Wendelstein 7-X

A technology step towards DEMO

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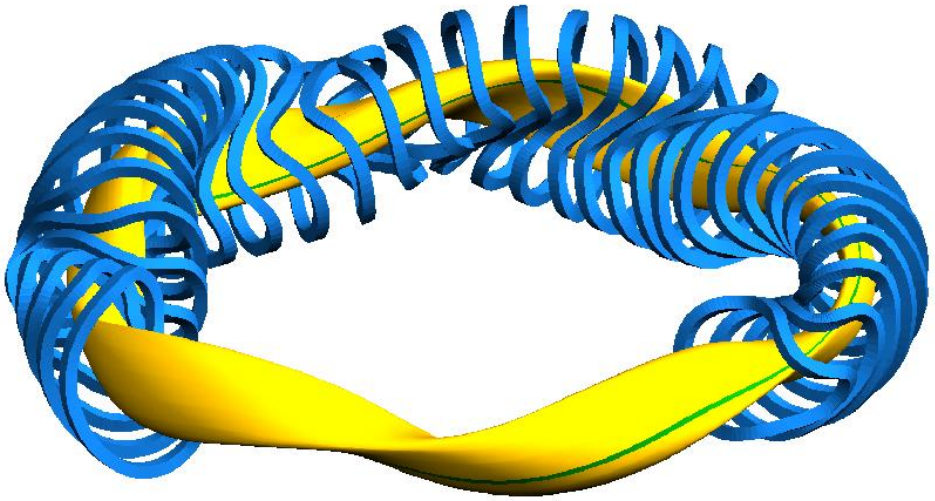
The optimized stellarator W7-X

- **Research and development tasks**
  - ⇒ steady state operation
- **Technological developments towards DEMO**
  - superconducting coils, current leads, …
  - steady state heating
  - steady state exhaust
- **Fabrication and Assembly**
  - assembly process
  - status
- **Outlook**

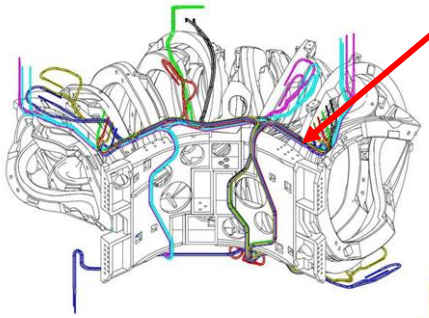
Wendelstein 7-X

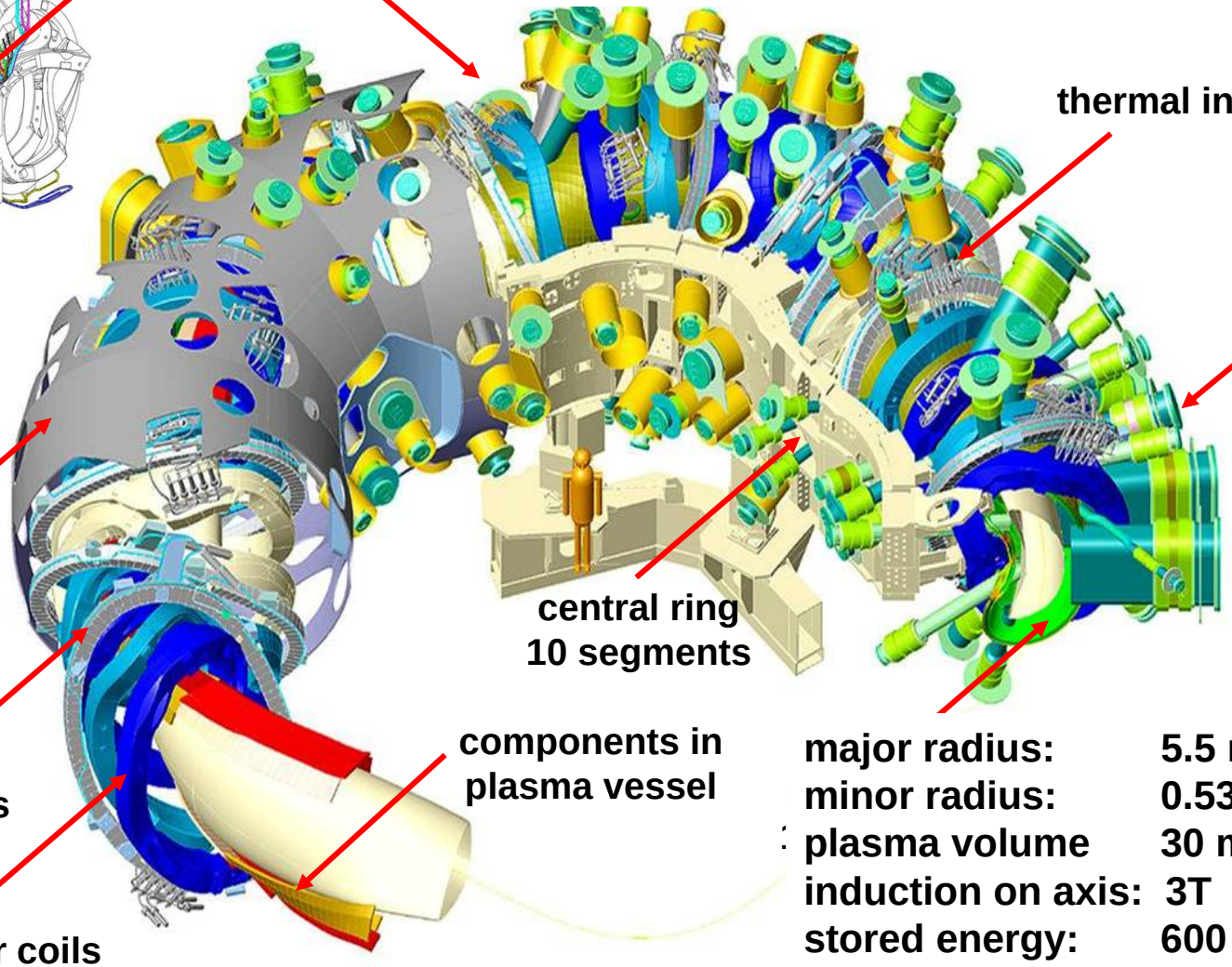


seven optimization criteria

1. **feasible modular coils**
2. **good, nested magnetic surfaces**
3. **good finite-β equilibria**
4. **good MHD stability**
5. **small neoclassical transport**
6. **small bootstrap current**
7. **good confinement of fast particles**

Wendelstein 7-X main components



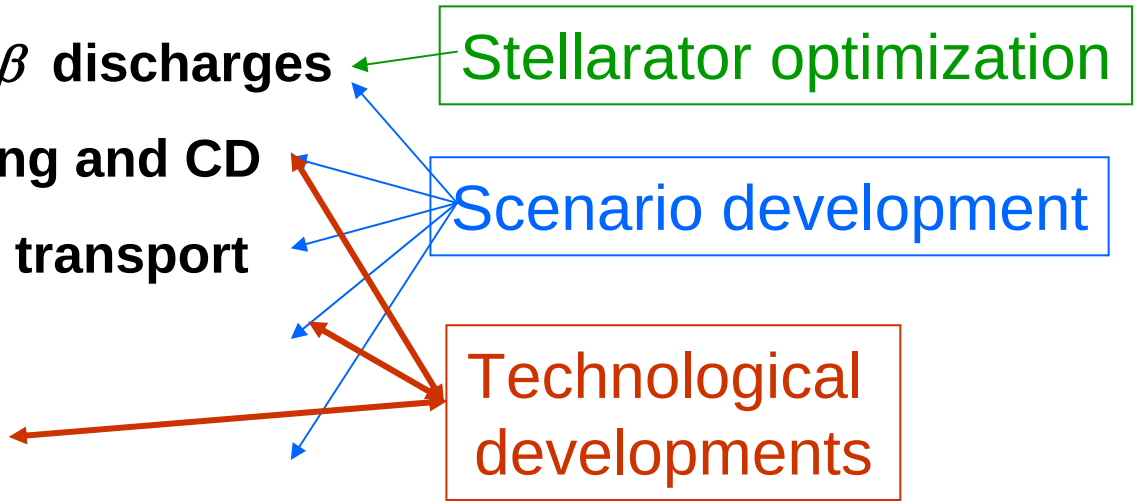


major radius:	5.5 m
minor radius:	0.53 m
plasma volume	30 m^3
induction on axis:	3T
stored energy:	600 MJ
machine mass:	725 t

