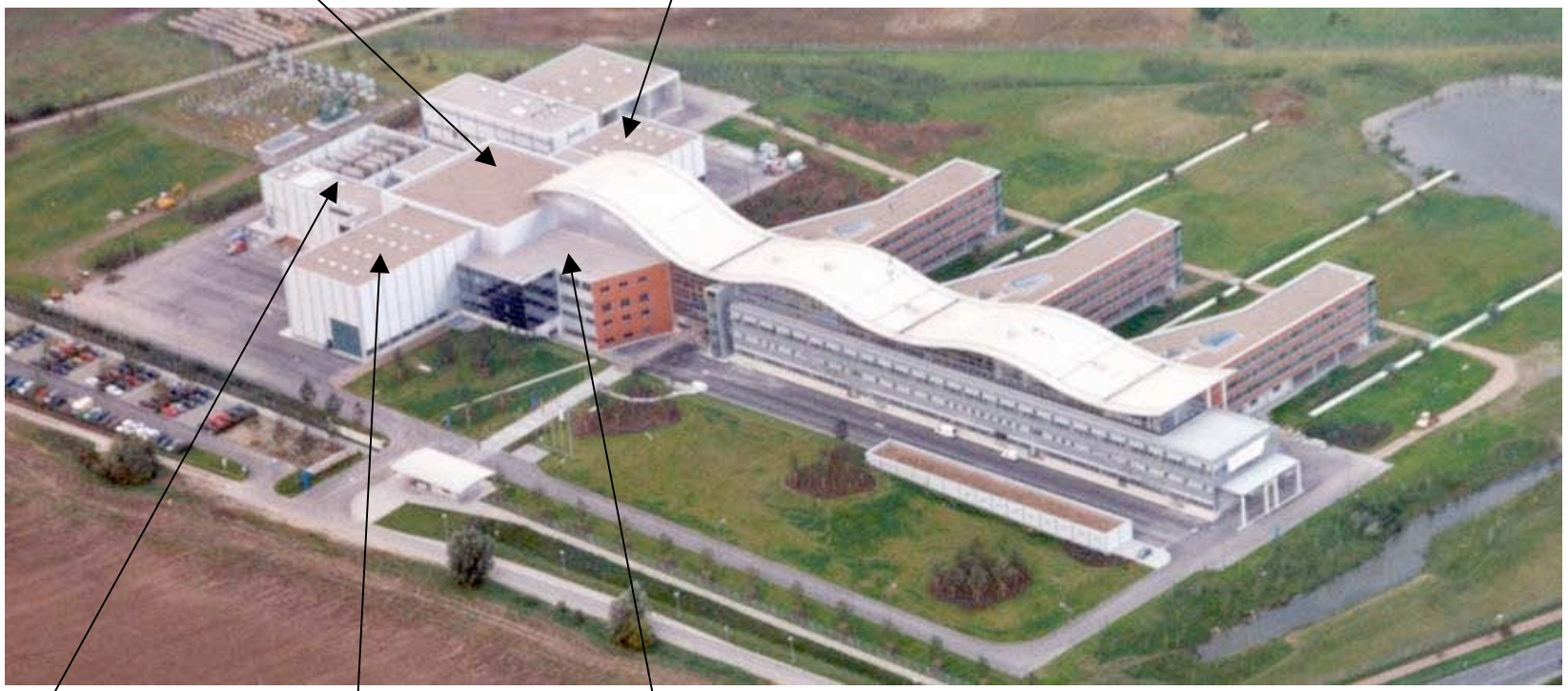
WENDELSTEIN 7-X
Overview and Status of Construction

H.-S. Bosch on behalf of the W7-X team

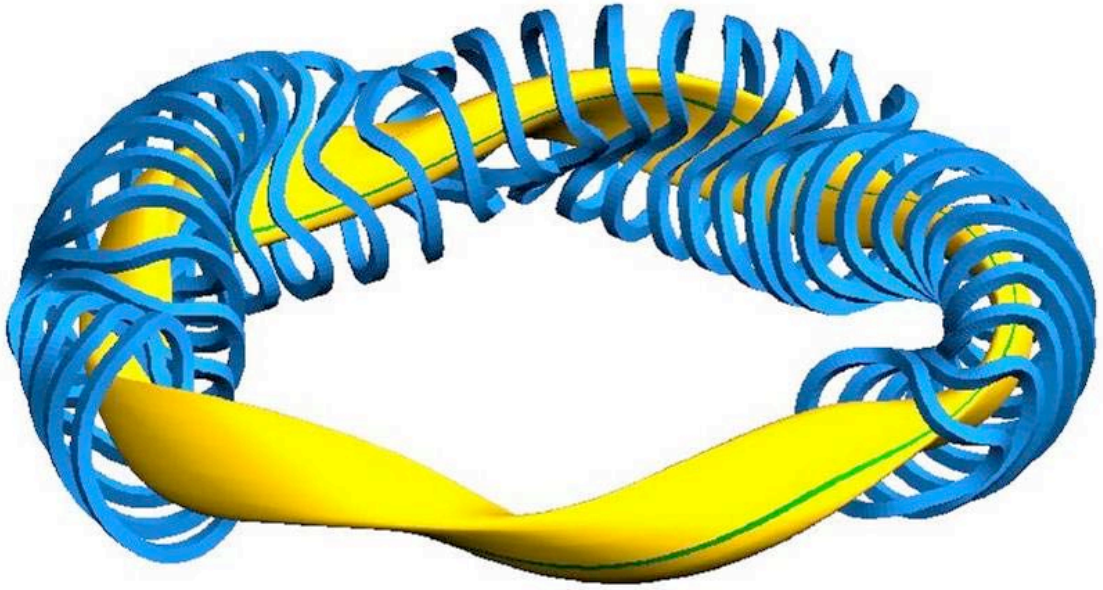
Max-Planck-Institute for Plasma Physics,
IPP-Euratom Association, D-17491 Greifswald

- **Introduction**
- **overview of W7-X device**
- **assembly of W7-X**

IPP at Greifswald



Stellarator WENDELSTEIN 7-X, the physicists view



Stellarators

only external coils required
to create the magnetic field
+ no current-driven MHD
+ steady state operation
  intrinsically available
- loss of axisymmetry

Latest step in the IPP-line of stellarators
EURATOM approval in March 1996,
new buildings in Greifswald opened in 2000

Scientific goals of W7-X

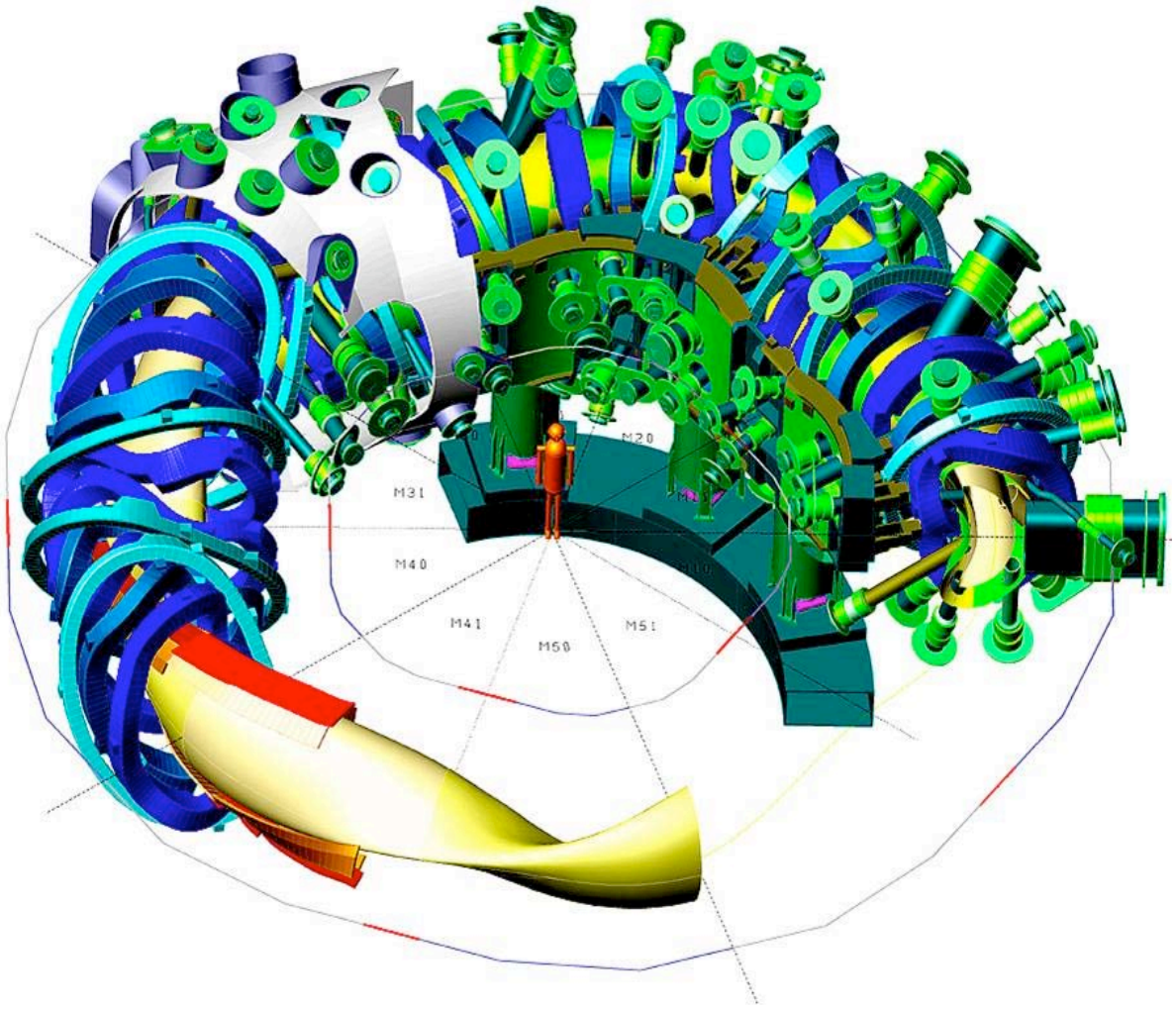
- Demonstrate the stellarator`s reactor potential
- steady state operation ⇒ superconduction magnet system, cw heating

Stellarator WENDELSTEIN 7-X, the engineers version

some parameters

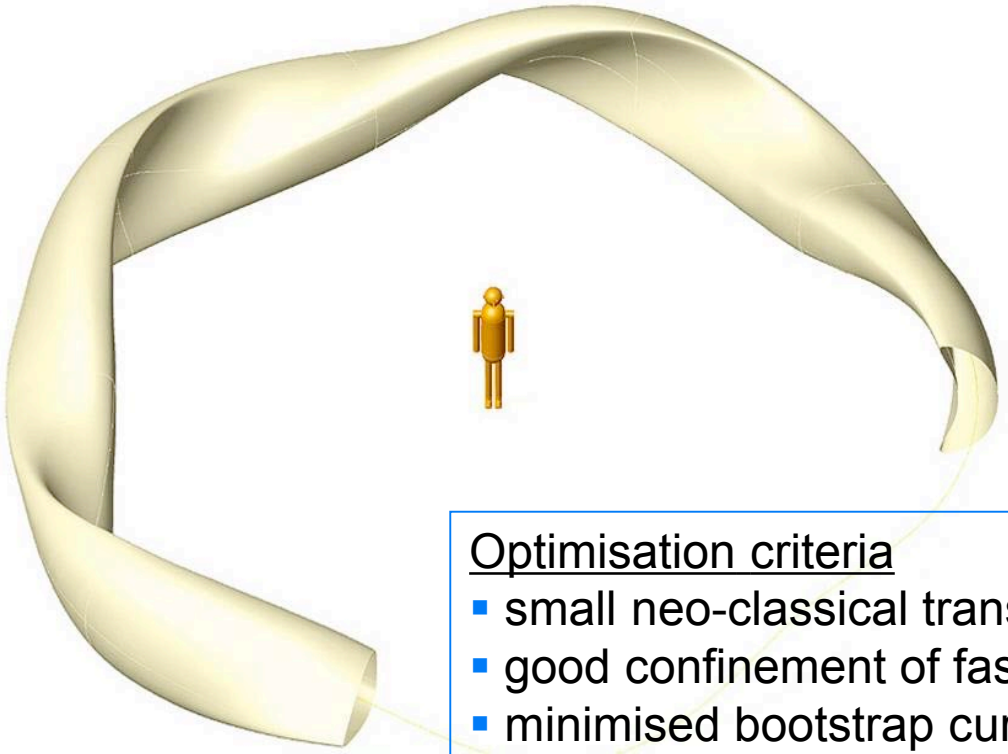
Major radius: 5.5 m
Minor radius: 0.53 m
Plasma volume 30 m^3
Non-planar coils: 50
Planar coils: 20
Number of ports: 299
Rot. transform: 5/6 - 5/4
Induction on axis: < 3T
Stored energy: 600 MJ
Heating power 15 - 30 MW
Pulse length: 30 min
Energy turn around: 18GJ

Machine height: 4.5 m
Machine diameter: 16 m
Machine mass: 725 t
Cold mass: 425 t



