Max-Planck-Institut für Plasmaphysik

The superconducting stellarator Wendelstein 7-X Status

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on behalf of the

enterprise Wendelstein 7-X

Outline of the talk

Max-Planck Society

National Funding via the Helmholtz Association

HELMHOLTZ GEMEINSCHAFT

Co-Funded by the European Commission

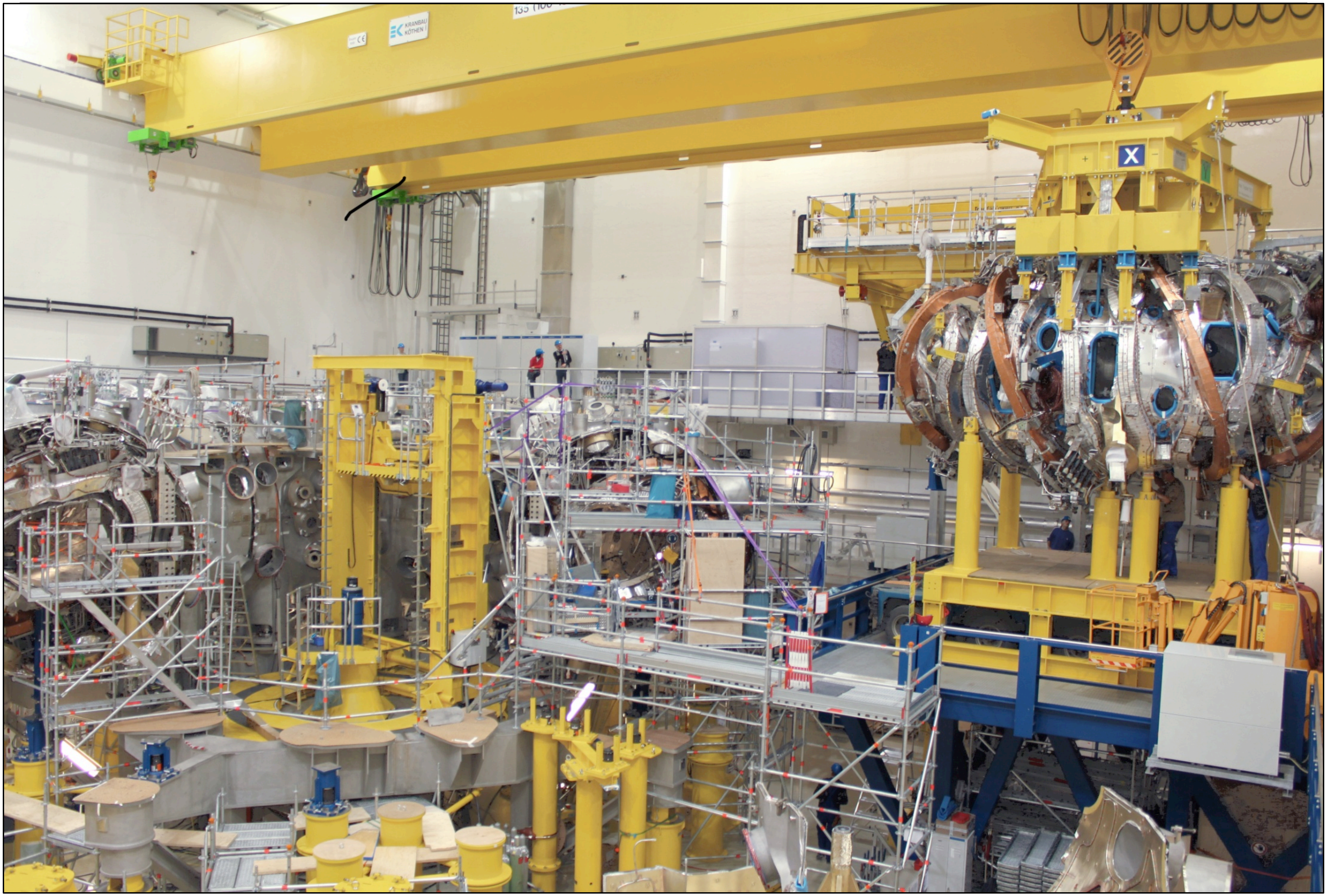
I. The device

II. Components

III. Integration

IV. Conclusions