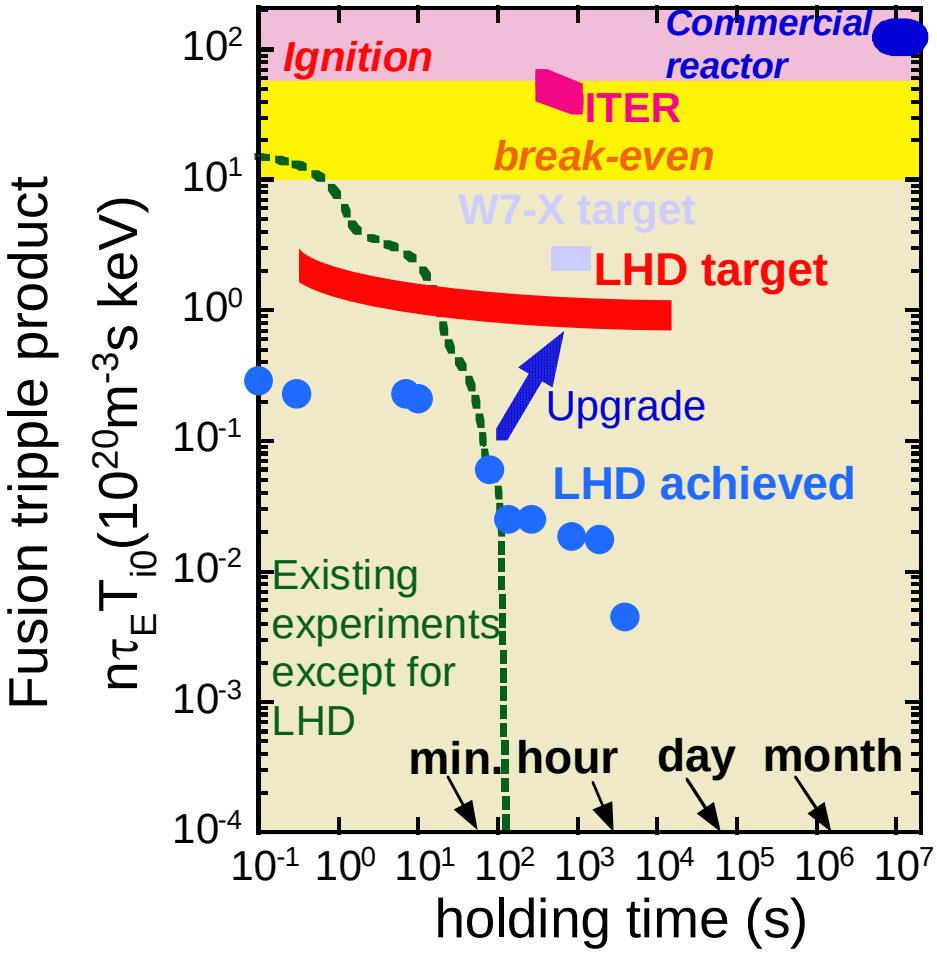
Research tasks of W7-X

five main development tasks

1. **optimum $nT\tau_E$ and high β discharges**
2. **High density, ECR heating and CD**
3. **impurity generation and transport**
4. **island divertor**
5. **steady state operation**



Steady state operation



Technological developments

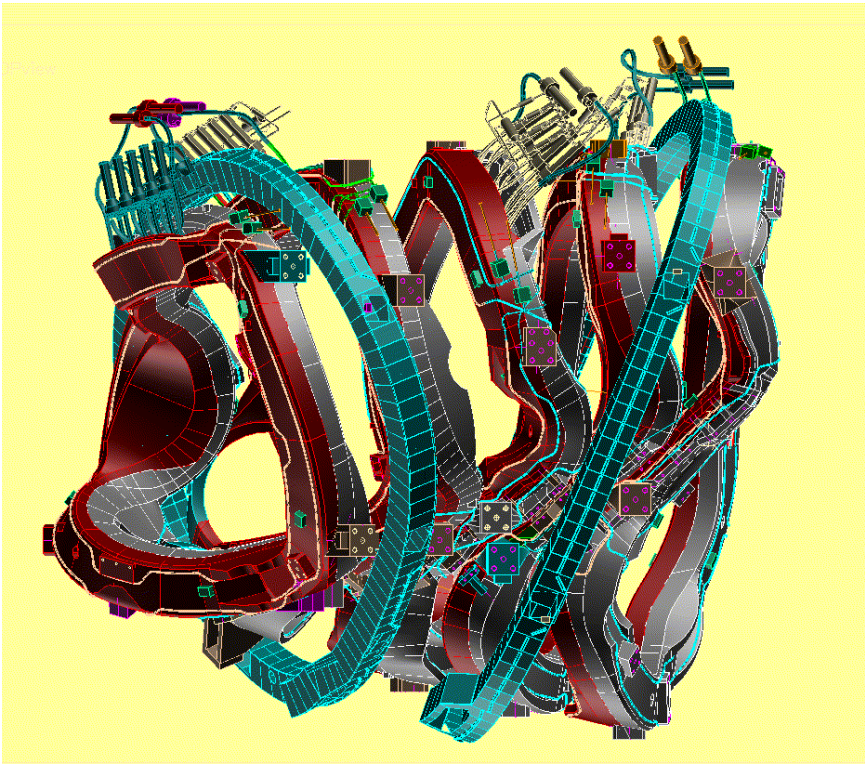
- **superconducting coils**
- **steady state**
  - **~ heating**
  - **~ exhaust**
  - **~ diagnostics**
  - **~ control**
  - **~ data acquisition**

Coil system

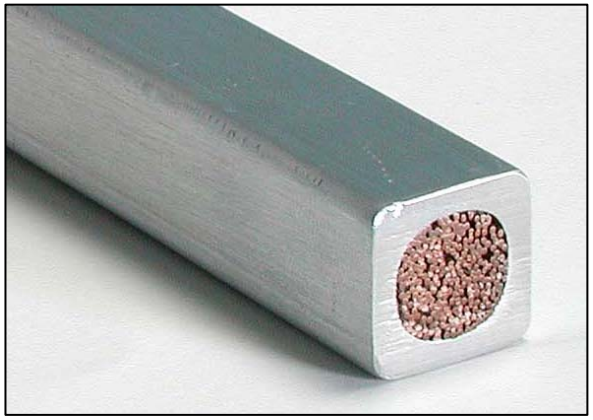
Symmetry of the device:
- five periods (modules)
- 2 flip-symmetric half-modules