WENDELSTEIN 7-X
plasma and magnetic field

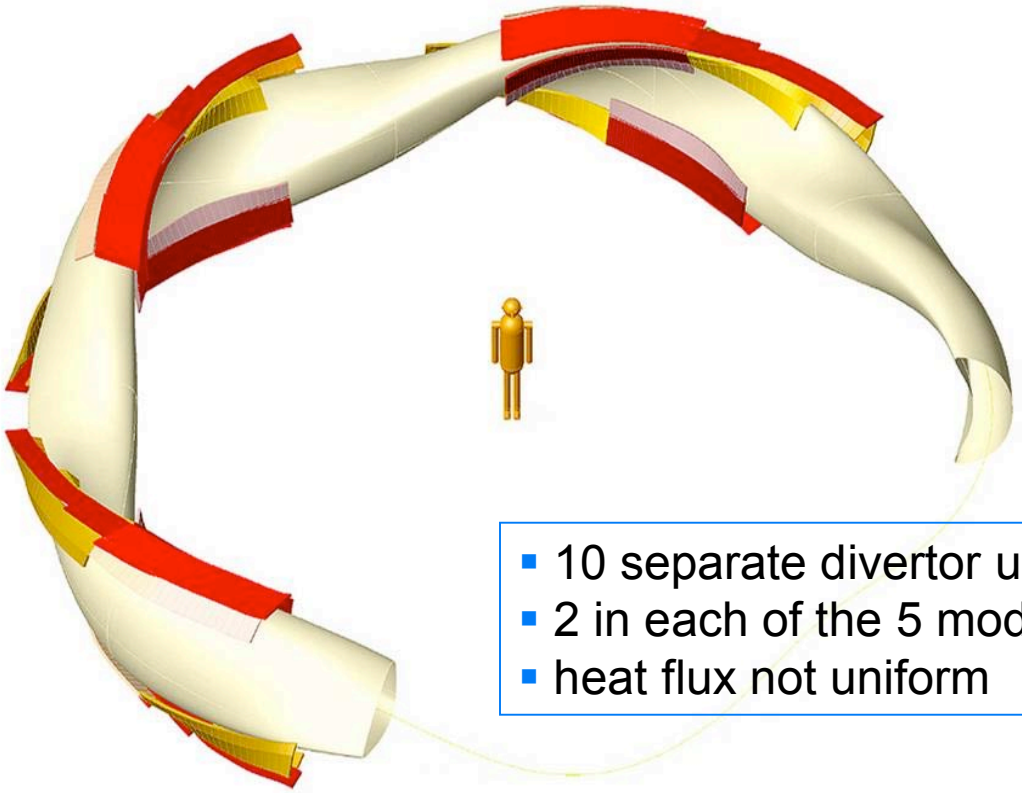
Fully optimized stellarator, *J. Nührenberg et al.*



Optimisation criteria
- small neo-classical transport
- good confinement of fast particles
- minimised bootstrap current
- good MHD stability
- good finite β-equilibria
- feasible modular coils

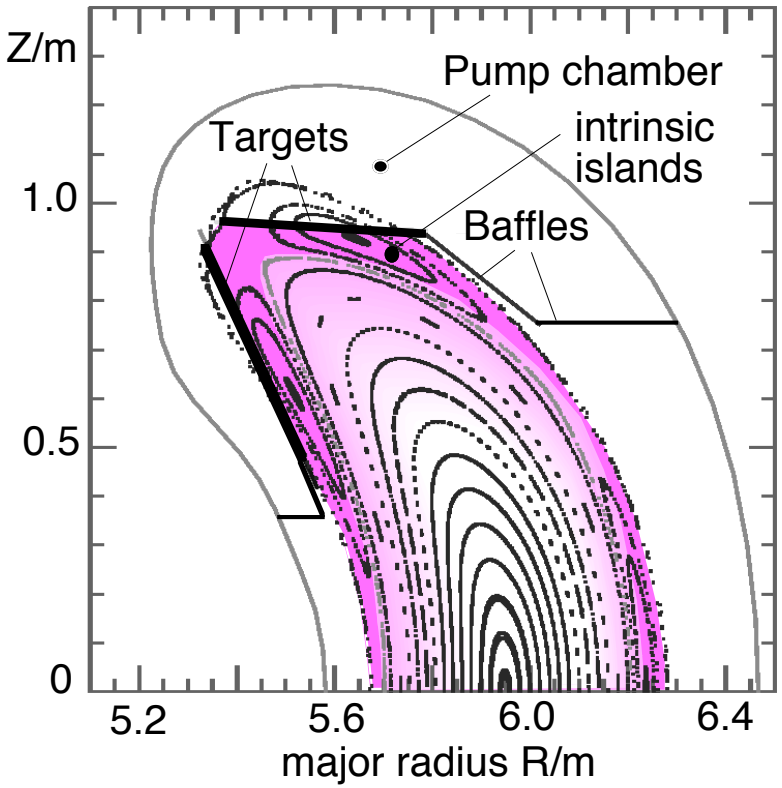
WENDELSTEIN 7-X
in-vessel components (divertor)

KiP project, IPP Garching

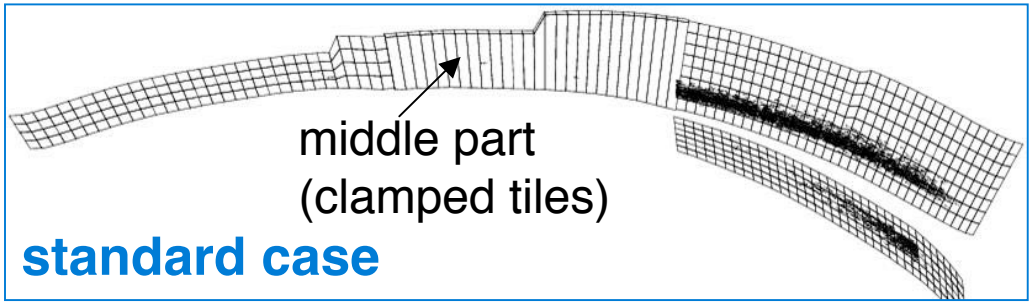


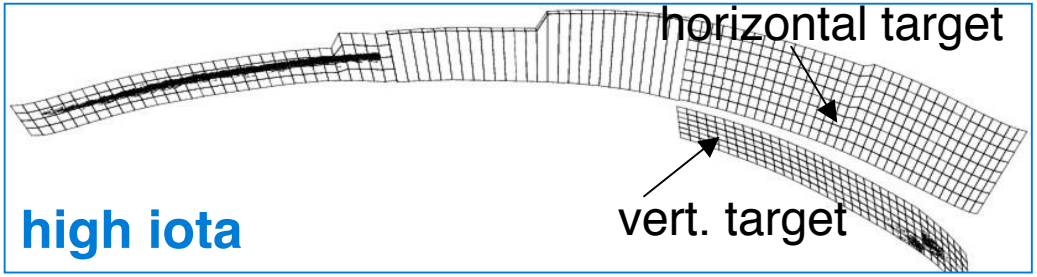
- 10 separate divertor units
- 2 in each of the 5 modules
- heat flux not uniform

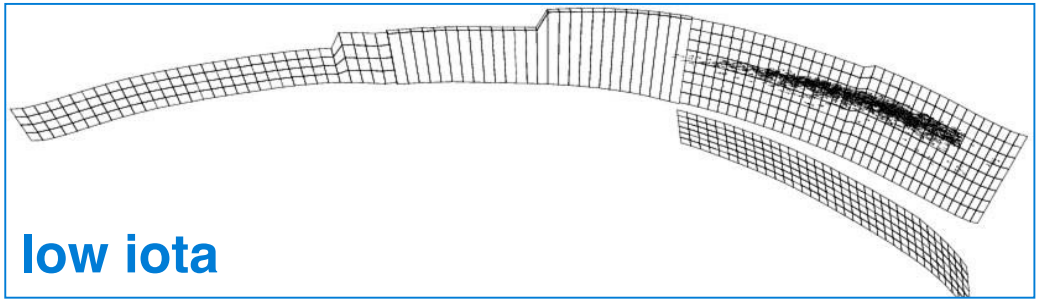
WENDELSTEIN 7-X
principle



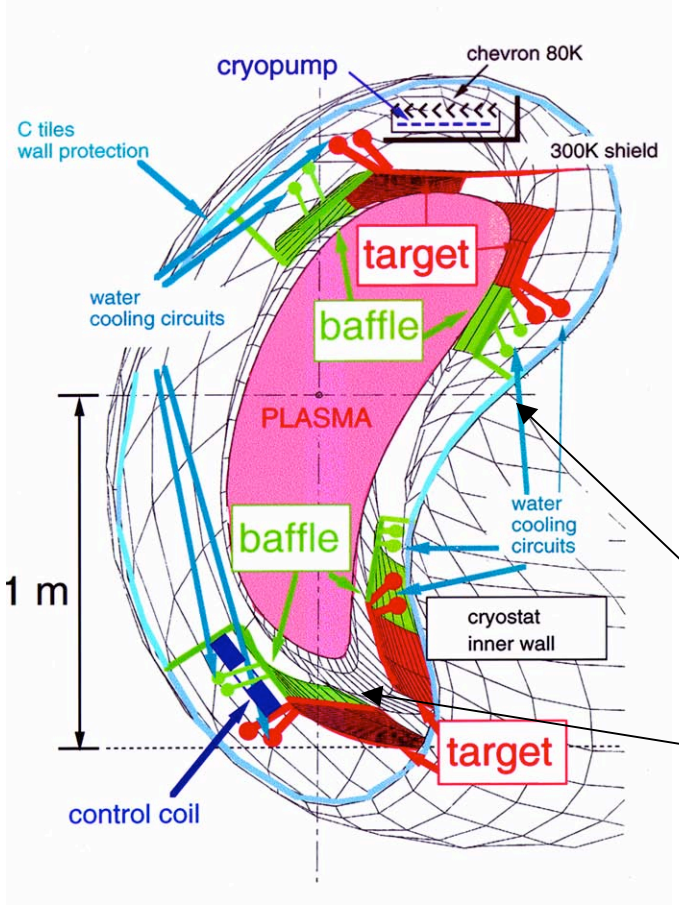
wetted areas (β = 0)







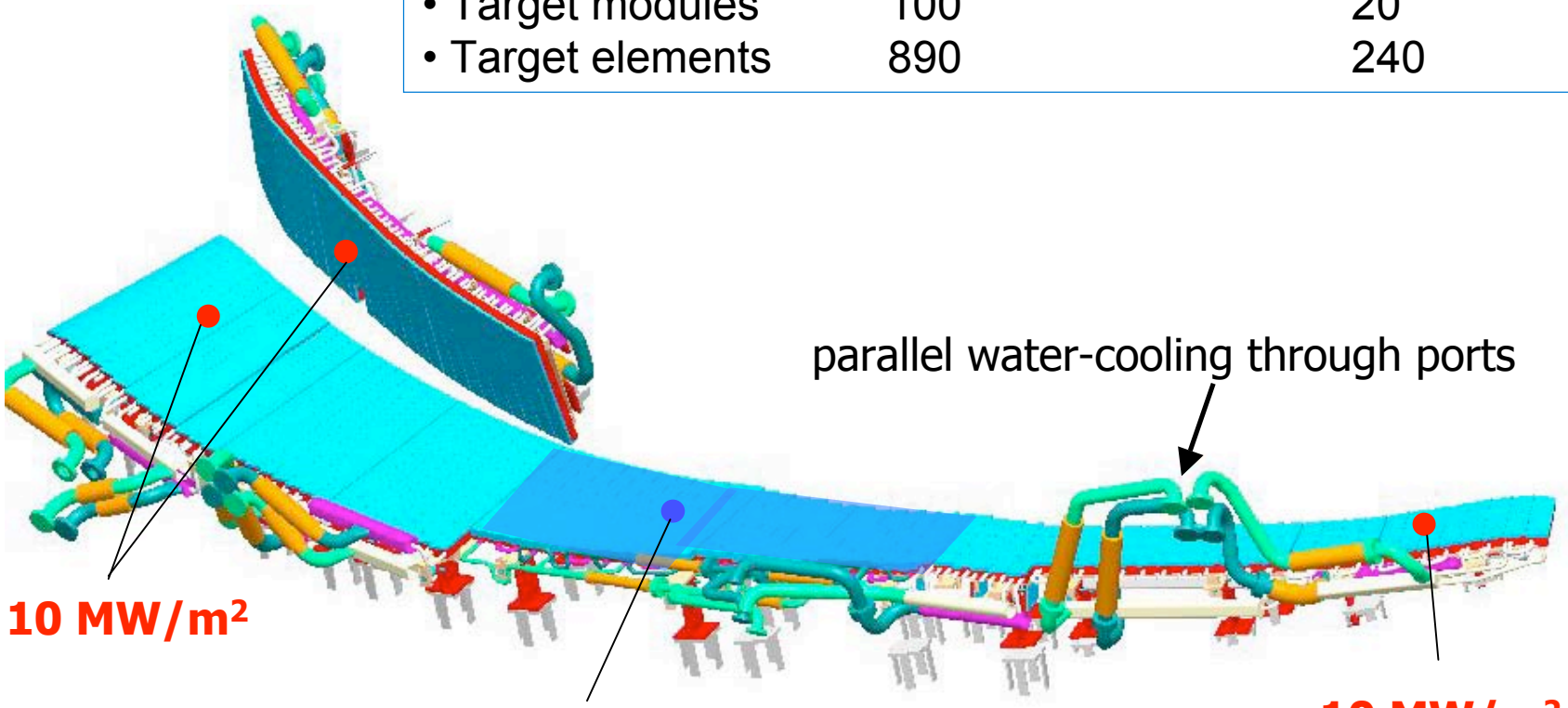
WENDELSTEIN 7-X
in-vessel components (divertor)



- 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

WENDELSTEIN 7-X
divertor module

	Target	Baffle
• Max. P/A	10 MW/m^2	1 MW/m^2
• Total area	19 m^2	5.6 m^2
• Target modules	100	20
• Target elements	890	240