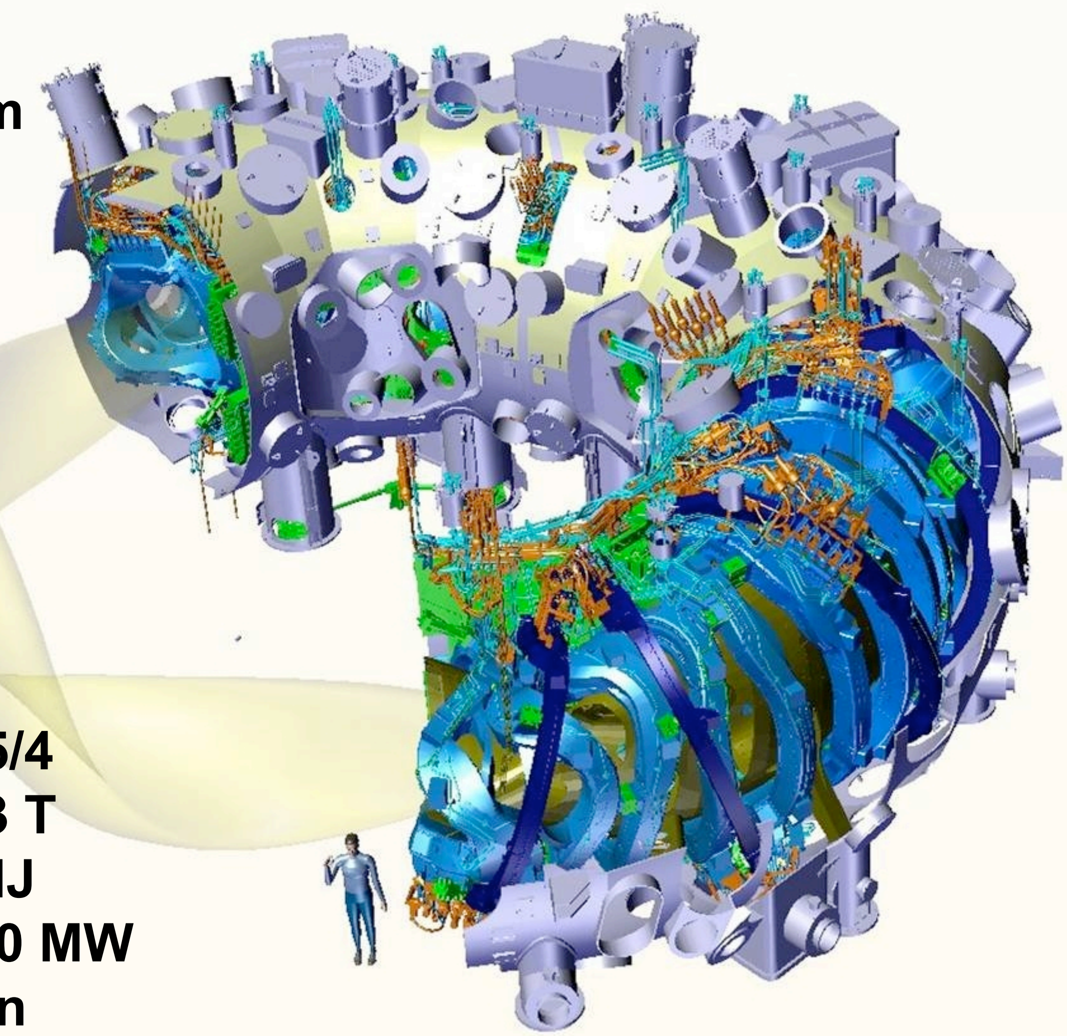
Stellarators are complicated?



The Wendelstein 7-X device

Key engineering and physics parameters

major radius	5.5 m
minor radius	0.53 m
plasma volume	30 m^3
number of ports	253
machine height	4.5 m
machine diameter	16 m
machine mass	725 t
cold mass	425 t
non-planar coils	50
planar coils	20
rotational transform	5/6 - 5/4
induction on axis	2.5 - 3 T
stored energy	600 MJ
heating power	15 - 30 MW
pulse length	30 min
energy turn around	18 GJ