In one half-module:
- 5 different non-planar coils
- 2 different planar coils Spulen

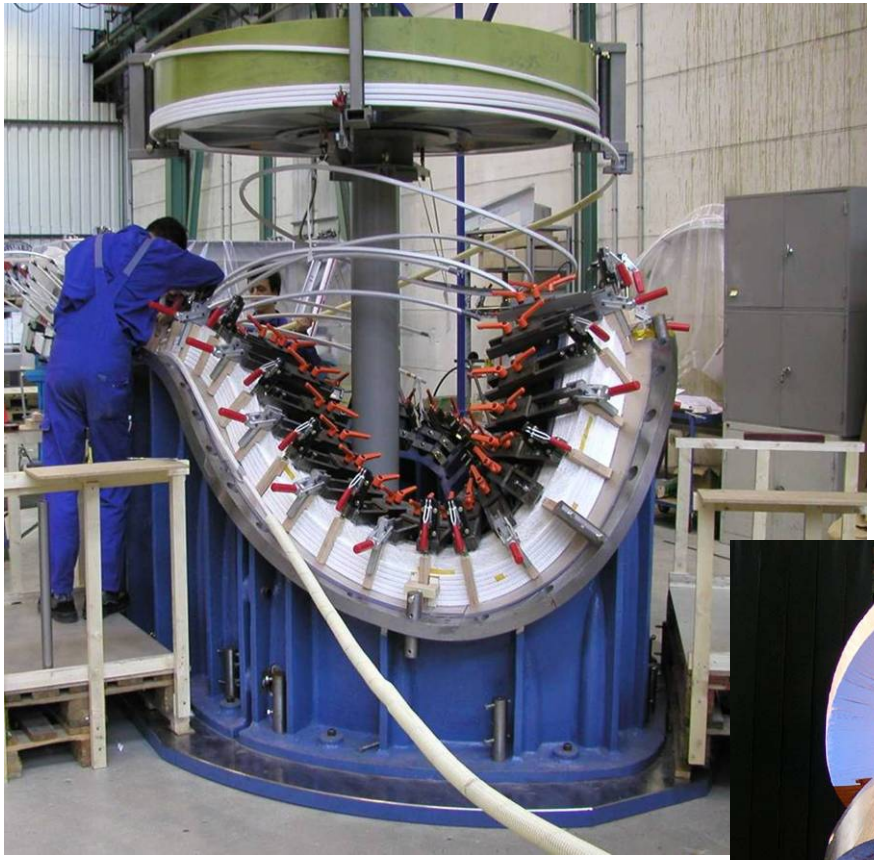
70 coils of 7 types



common superconductor:
- 243 single NbTi/Cu strands
- cable-in-conduit conductor
- He-cooling through the voids
- soft Al-alloy for winding accuracy



Non-planar coils



Non-planar coils

Coil tests under cryogenic conditions

CEA Saclay, France:

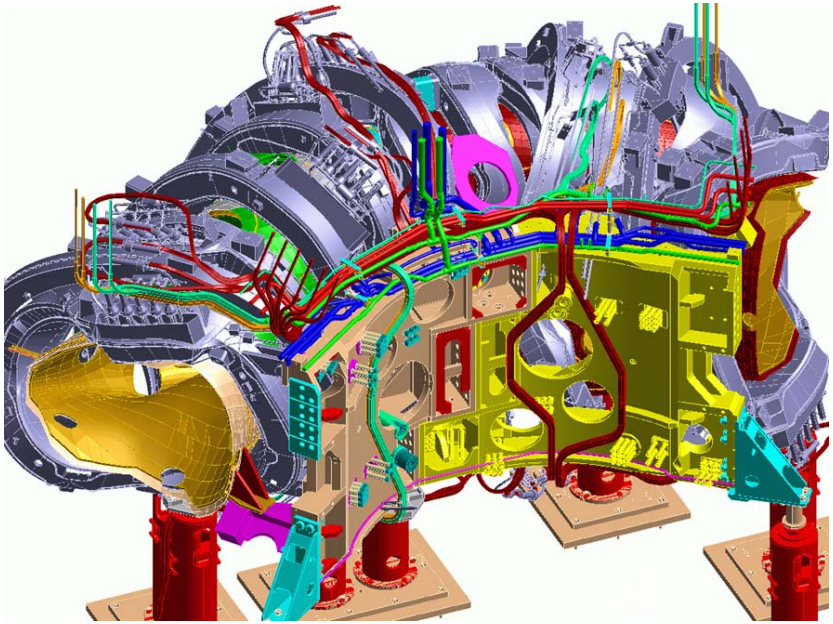
- Tests at 5K
- Thermal properties
- Cold leak tightness
- Helium flow rates
- Electrical insulation
- Superconductivity

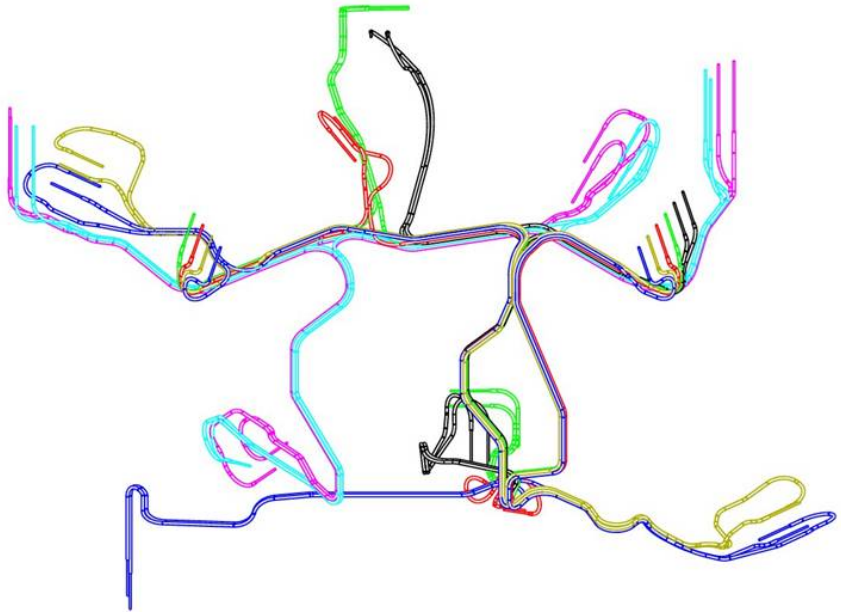
Paschen testing of coils

- critical scenario: air influx into outer vessel causes pressure increase and quenching of a coil
- High voltage @ increased pressure ⇒ Paschen discharge?
- Therefore all coils are tested under Paschen conditions (between 0.001 and 100 mbar) with 6 kV
- This has proven to be a valuable measure to verify insulation quality.