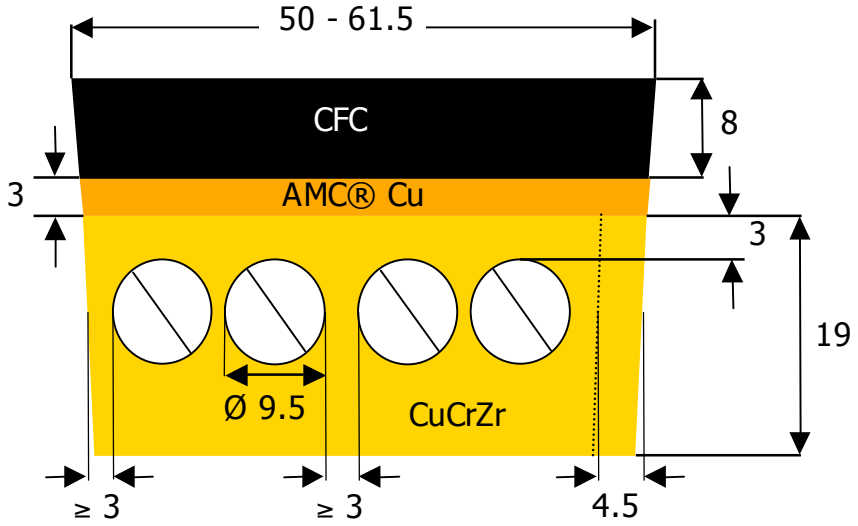


WENDELSTEIN 7-X
Design of target and baffle elements

10 MW/m² loaded (HHF) target element

Design

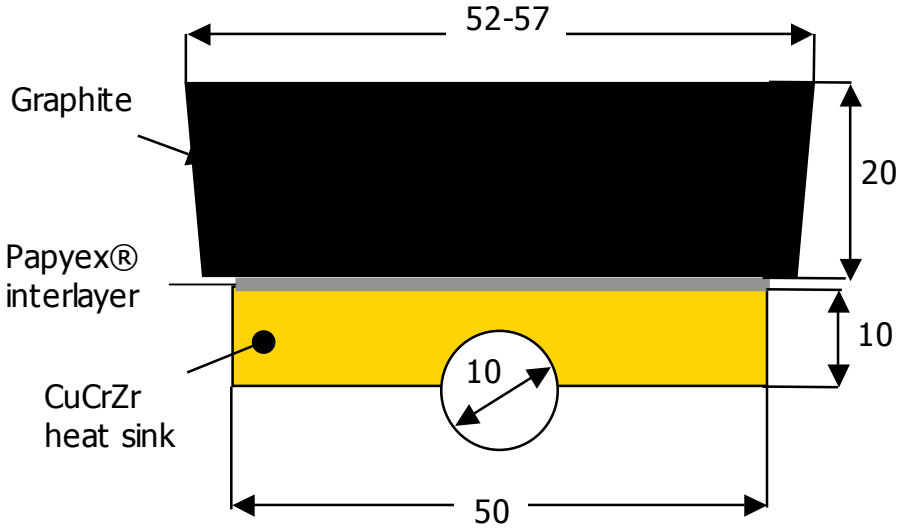
Heat sink	CuCrZr
Plasma facing material	CFC Sepcarb® NB31
Joining CFC-Heat sink	AMC® / EBW or HIP
Interlayer CFC-Heat sink	pure Cu
Cooling tube	swirl



1 MW/m² loaded target element

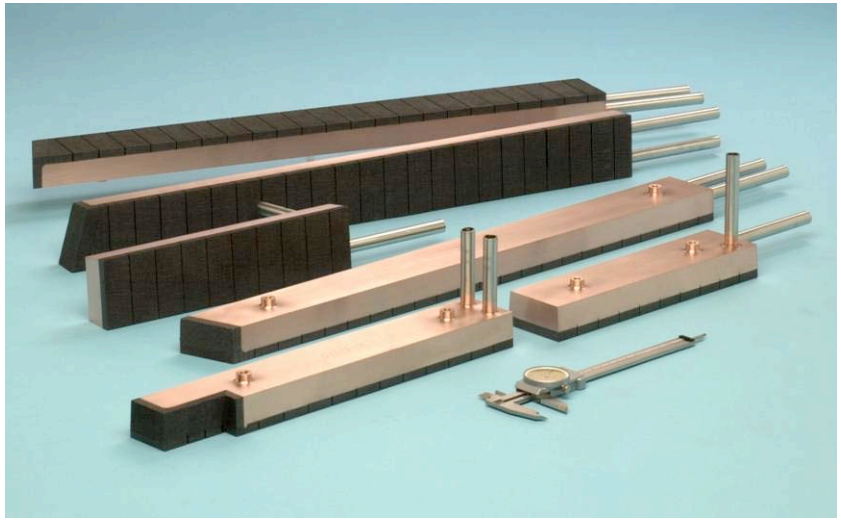
Design (similar to baffle and wall protection)

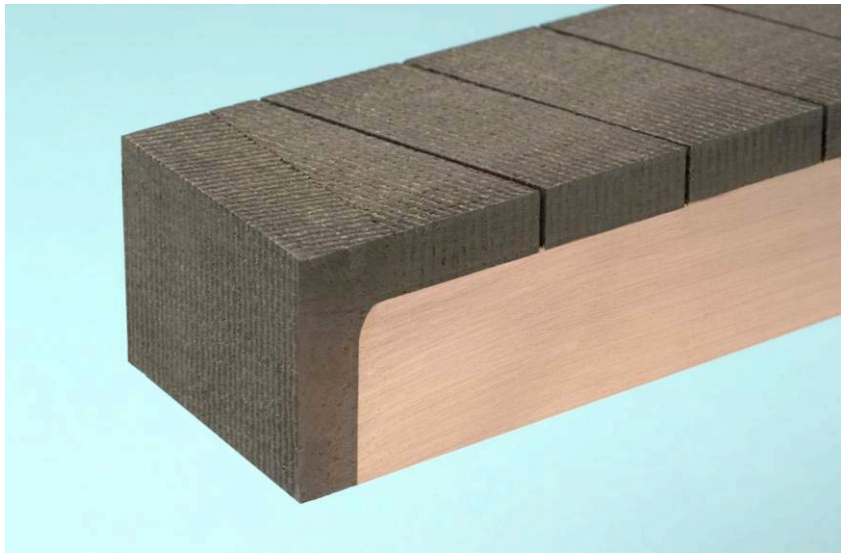
Heat sink	CuCrZr
Plasma facing material	Graphite
Joining CFC-Heat sink	clamped
InterlayerCFC-Heat sink	Papyex®
Cooling tube	brazed stainless steel

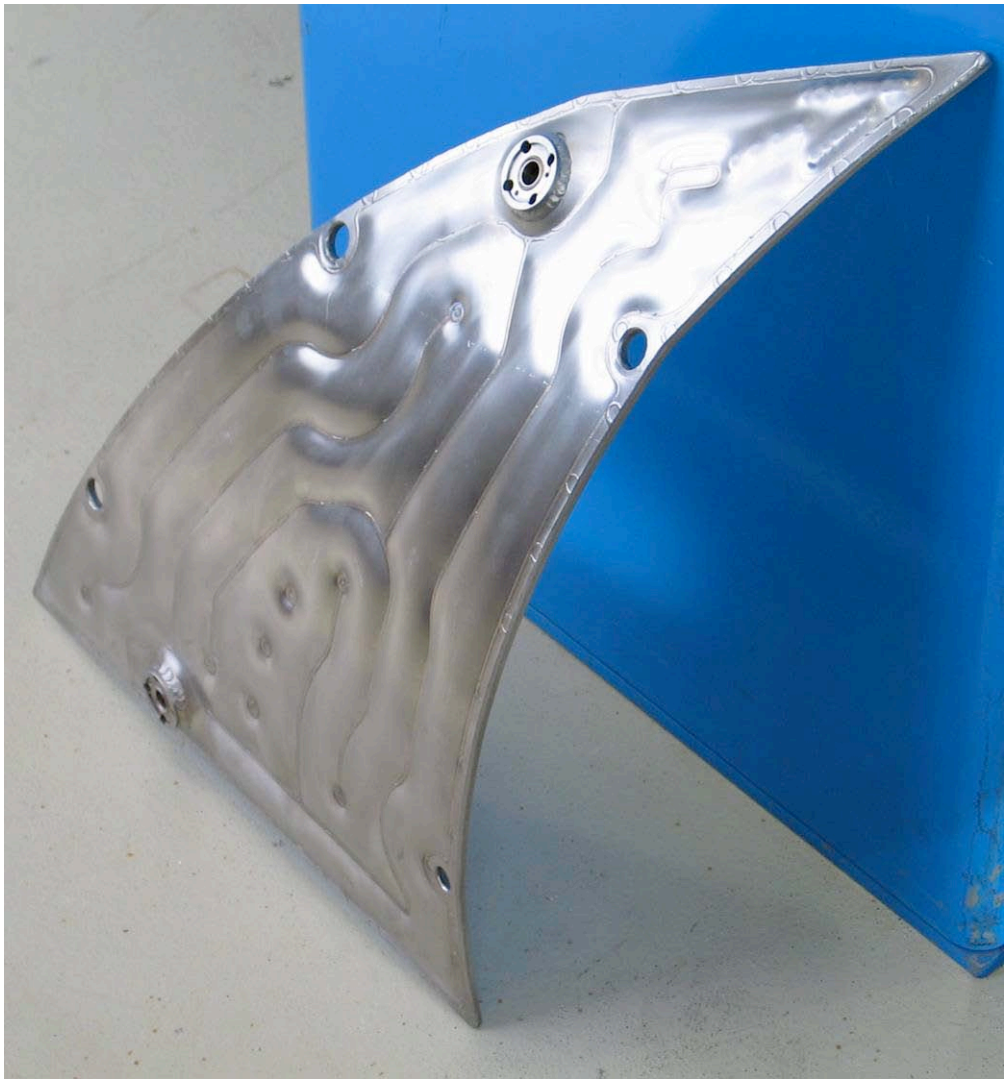


Cross section

WENDELSTEIN 7-X
Prototypes of target elements and wall protection panel

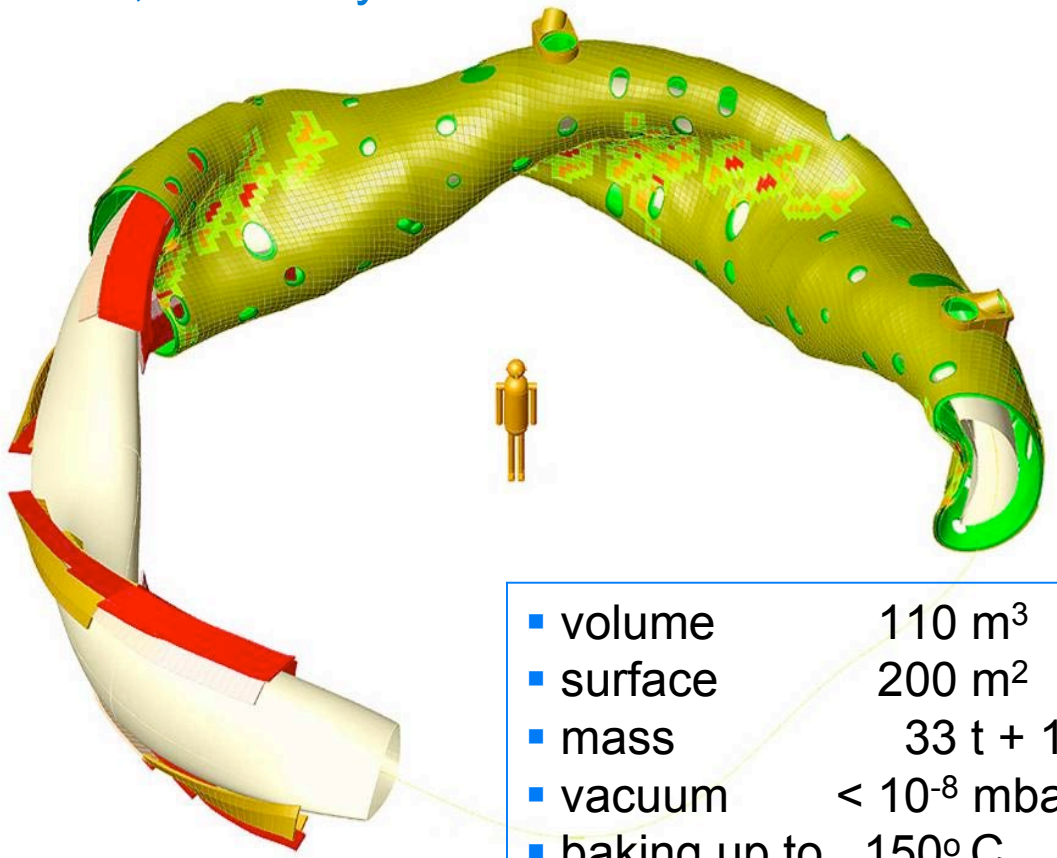






WENDELSTEIN 7-X
plasma vessel and thermal shield

Deggendorfer Werft, Germany



- volume 110 m^3
- surface 200 m^2
- mass 33 t + 15 t
- vacuum < 10^{-8} mbar
- baking up to 150° C
- tolerances < ± 2 mm

W 7-X Vacuum Vessel

W 7-X Vacuum Vessel

Plasma vessel with
cooling pipes
(MAN DWE)

W 7-X Thermal Insulation

Multi-Layer Insulation
- 20 layers of crinkled Kapton foil
- Al-coating for reflection

Thermal shield
- glass fibre (robust, small tolerances)
- to be Al-coated
- He-cooled (gas)

