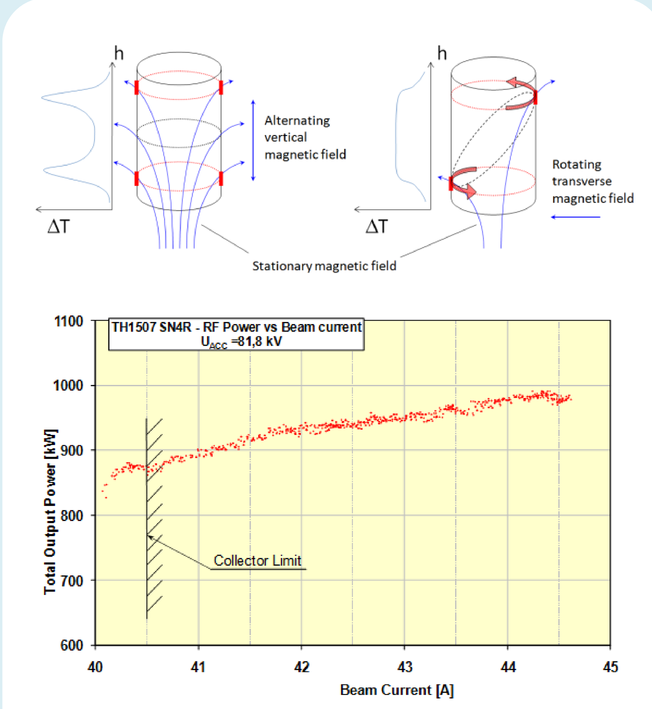


Collector sweeping improved: vertical + transverse 50 Hz, smooth power distrib.

Diamond Windows
Water- replaced by oil-Cooling (prevent long term corrosion)
Body-insulation improved (+ 30 kV)

e-beam tunnel improved
suppress parasitic oscillations

RF-absorption in gyrotron shaft reduced (temperature rise 7 deg/min limits pulse duration to < 30 min, cooling difficult, restricted repetition rate



≥ 1MW due to improved collector sweeping

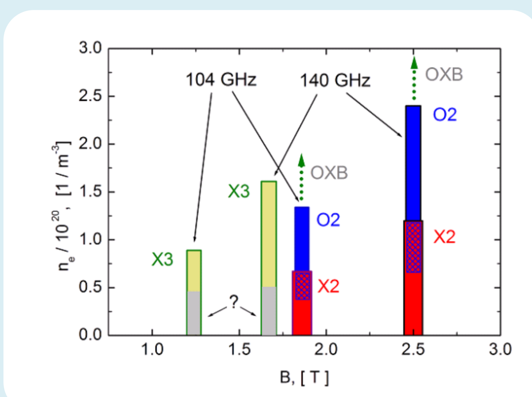
In addition, remote steering launcher from HFS

2 ports, 1 MW each; LFS ECRH: heating of bulk electrons; HFS ECRH: preferably coupling to fast electrons; owing to weak B-gradient in HFS launching plane tail in distribution function

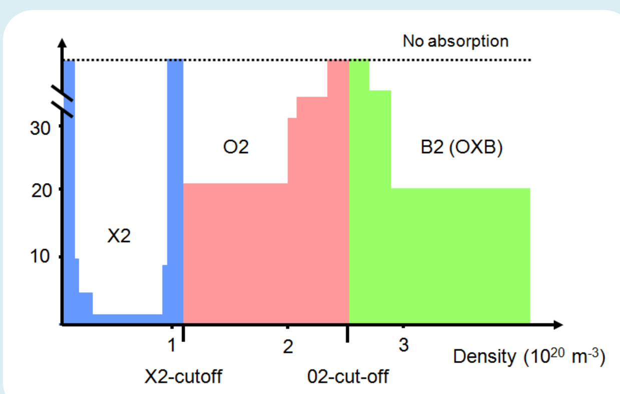
Comparison of confinement of different electron distribution functions directly related to W7-X optimization

Plasma heating scenarios

High density ECRH is essential for making use of the advantages of the stellarator (little or no CD requirements)