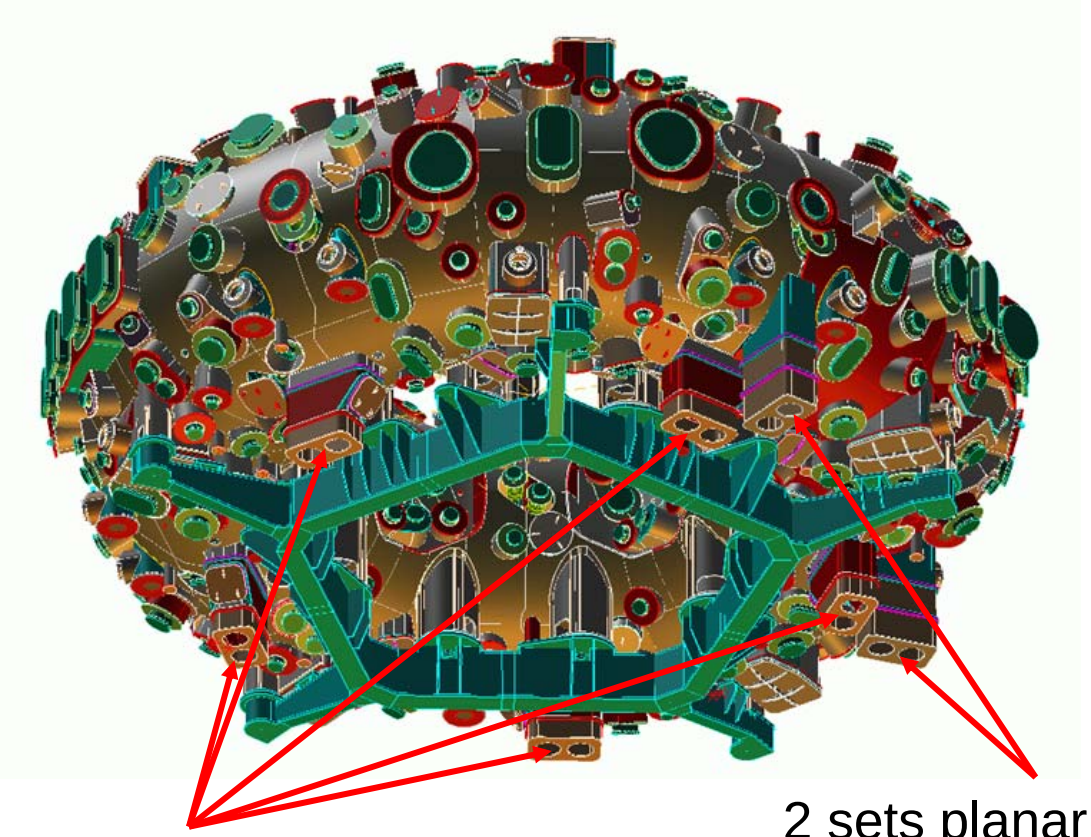
Busbar system (FZJ)

- Superconducting bus-bar system
  - between coils
  - and between coils and power supplies
- bifilar winding to avoid error fields
- design and qualification in FZ Jülich finished, fabrication ongoing





Current leads (FZK)



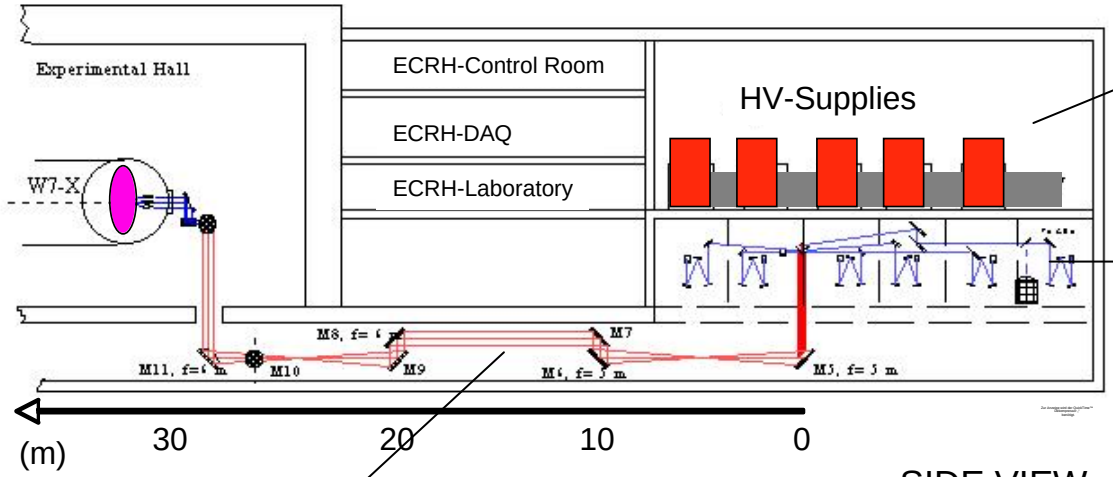
5 sets non-planar coil CL's

2 sets planar coil CL's

- 7 independently controlled coil groups
- large flexibility in magnetic configuration
- 7 pairs of current leads
- power supplies in the basement
- CL "upside down"

- Design and manufacturing by FZ Karlsruhe
- The design has been approved
- A prototype will be manufactured in 2009