W 7-X Vacuum Vessel and Thermal Insulation

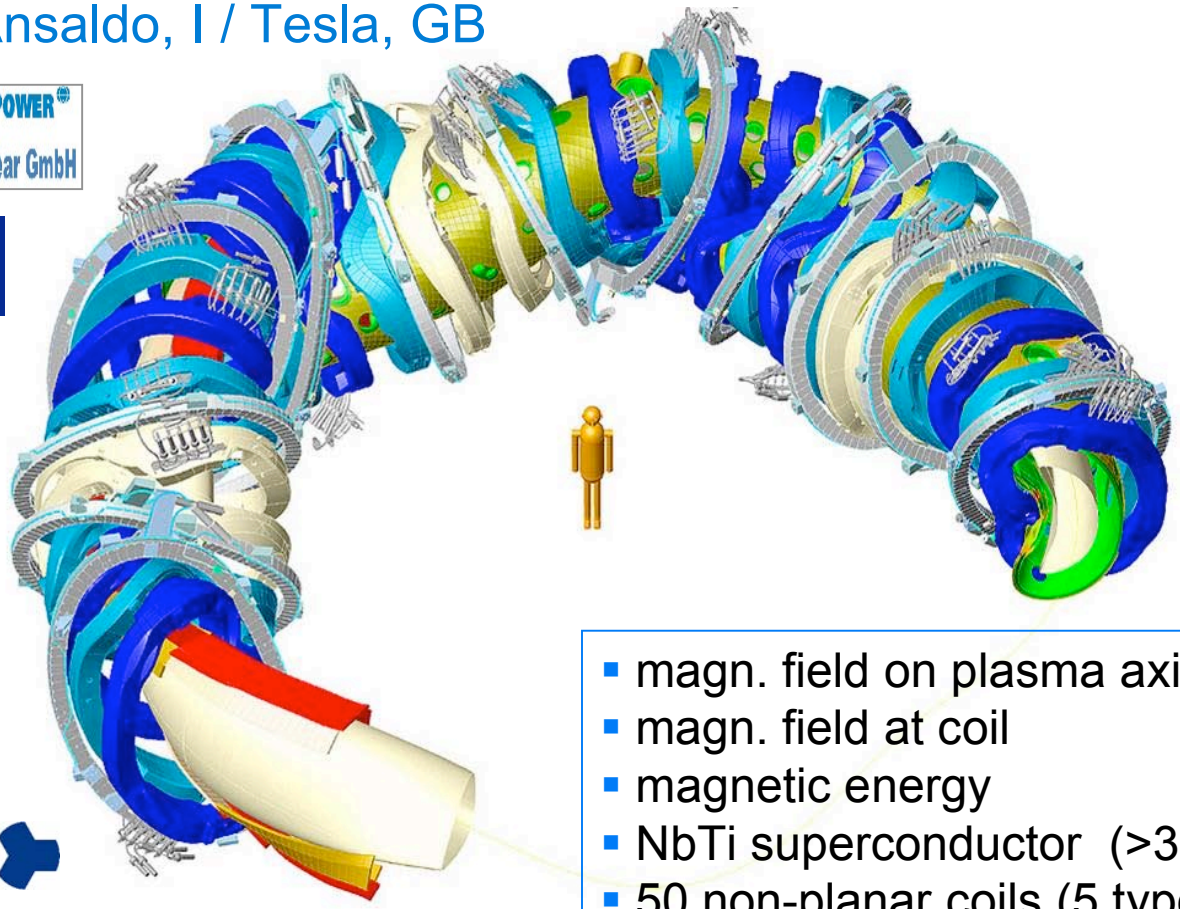
Glass fibre panel with MLI
- Al-coated
- Cu-braids for connection to He-cooling pipe

- Thermal shield (right) above
- Multi-Layer Insulation (middle) on
- vacuum vessel with water cooling pipes (left)

W 7-X Vacuum Vessel and Thermal Insulation

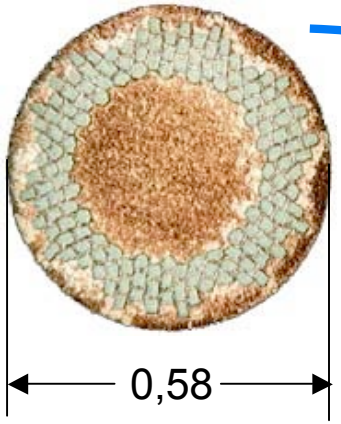
WENDELSTEIN 7-X
Magnet system

BNN, G / Ansaldo, I / Tesla, GB

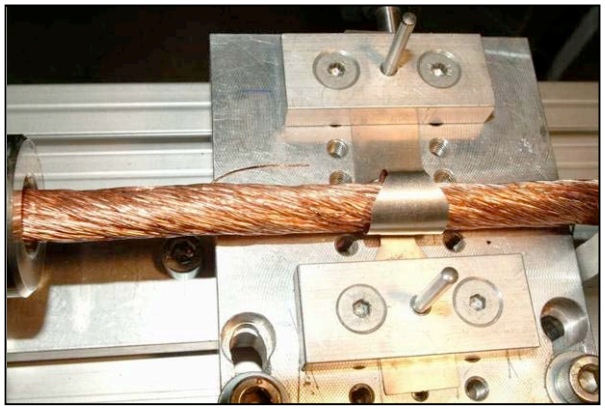


- magn. field on plasma axis 2.5 T (< 3T)
- magn. field at coil 6.8 T
- magnetic energy 600 MJ
- NbTi superconductor (>3.4 K)
- 50 non-planar coils (5 types)
- 20 planar coils (2 types)

WENDELSTEIN 7-X magnets
superconductor



Strand
Ni and Cu



cabling

243 single strands
(3 x 3 x 3 x 3)

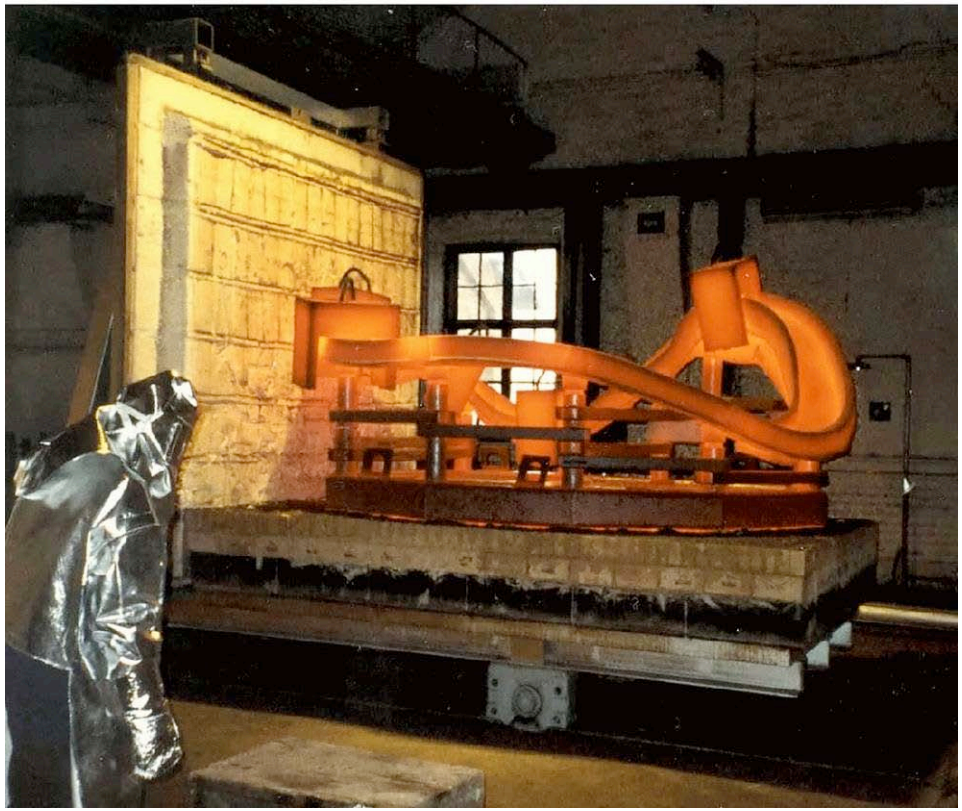
Cable-in-Conduit (Coextrusion)

I_n up to 17.6 kA

WENDELSTEIN 7-X non-planar coils windings and casings

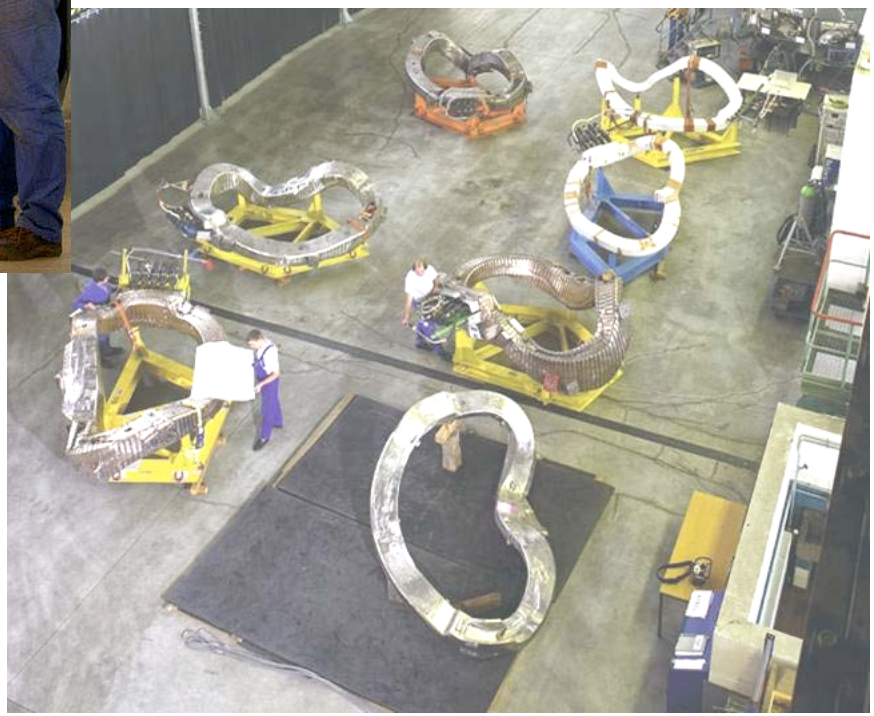
Winding of a coil
(ABB, Augsburg)

cast casing after tempering
(Österby, Sweden)