At 104 GHz, 1.8 T output power ~ 50%



O2, B2 require multi-pass absorption

Wendelstein 7-X Stellarator

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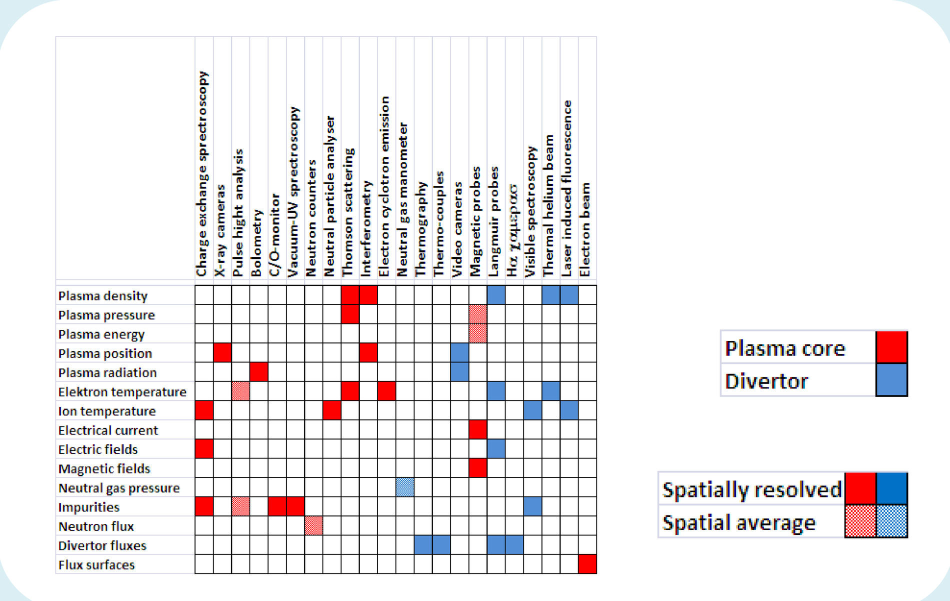
Steady-state diagnostics

Comprehensive diagnostic set



Steady-state operation adds a completely new level of complexity to the diagnostic requirements

Convective and radiative loads from the plasma onto plasma facing components

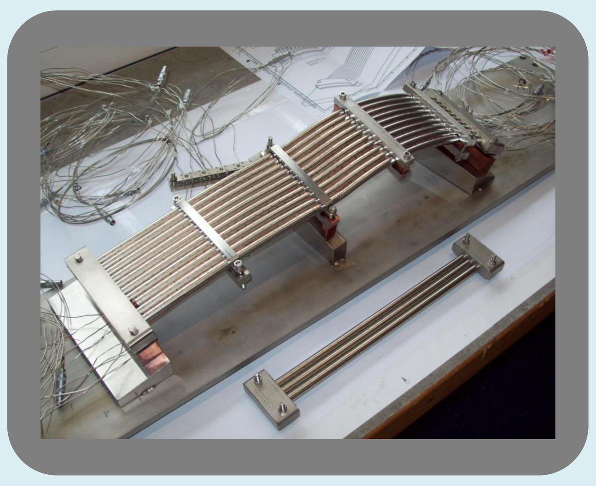
80 kW/m^2 plasma radiation

Dissipation by cooled stainless steel structures, cooled windows and apertures, where possible using pinholes

For non-continuous plasma observation use of cooled shutters

Stray radiation protection inside entire plasma vessel including ports

All in-vessel components qualified for 50 kW/m^2 corresponding to 1 MW of non-absorbed microwave power



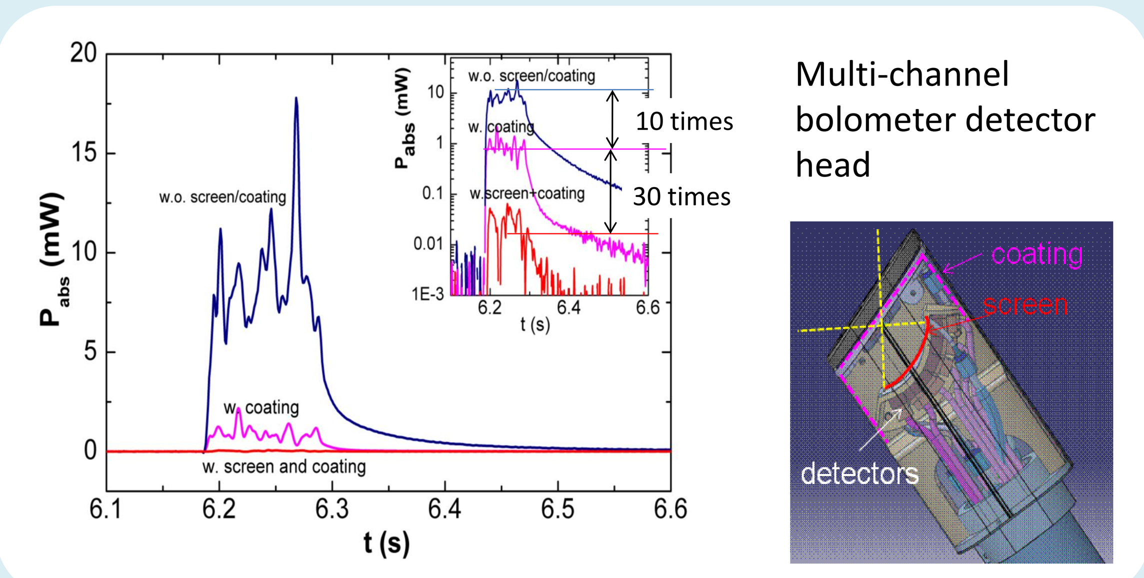
Segmented Rogowski coils

Stainless steel tubes for stray radiation protection

Wholes (Ø < λ) for vacuum pumping

Bolometer

Combination of microwave absorber (150µm-Al_2O_3/TiO_2, 83:17) and metal-mesh suppresses micro-wave effect by a factor of 300