Steady state ECRH



SIDE VIEW

HV-Modules

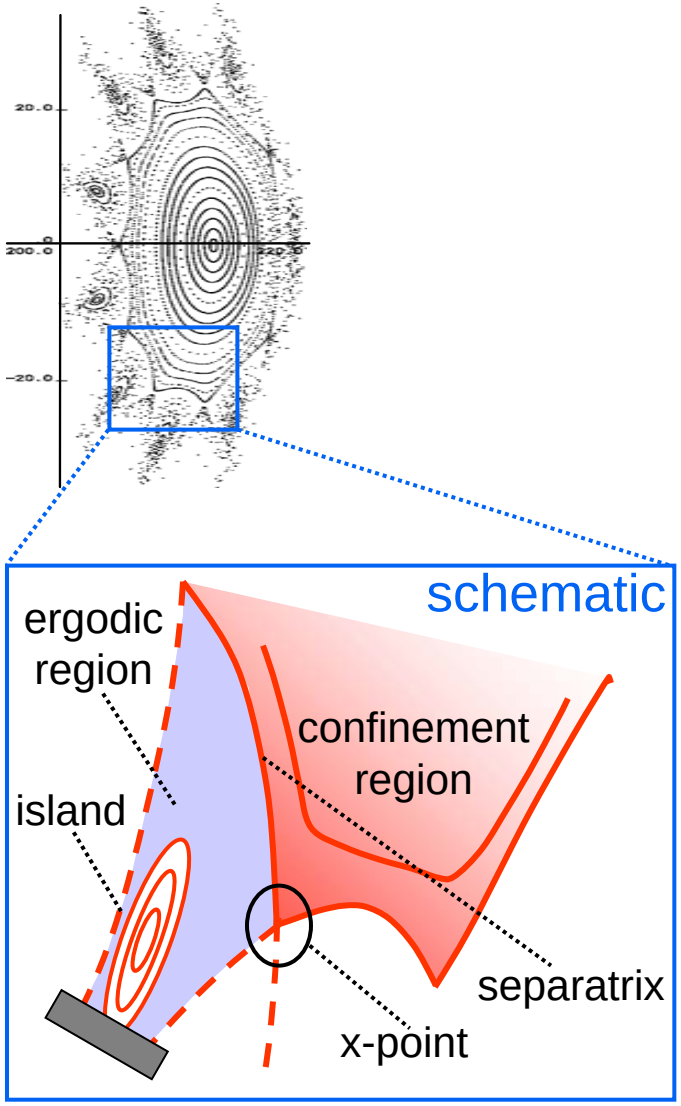
Gyrotrons and Single Beam Section

Multi-Beam Section

M. Thumm
I-13, Wed

The W7-AS island divertor

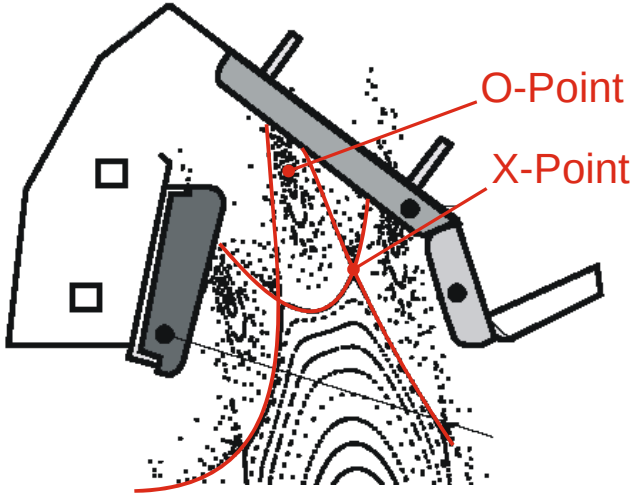
elliptical plane



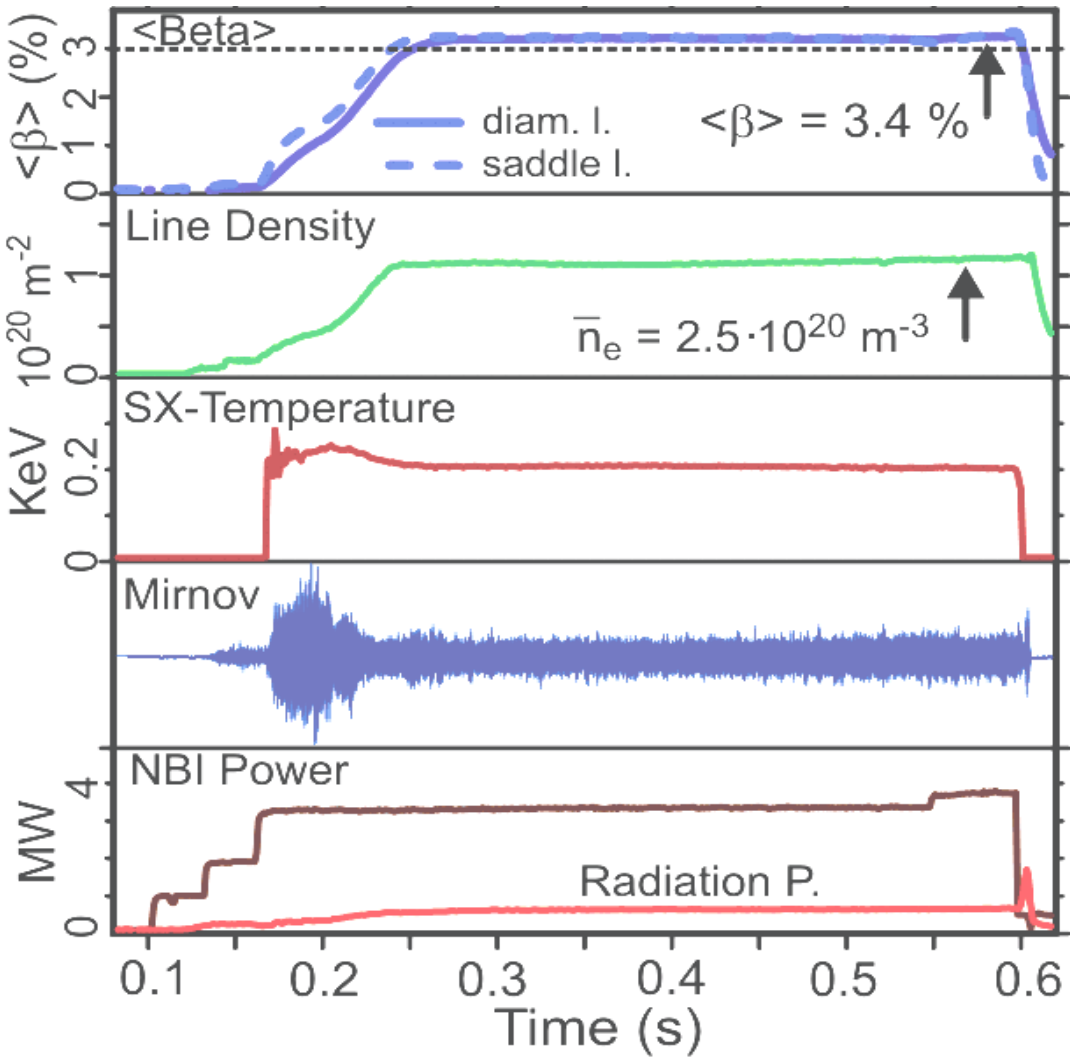
key idea:

natural islands are intersected with target

Technical realisation:



The HDH-mode in W7-AS



high pressure $\beta = 3.4\%$
$\beta_N \sim 9.3$

high density $n_e = 2.5 \cdot 10^{20}\ m^{-3}$
$n_e/n_{eGW} = 2.5$

confinement $H_{ISS95} = 1.4$

MHD stability

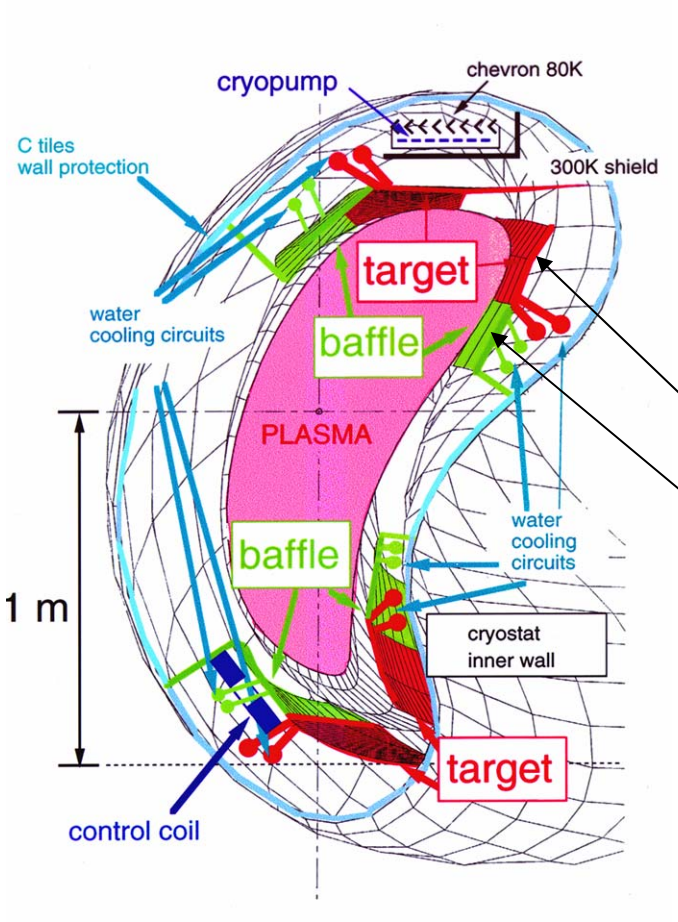
absorption $P_{abs} = 2.5$ MW

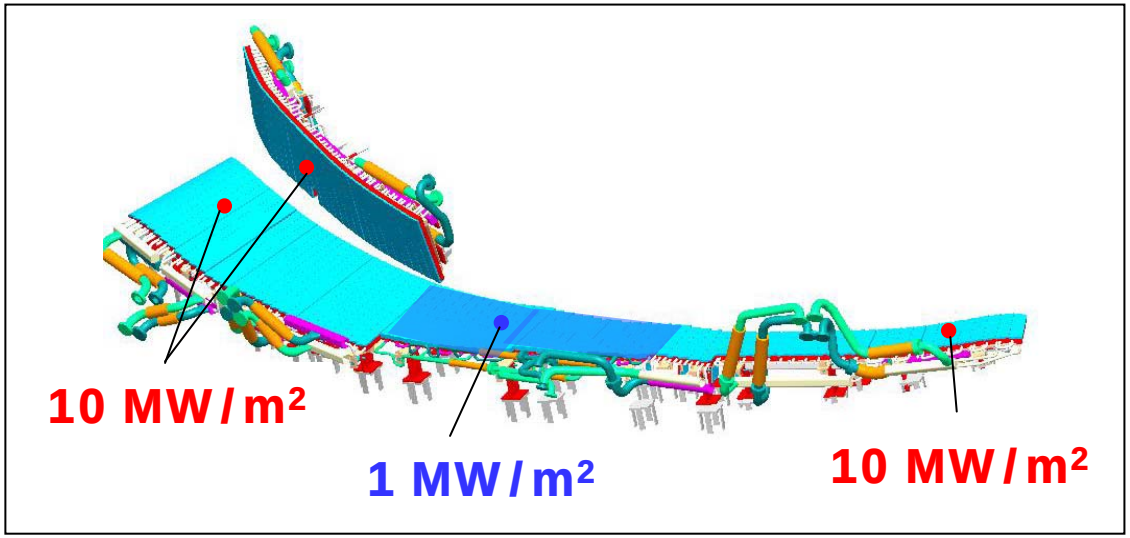
stationarity $T_{flattop} \sim 100\ \tau_E$

Divertor operation is essential for HDH-mode

W7-X in-vessel components

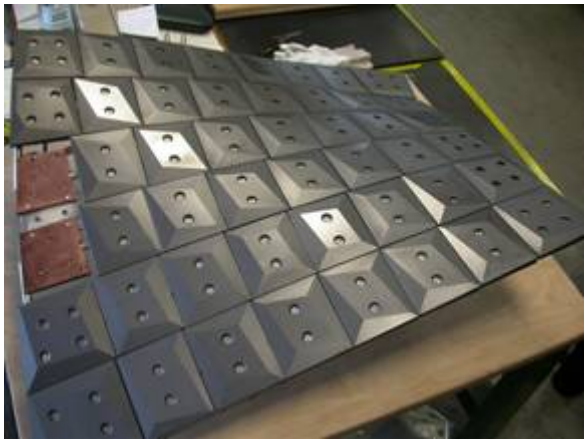
R. Stadler
I-24, Thur





- target elements (10 MW/m^2)
- baffles (1.0 MW/m^2)
- first wall B_4C (0.2 MW/m^2)
- control coils
- cryo pumps
- Instrumentation and diagnostics
- about 1 Million parts

In-vessel components, status

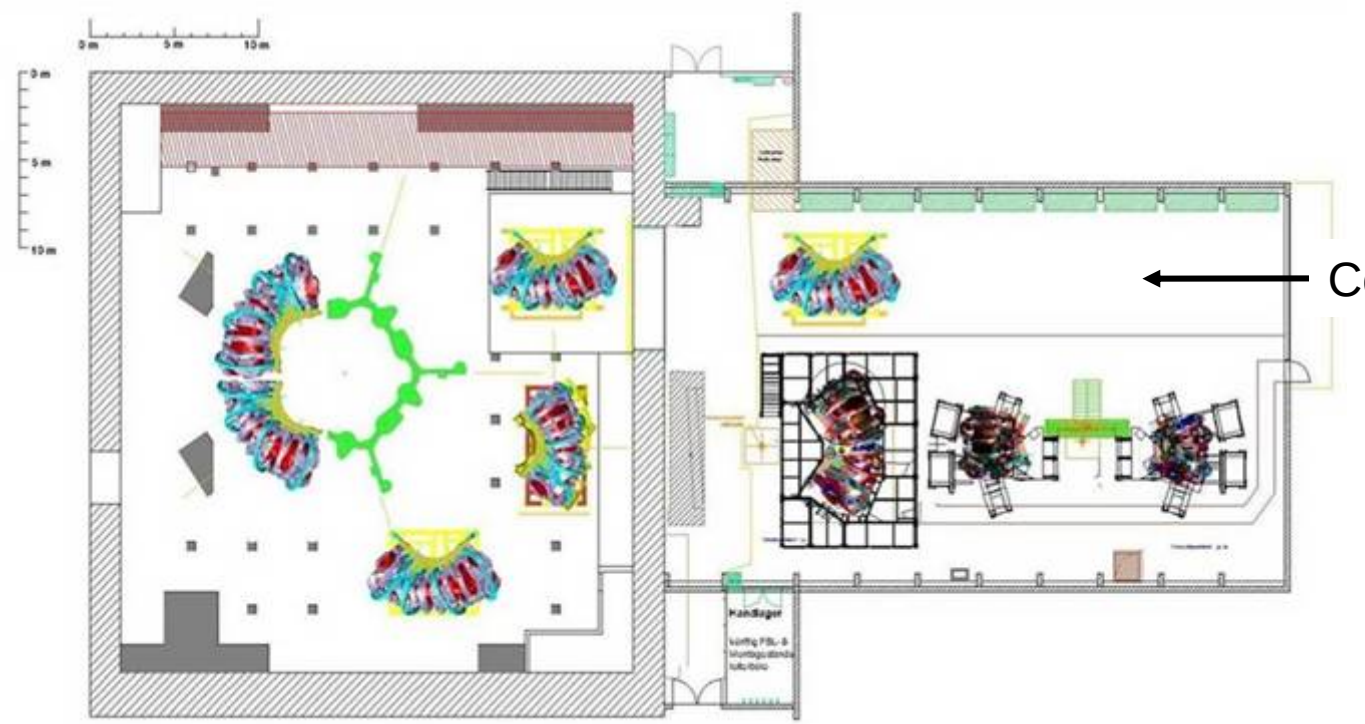


Target plates
- prototypes finished
- manufacturing about to start

heat shields
- 50% of these components are manufactured
- The graphite tiles are also in manufacture

vall panels
200 panels from a total of 320 panels have been delivered by MAN DWE (Germany)

Pre-assembly, I



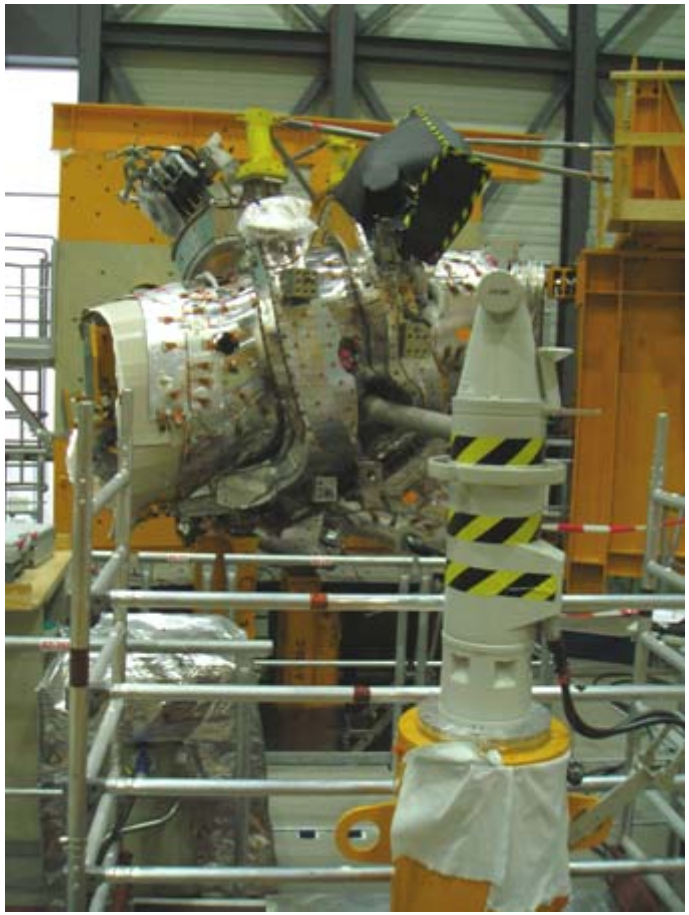
Final Assembly in the Torus Hall; 900 m²