WENDELSTEIN 7-X non-planar coils
coil assembly

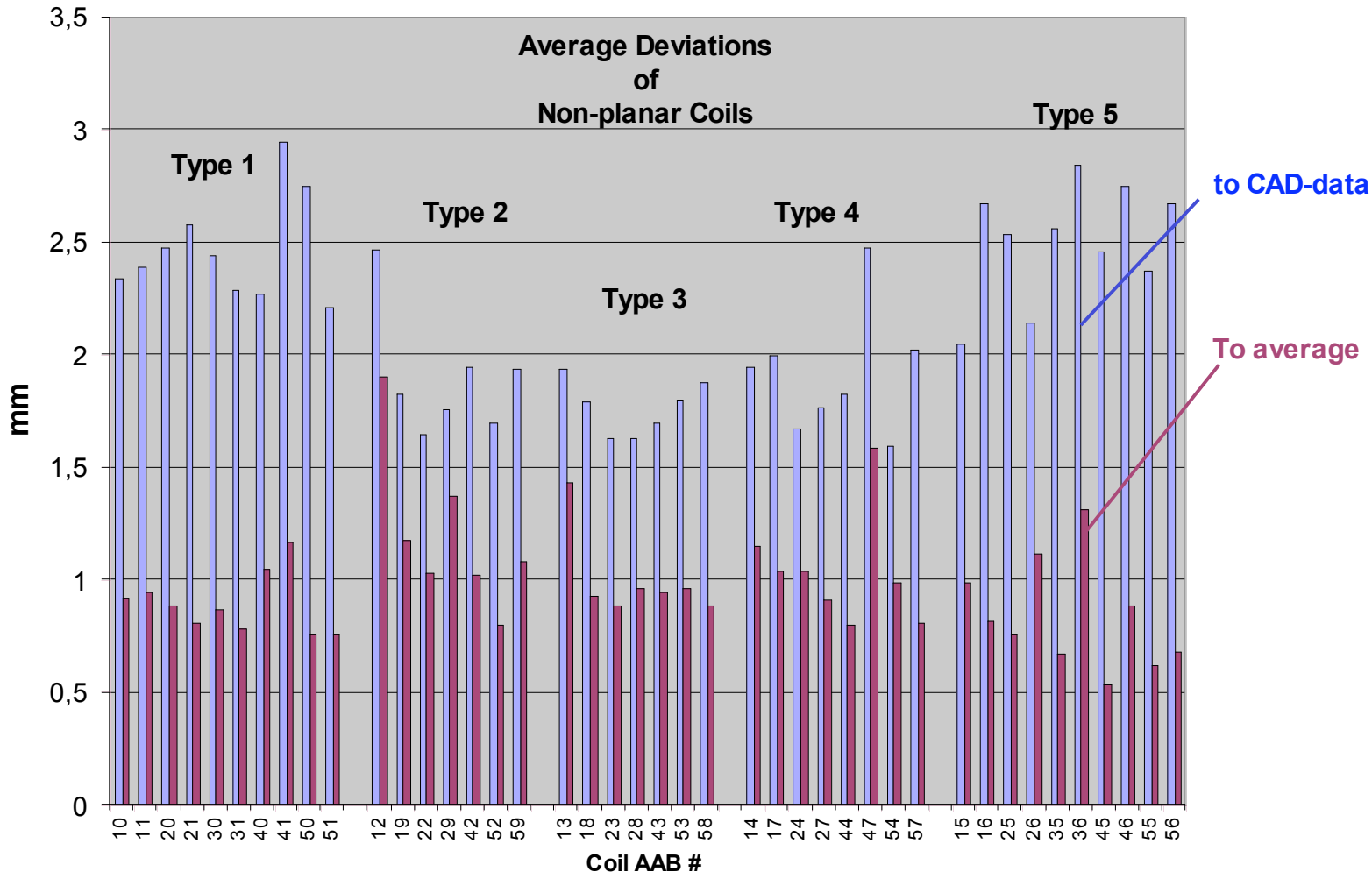
Winding pack and casing



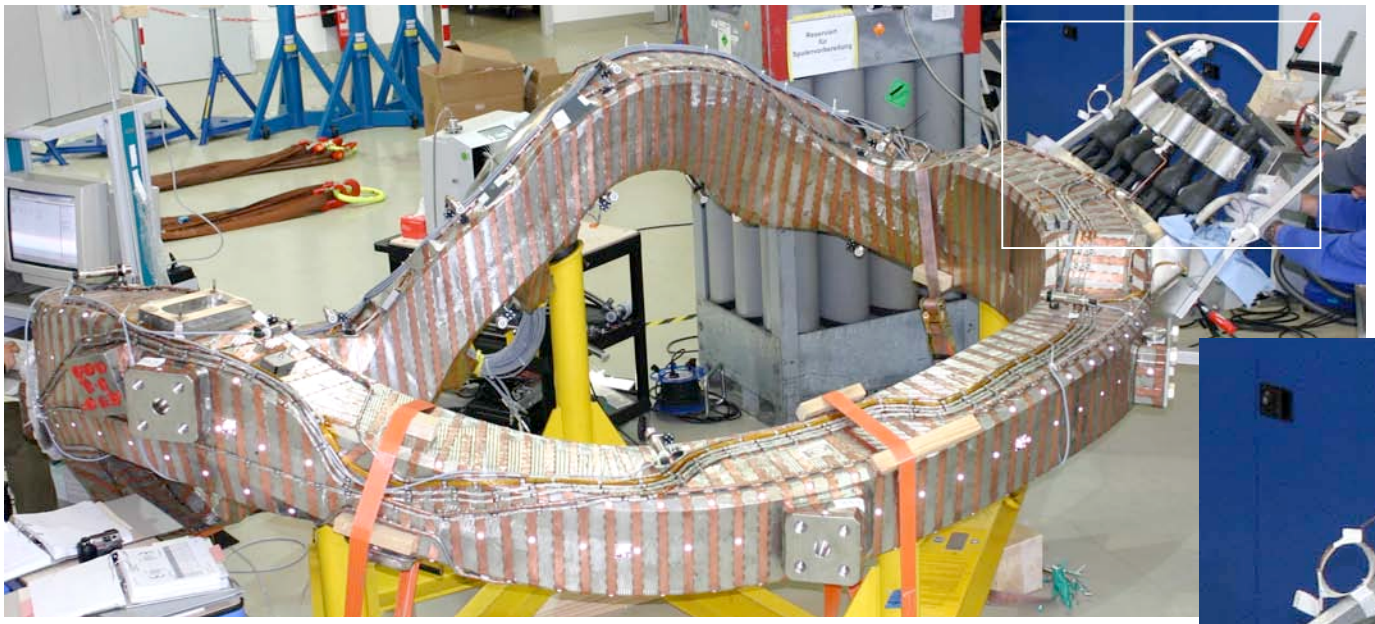
Overview of
Production hall
(BNN, Zeitz)

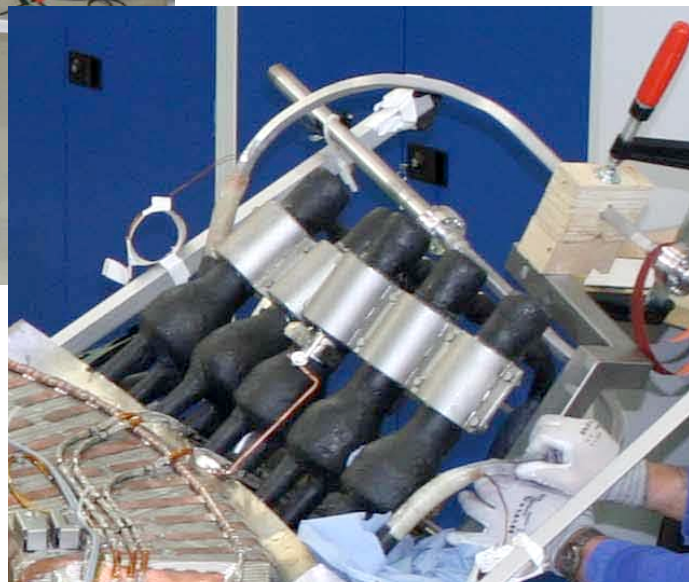
WENDELSTEIN 7-X non-planar coils
accuracy of winding packs

High accuracy of the field required: $\Delta B/B_{00} < 2 \cdot 10^{-4}$



WENDELSTEIN 7-X non-planar coils
the first coil, AAB18





- 99% of superconductor produced
- 43 out of 50 winding packs finished
- all 50 casings cast,
- 44 casings finished
- 27 coils embedded
- 7 coils delivered (now about 2 per month)
- 3 coils tested at 4 K
- 2 coils assembled

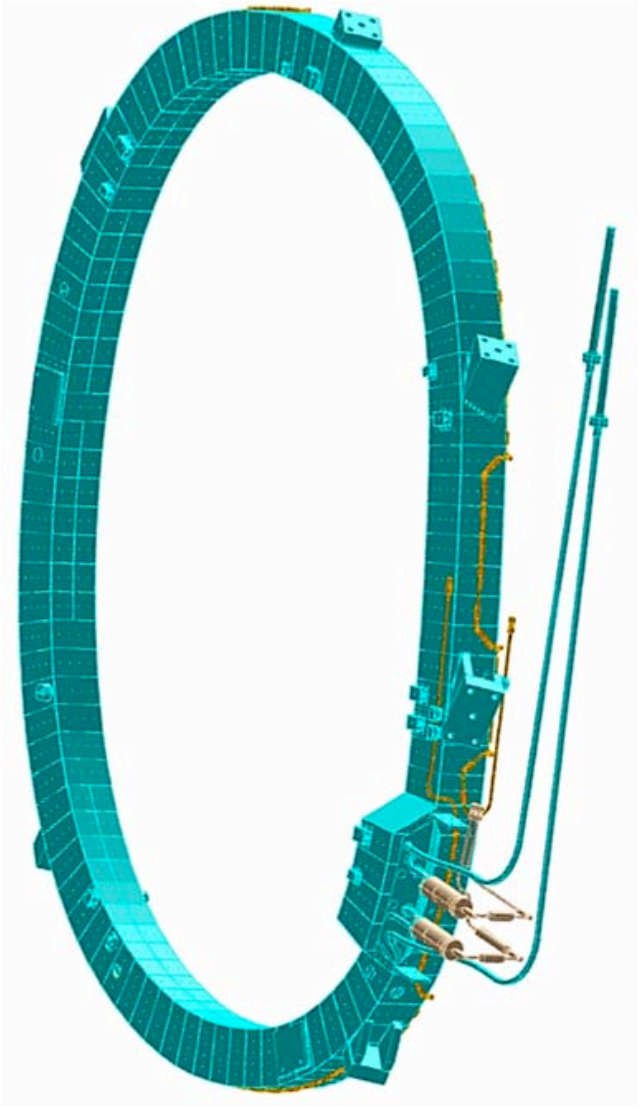
WENDELSTEIN 7-X non-planar coils
Paschen tests

- critical scenario: air influx into outer vessel causes pressure increase and quenching of a coil.
- During a quench, high voltages arise – at increased pressure
- Therefore all coils are tested under Paschen conditions (between 0.001 and 100 mbar) with 9 kV
- This has also proven to be a good procedure to verify a good insulation.

W 7-X planar Coils

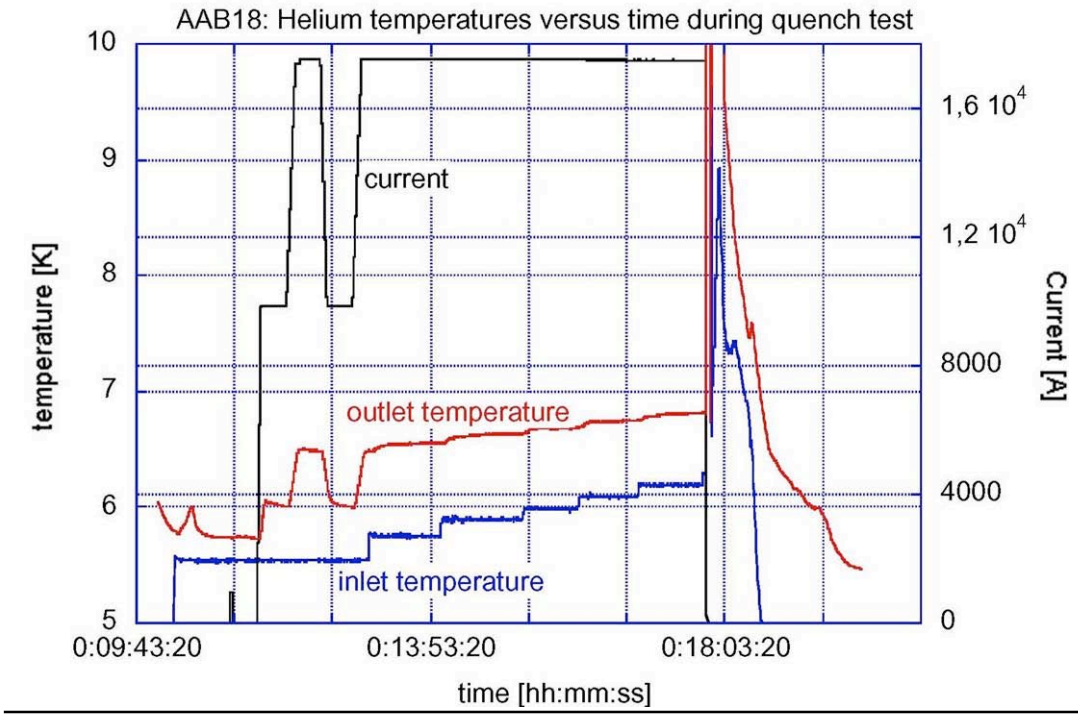
Planar Coil
(Tesla, UK)

- same superconductor, supply finished
- bolted casings, presently being reinforced with 300 shear pins per coil
- all winding packs finished
- 8 coils embedded
- 1 coil delivered (now about 1 per month)
- 1 coil tested at 4 K



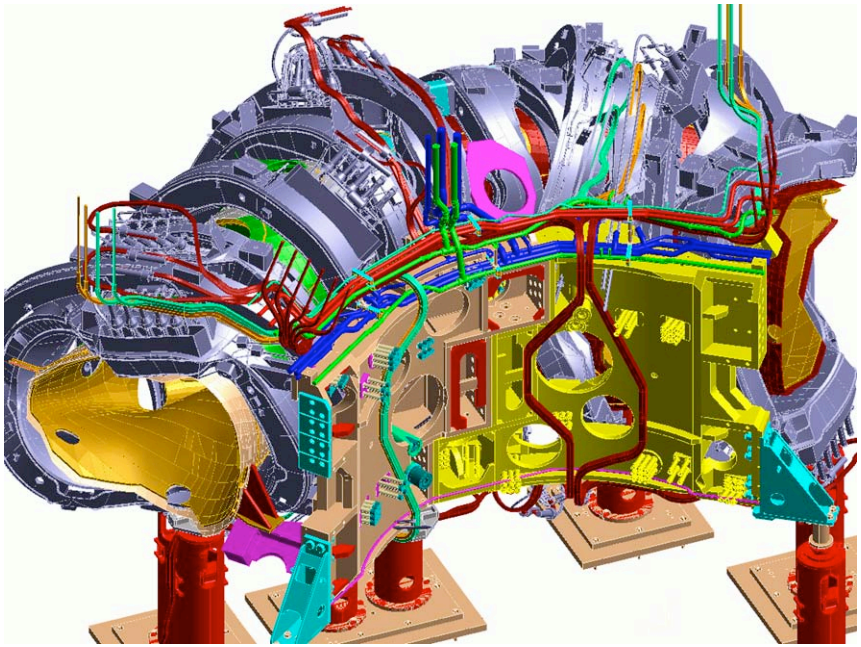
CEA Saclay, France
Coil test

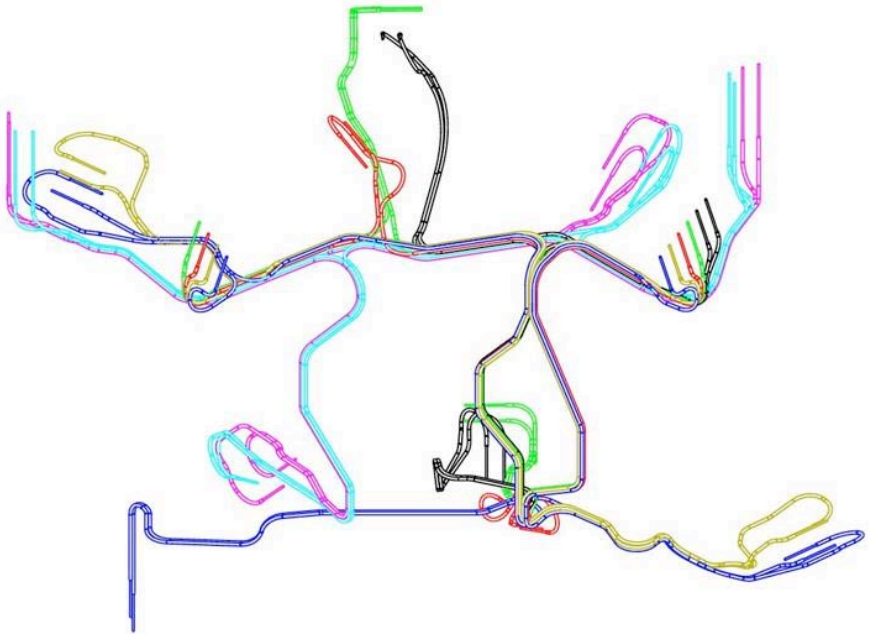
- 2 cryostats
- handle 2 coils each
- full current tests at 5 K
- quench test to check margin
- about 2 coils per month
- facility running routinely