Diagnostic specific issues

Windows, mirrors: Build-up of soft hydrocarbon layers

Dispersion interferometer (line integrated density): Insensitive against vibrations, slow temperature changes and capable of measuring fast density changes without loss of signal

Long pulse digital integrators for magnetic probes

Control and data acquisition

Segment based control framework

Short pulses, steady-state plasmas and arbitrary sequences of phases with different characteristics in one plasma pulse

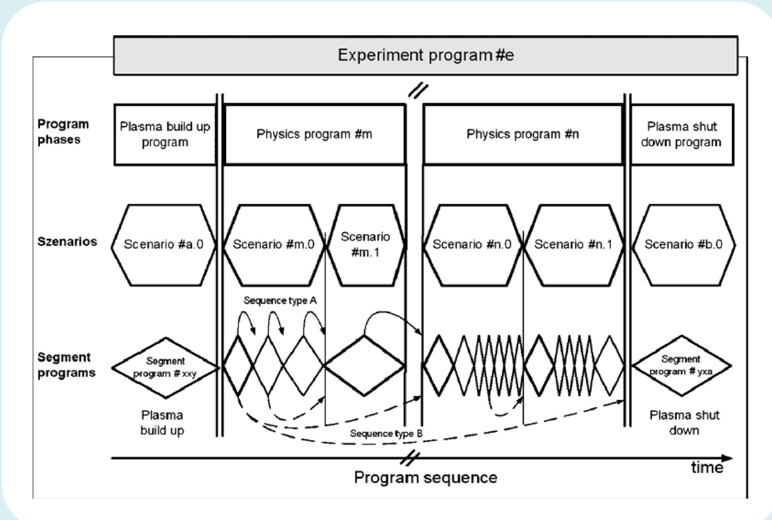
Scenarios subdivided into segments

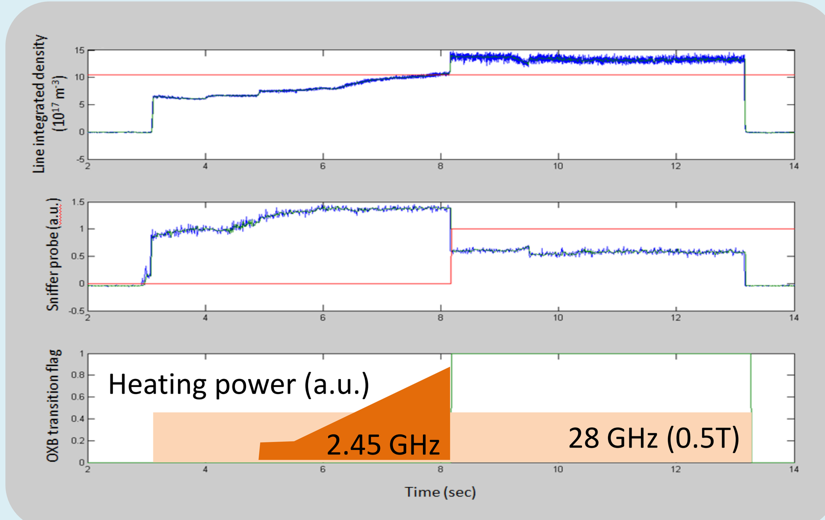
Segment programmes for components of plasma and device control

If segment is not ready for execution jump into “jump-in” segment

Variety of segment transition conditions (time, machine state, plasma state …)

Adaptive control segment switch conditions





Test on small stellarator WEGA

Event driven segment transition to Bernstein wave heating

Before transition non-resonant magnetron (2.45 GHz) & resonant gyrotron (28 GHz, 0.5 T) heating, after transition only gyrotron heating is applied

Switch-off of magnetron as soon as density threshold for OXB conversion is reached, indicated by drop of stray radiation signal (sniffer probe)

Data acquisition

Steady-state requires supervision of PFCs (visible and IR)

~ 30 Gbyte/s; ~ 50 Tbyte/30 minutes

Acquired data are immediately written onto network devices

One data stream for online data analyses and monitoring purposes and a second one for data archiving.

The data acquisition software development is particularly demanding with respect to the reliability of the software for steady-state operation

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