Pre-Assembly Hall

- The module assembly is carried out on 8 different Mounting Stands (MST)
- Preparation of components is organised independently from the assembly activities
- Assembly area ~ 1600 m²; component preparation and storage ~ 4000 m²

Pre-assembly, I

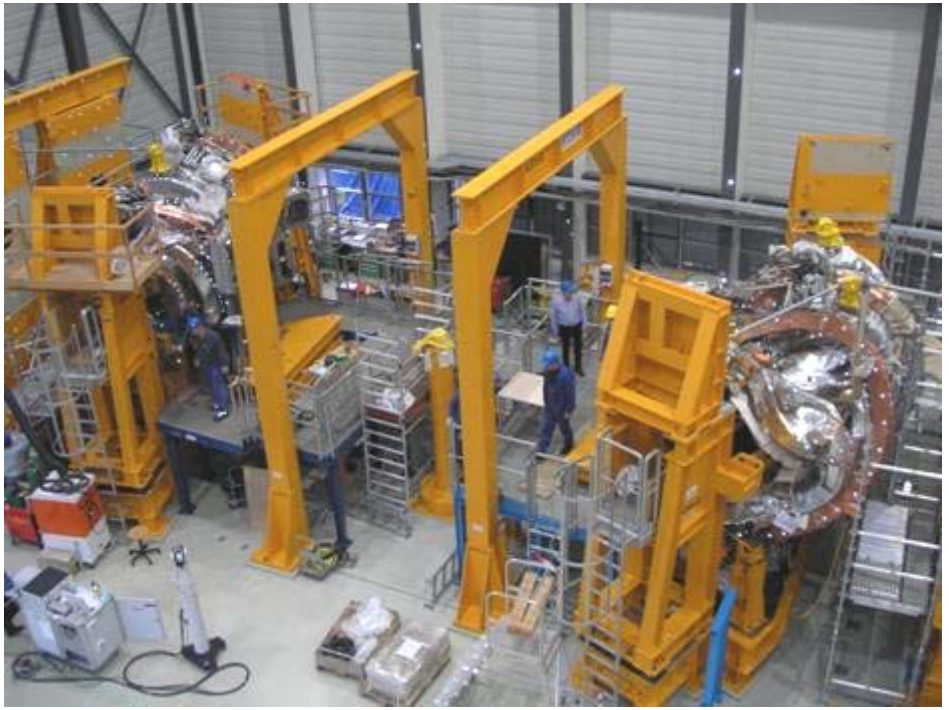
Coils are threaded across the plasma vessel



Insulation is completed

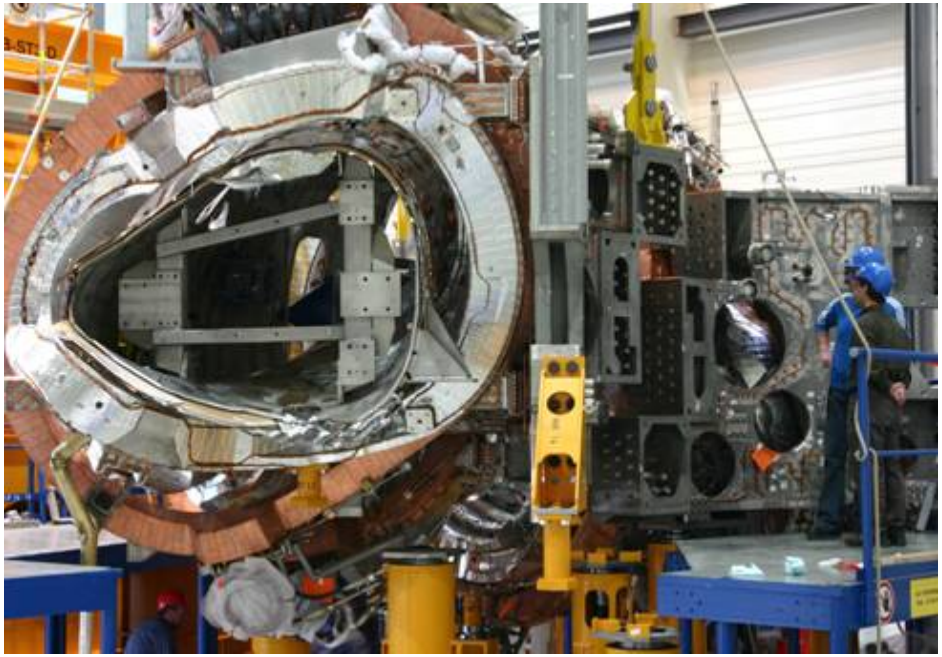
Pre-assembly, II

- The coil support structure is positioned in front of the 7-coil pack
- Central supports are shimmed and bolted



Two flip-symmetric half modules are ready

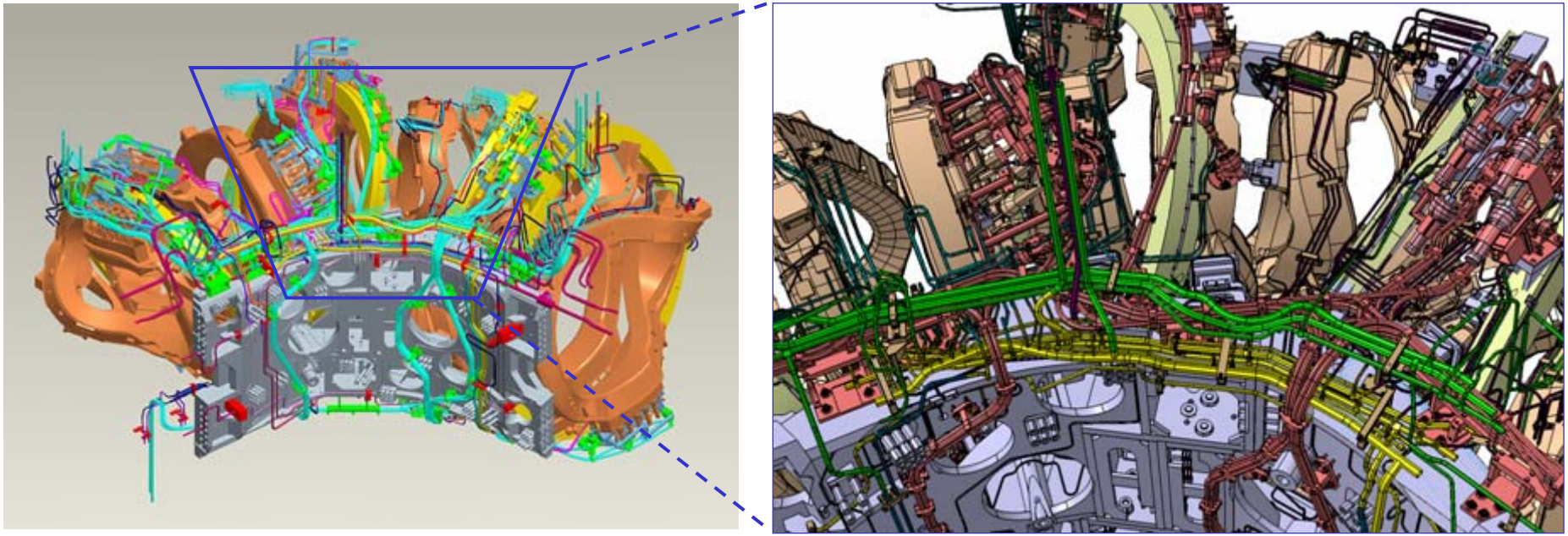
Pre-assembly, MST II



- The flip-symmetric half-module is aligned
- The stairs-flange is screwed together
- Fitting pins
- Both vessel half-modules are welded
- Thermal insulation
- Inter-coil structure