W 7-X bus-bar System

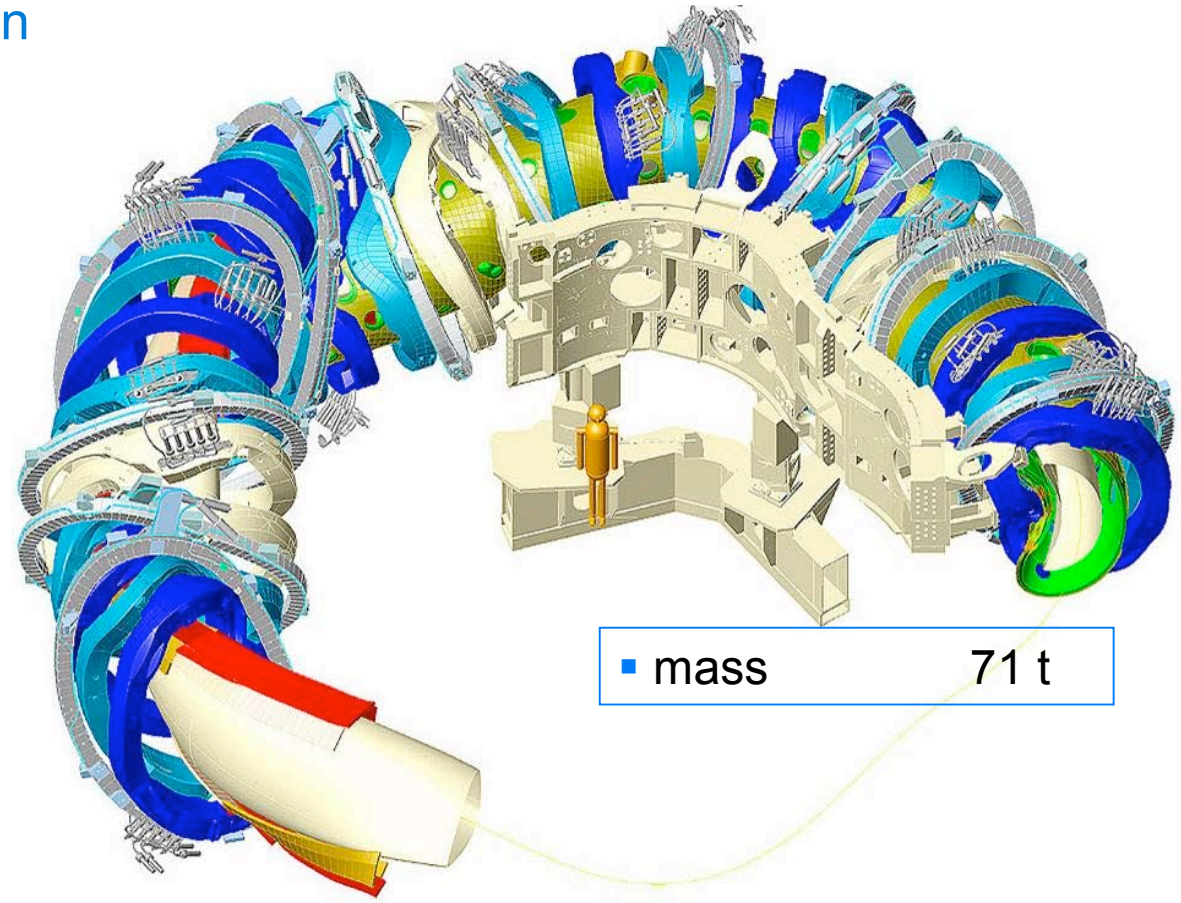
- Manufactured by the Research Centre Jülich (FZJ, Germany)
- Superconducting bus-bar system
  - between coils
  - and between coils and power supplies
- bifilar winding to avoid error fields
- design and qualification almost finished,
- fabrication will start soon





WENDELSTEIN 7-X
central support structure and support elements

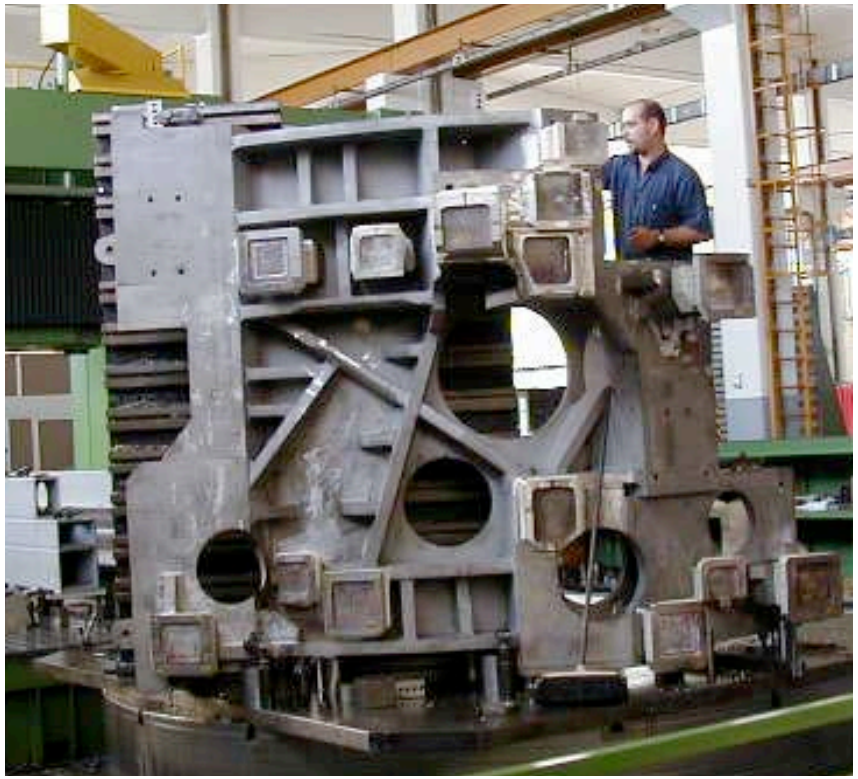
Ensa, Spain



- mass 71 t

W 7-X support structure

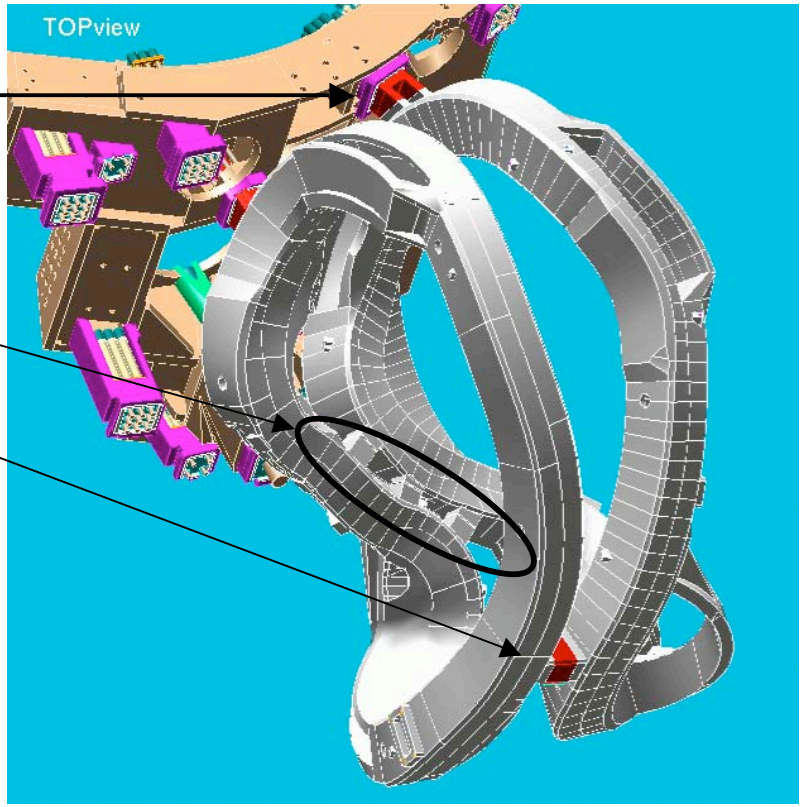
- Welded construction in 10 half-modules, supports the whole magnets system
- final machining before assembly garantues exact shape
- structural calulations of the complete system important
- a reinforcement of the central ring is presently performed
- first segment to be delivered early in 2006



W 7-X support structure

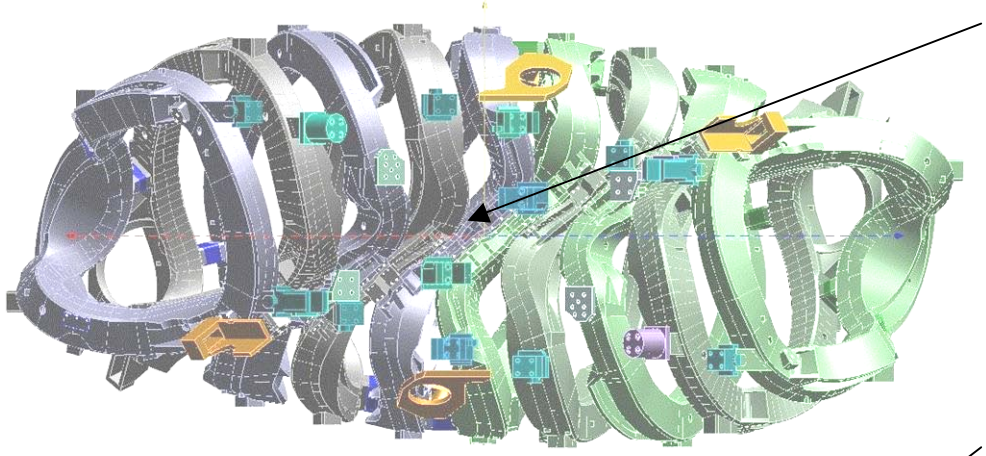
The coils are fixed to the
central support structure by
Central Support Elements (CSE)

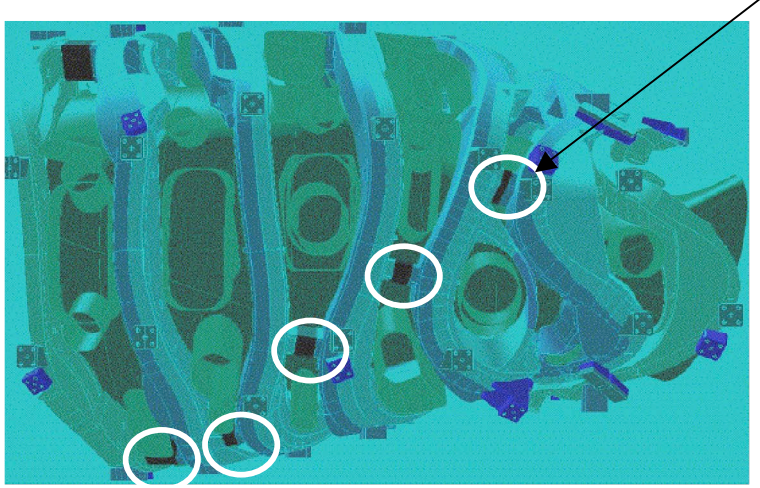
and interlinked by
Narrow Support Elements (NSE)
Lateral Support Elements (LSE)



Central Supports
- long extensions for coil fixation
- large forces and moments
- a bolted solution was found

W 7-X support elements

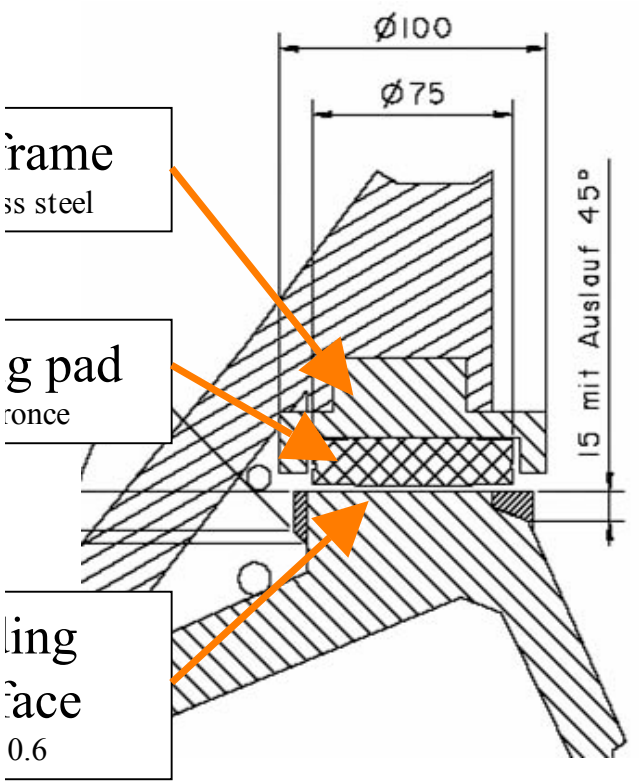




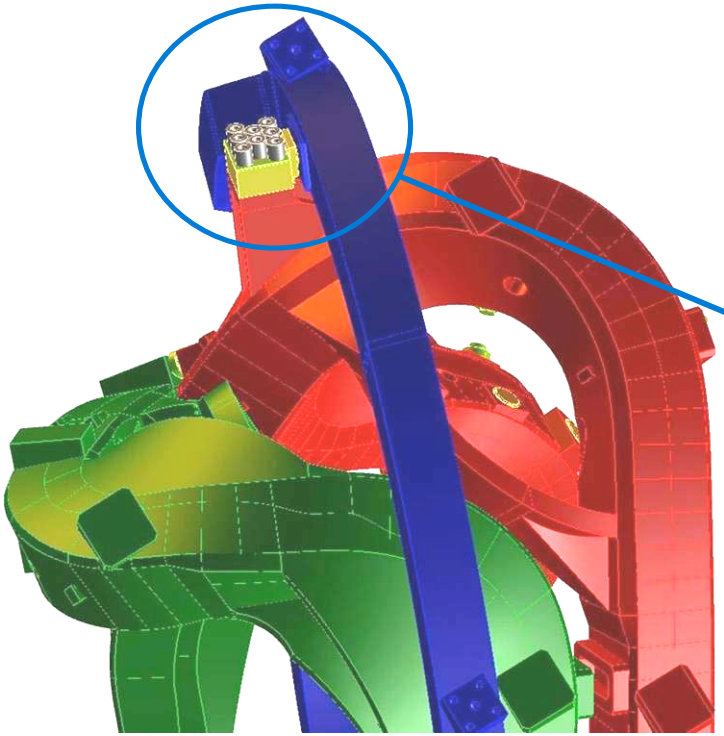
- **Narrow Supports** on inner side
- sliding connection
- forces up to 1.5 MN
- contact must allow sliding (<5 mm) and tilting (<1°).
- Al-bronce pad with MoS_2 layer