The three missions of the project

mission I
optimized superconducting stellarators can be build

mission II
optimized stellarators achieve integrated fusion parameters

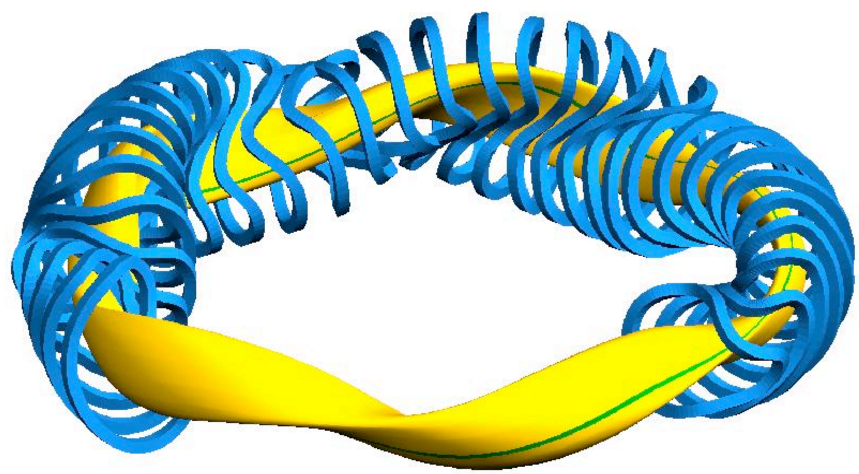
mission III
optimized stellarators can operate fusion plasmas in steady-state

Stellarator optimisation: W7-X

Physics optimization

1. feasible modular coils
2. good, nested magnetic surfaces
3. good finite-β equilibria
4. good MHD stability at high β
5. small neoclassical transport in $1/\nu$
6. small bootstrap current <100kA
7. good confinement of fast particles

magnet system

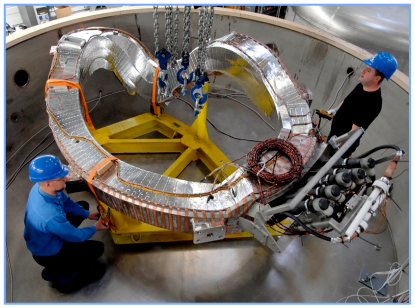


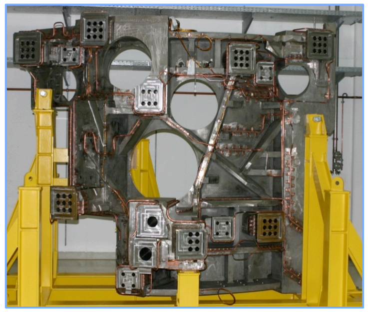
Stellarator features

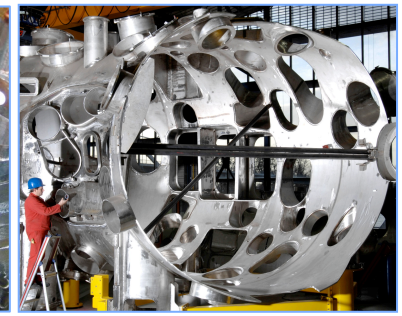
1. no current disruptions - no runaways
2. no current - inherently better stability
3. inherently steady-state capable
4. optimisation → tokamak performance
5. reactor-potential to be demonstrated

Major Device Components

The major components are manufactured, tested, delivered and assembled.







1 machine base	**delivered and assembled**
50 non-planar superconducting coils	**delivered and assembled**
20 planar superconducting coils	**delivered and assembled**
10 central support ring segment	**delivered and assembled**
about 300 support elements	**delivered and assembled**
20 plasma vessel sectors	**delivered and assembled**
10 outer vessel sectors	**delivered and assembly in progress**

Major Device Components

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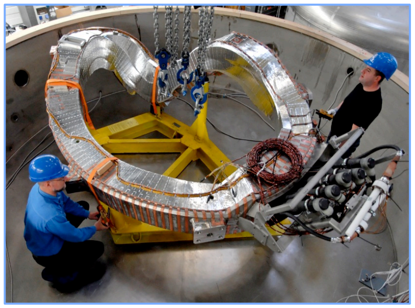
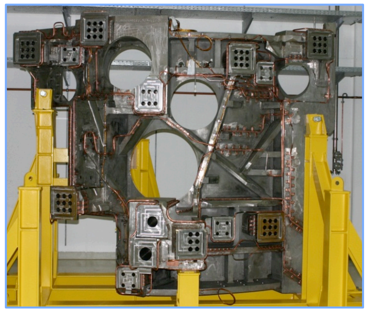
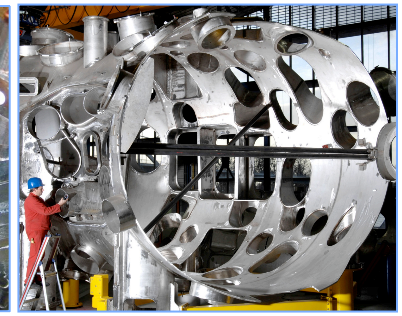