- Trial assembly of 24 bus-bars
- Bus-bar ends are adapted to the position of the coil terminals
- 200 supports for cryo-pipes are mounted
- The first batch of helium pipes is installed
- Layers of pipes and bus-bars are stacked above each other

Pre-assembly, MST III

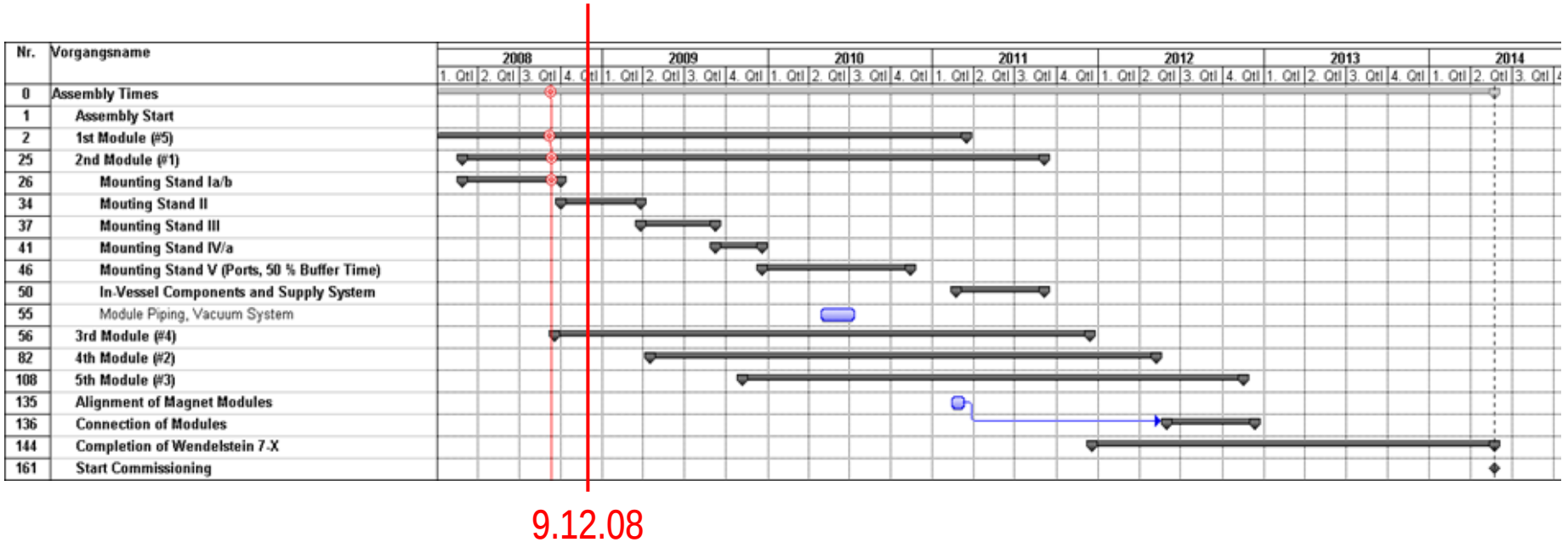


- Helium pipes are positioned and welded
- Bus-bars are finally installed
- 28 electrical joints are welded
- Instrumentation cabling
- Comprehensive collision checks during design, layout and installation neccessary

Final assembly

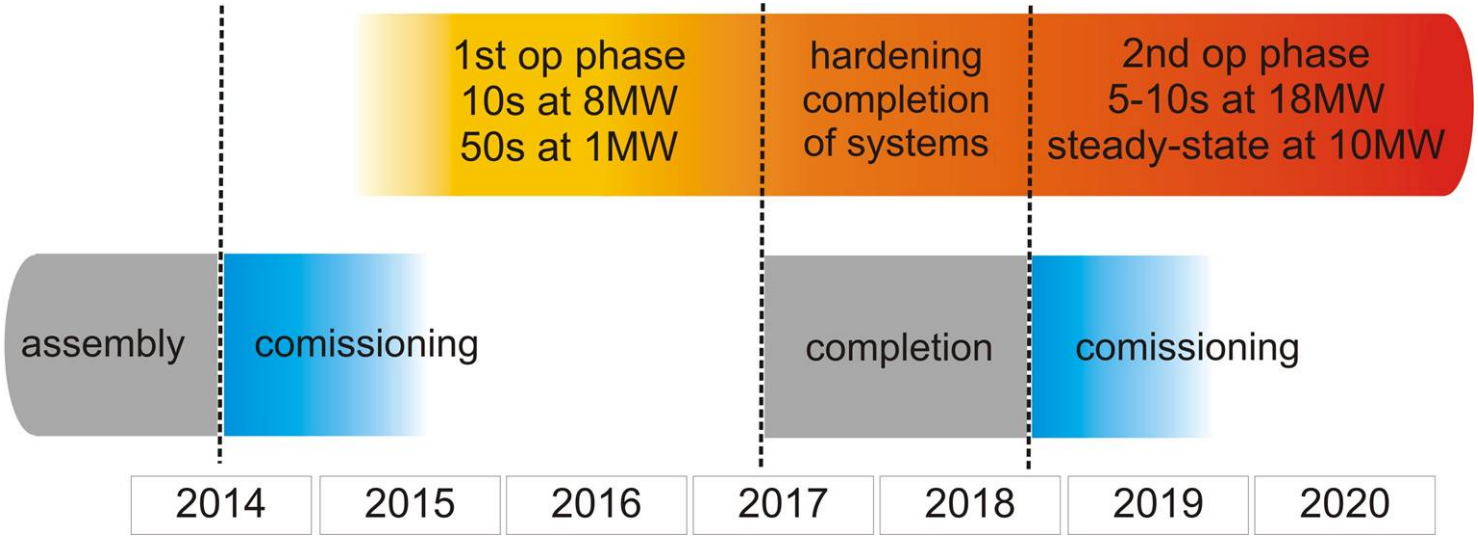
- Lower shell of outer vessel to be positioned on machine base,
- Installation of thermal insulation.
- Magnet modul lifted into lower shell
- Outer vessel module closed with upper shell
- Assembly of ports
- Connection to modules to torus

Schedule



- The module assembly is organised in parallel
- Three out of 5 modules are in the works
- The assembly schedule contains approximately one year buffer times
- Assembly will be finished in summer 2014

The start of exploitation



- **1st operation phase with 10s @ 8MW and 50s @ 1MW**
- **inertially cooled divertor and only partial cooling of in-vessel comp‘s**
- **shut-down (15 months) for completion and hardening**
- **2nd operation phase to approach 30min @ 10MW**
- **3rd operation phase with 10MW ECRH, 20MW NBI and 10MW ICRH**