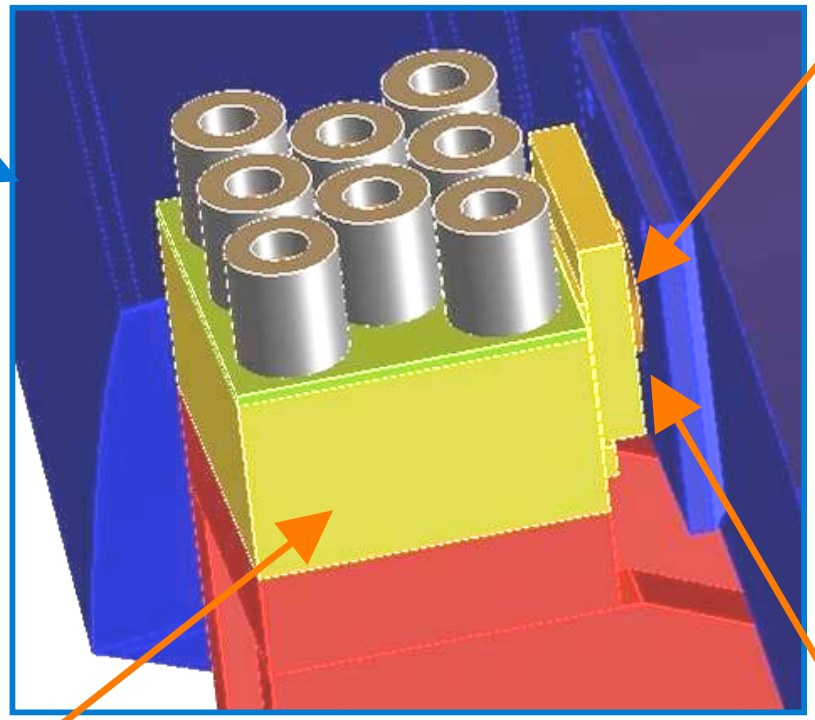
- **Lateral Supports** on outer side
- Rigid (bolted/welded) connection

W 7-X Narrow Support Elements design principle



W 7-X Planar Support Elements design principle





sliding pad
Al-bronce

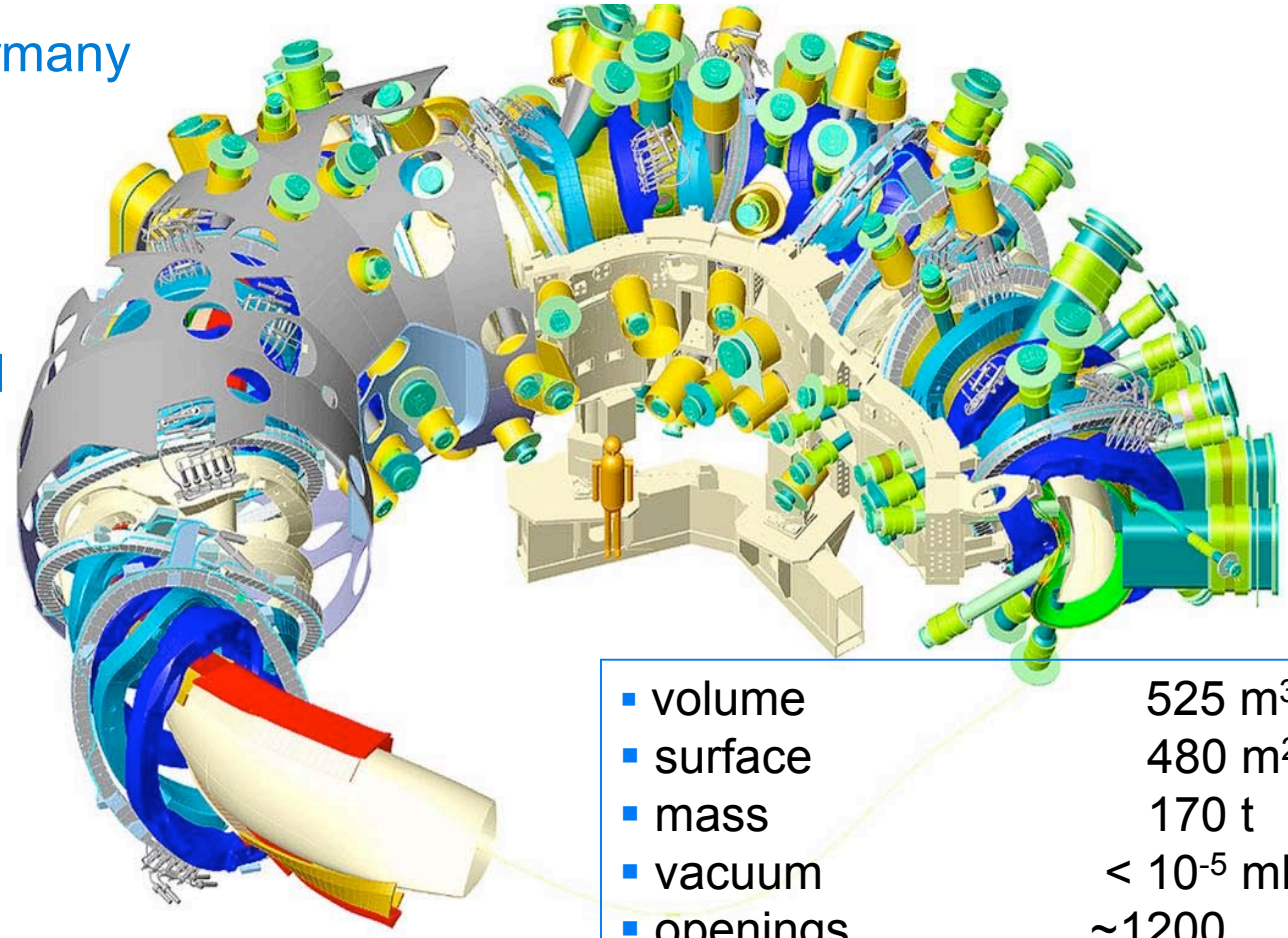
Bolted Support with Pad frame
sainless steel

sliding surface on planar coil
Rz 0.6

WENDELSTEIN 7-X
outer vessel and ports

DWE, Germany

Romabau, Switzerland



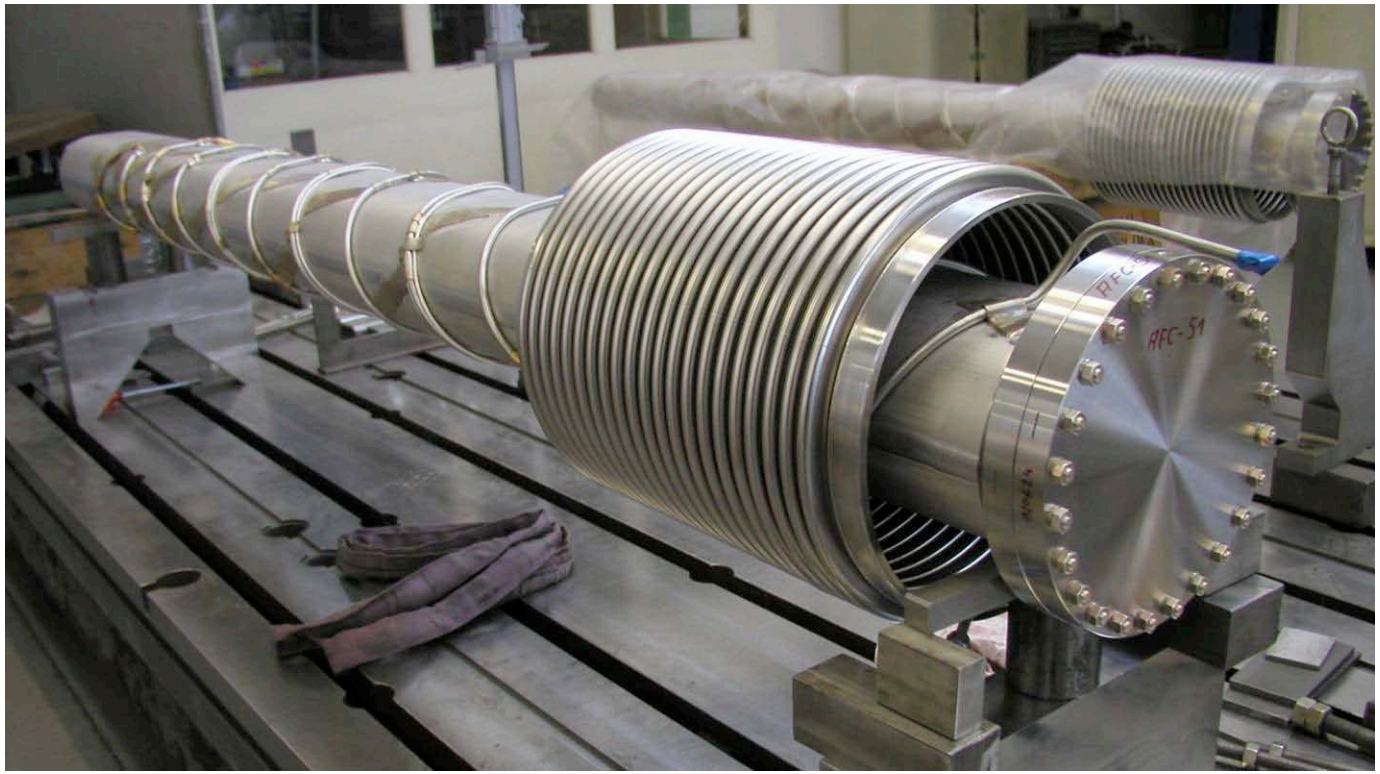
- volume 525 m^3
- surface 480 m^2
- mass 170 t
- vacuum < 10^{-5} mbar
- openings ~1200
- number of ports 299

WENDELSTEIN 7-X
outer vessel

laser cutting in a half shell
domes and ports
(DWE, G)

- 10 module half-shells welded
- 4 half-shells have been milled
- 2 half-shells equipped with about 60% of the domes/flanges
- first module to be delivered by the end of 2005
- last module to be delivered in July 2007

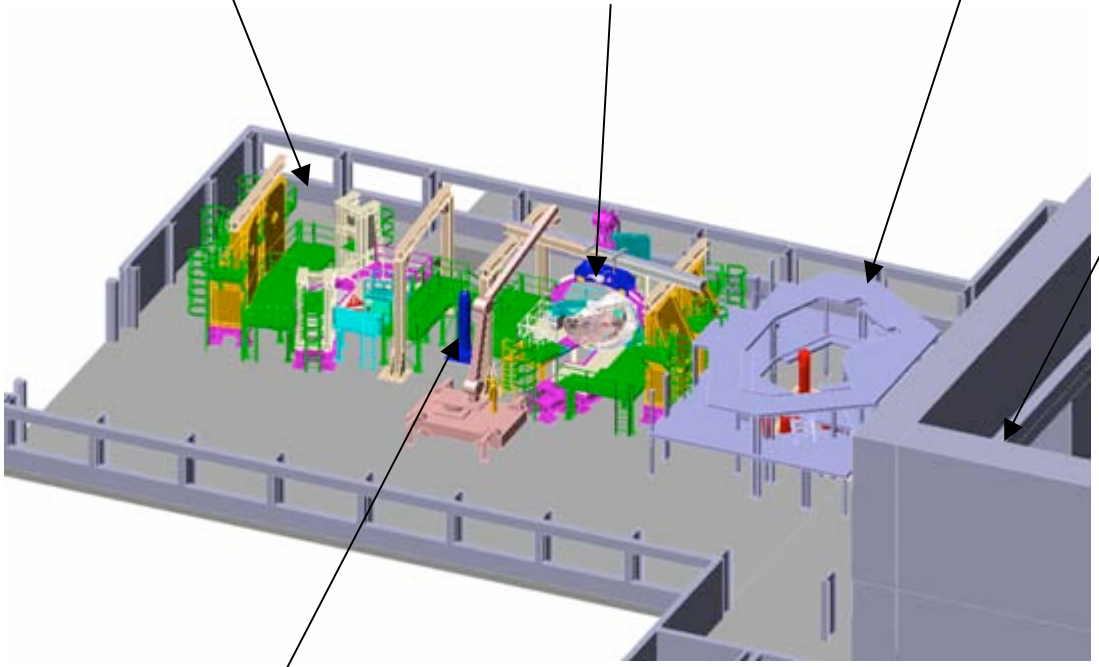
WENDELSTEIN 7-X
ports



Supply port
(Romabau, CH)

- 299 ports, 190 for diagnostics, 19 for heating, 20 for pumping and 70 for divertor supply
- 226 delivered
- fixed to both vessels, flexible mebranes in between
- final delivery in March 2006

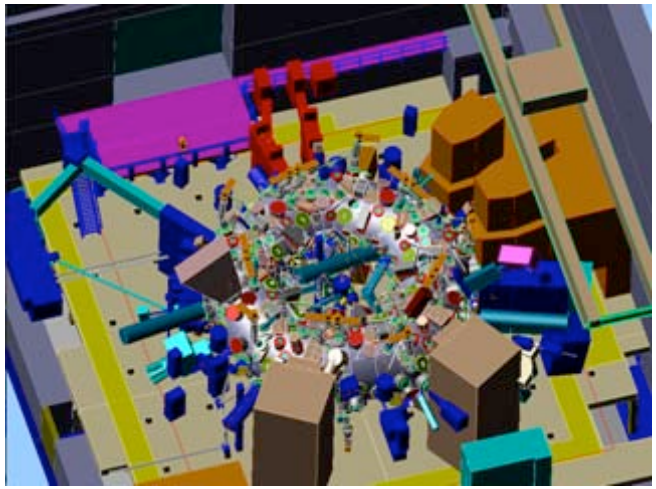
WENDELSTEIN 7-X construction
Pre-assembly phase – mounting of 5 magnet modules



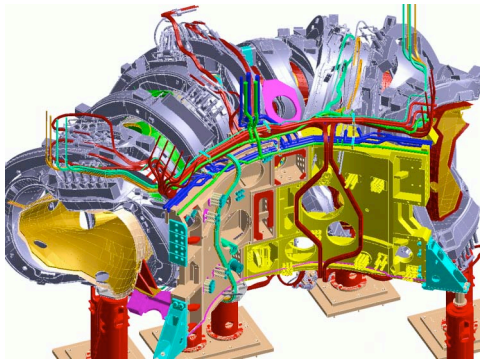
Experimental hall
(final assembly)

WENDELSTEIN 7-X construction
Final assembly phase – torus assembly

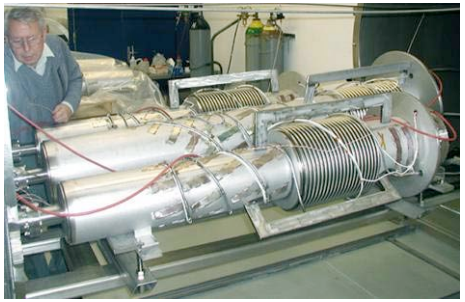
5 x 2 half-shells
of the outer vessel with
thermal insulation, shield



W 7-X – basic machine with heating
systems and diagnostics

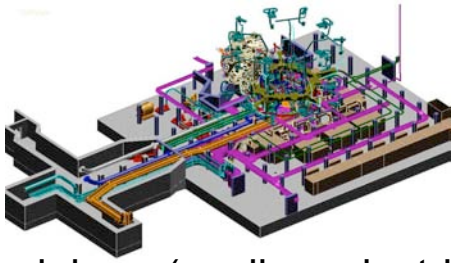


5 magnet
modules



299 ports with
thermal insulation

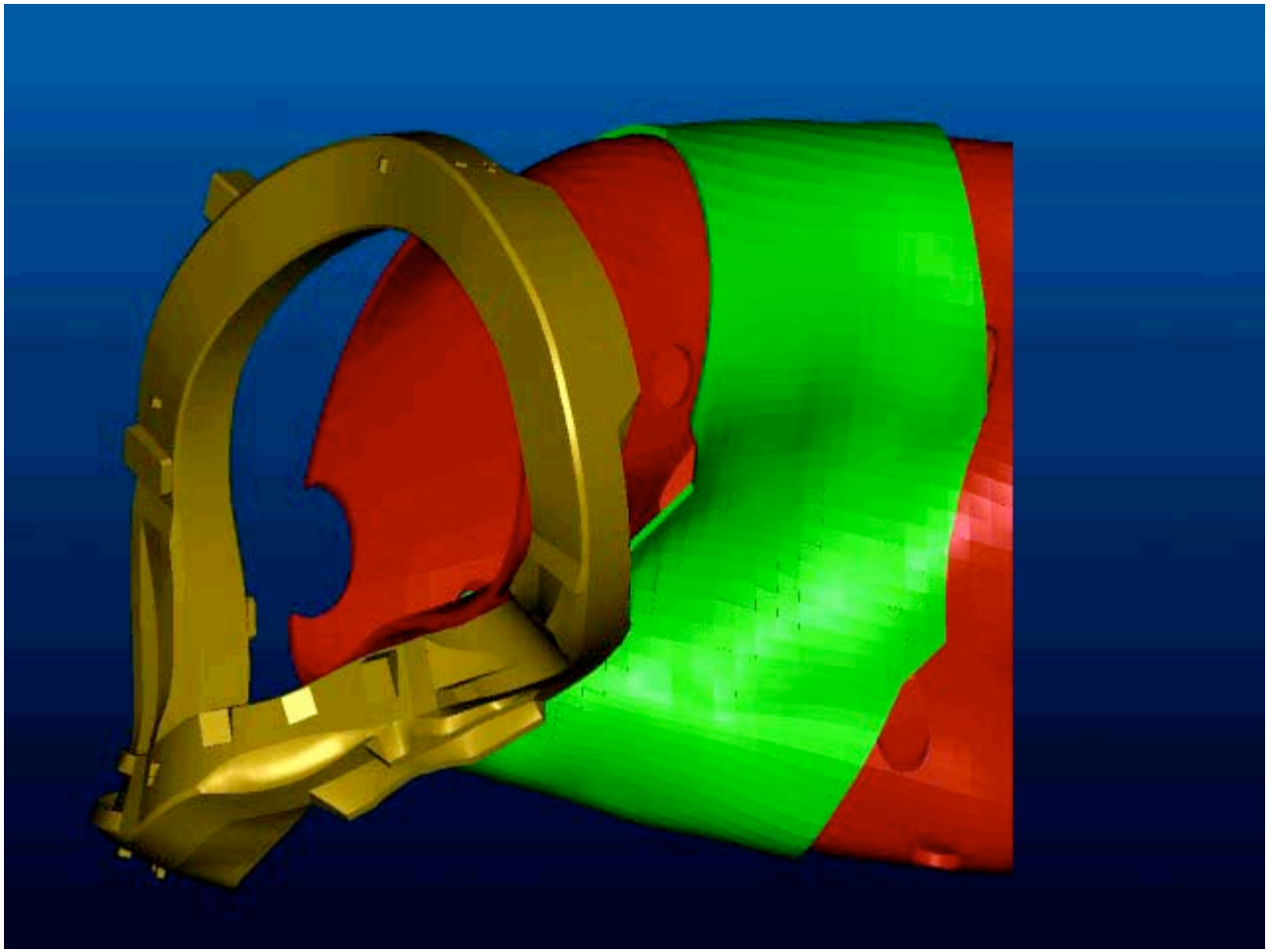
Machine base , in-vessel components,
instrumentation, current feed-through, joints, …



Periphery (cooling, electric,
auxiliary supplies)

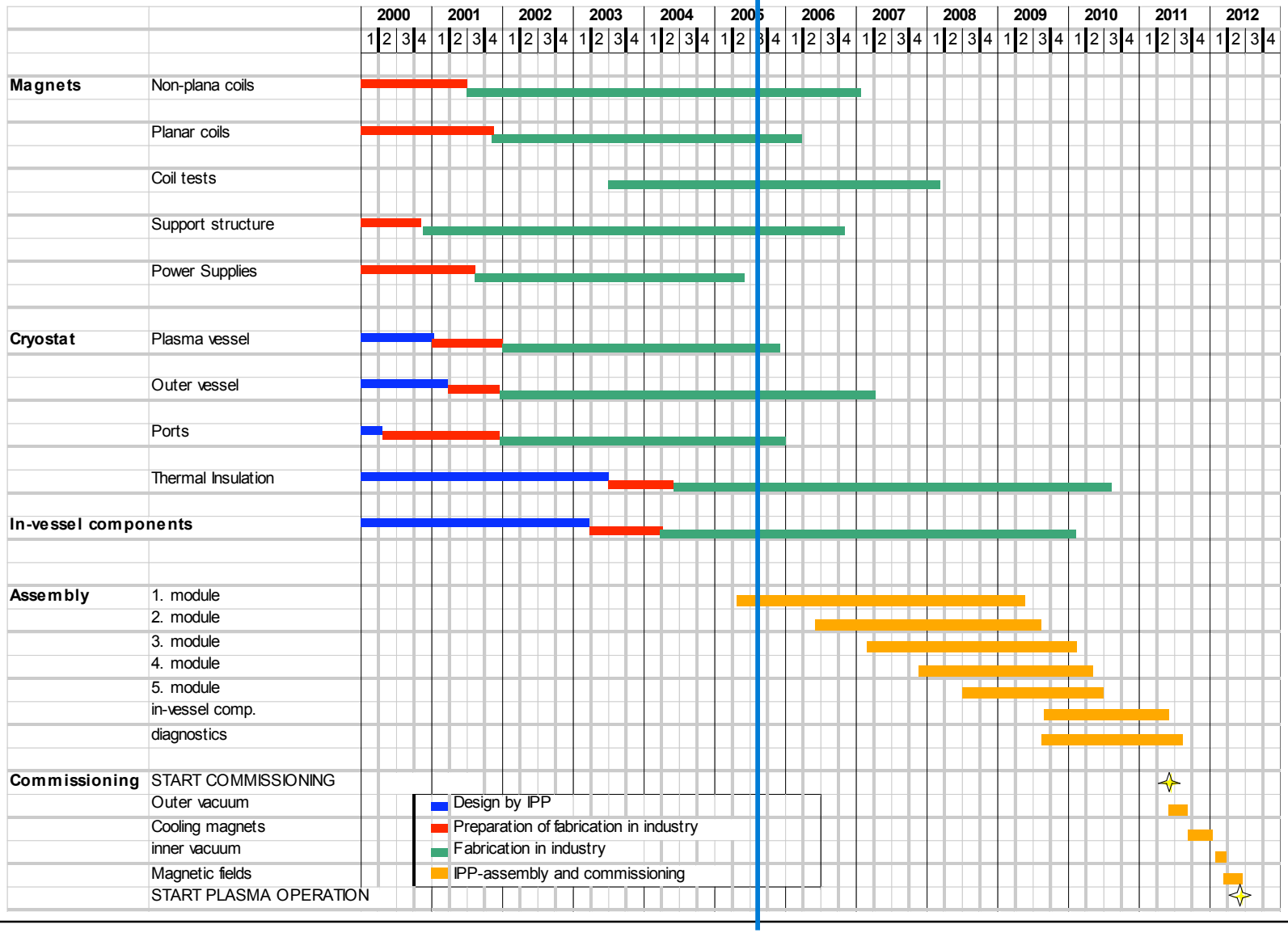
WENDELSTEIN 7-X construction
Start of assembly, 7 April 2005

WENDELSTEIN 7-X construction
Simulation of coil threading



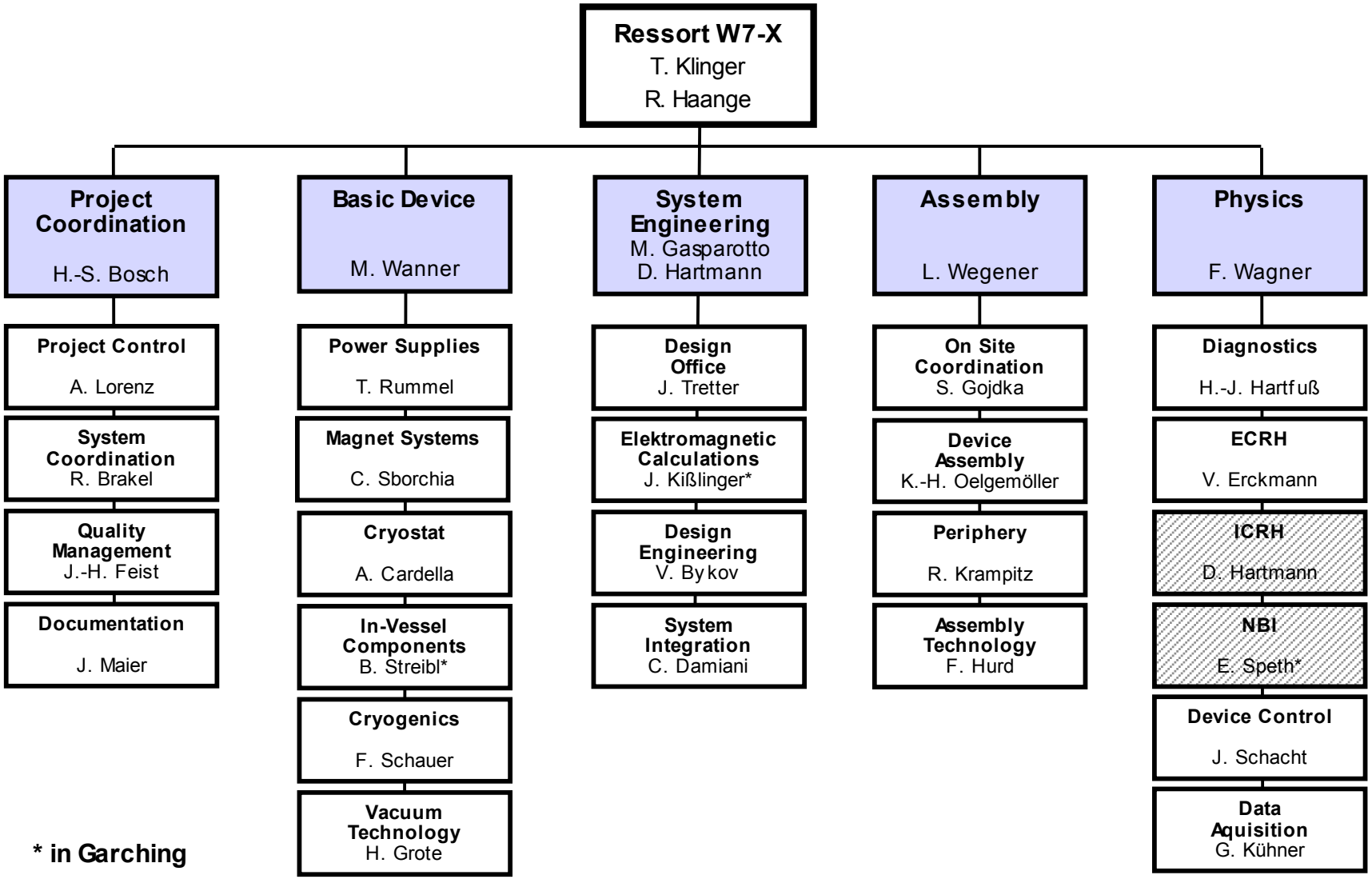
WENDELSTEIN 7-X construction
Threading trial of first planar coil, July 2005

W 7-X Project Schedule
Status of 4/05



IPP branch institute Greifswald

WENDELSTEIN 7-X, Organigram, 9/05



*** in Garching**