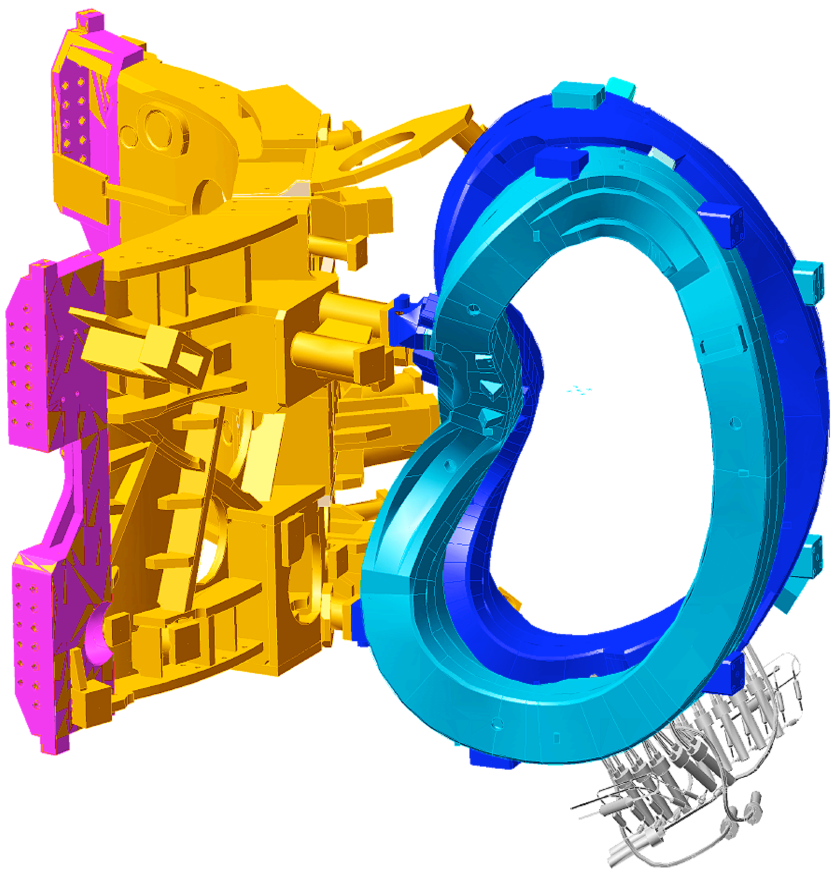



254 ports	**delivered and assembly in progress**
about 1700 cryo pipes and supports	**delivered and assembled**
15 cryo legs	**delivered and assembled**
about 113 bus bars and 400 supports	**delivered and assembled**
150 wall panels for plasma vessel	**delivered**
about 1000 thermal insulation elements	**delivery acc to schedule**
14 current leads	**series production in progress**

Superconducting coils

CAD model of non-planar coil

CAD model of central ring seg

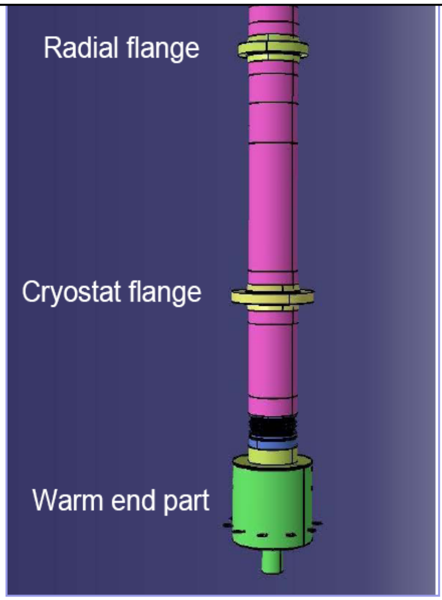


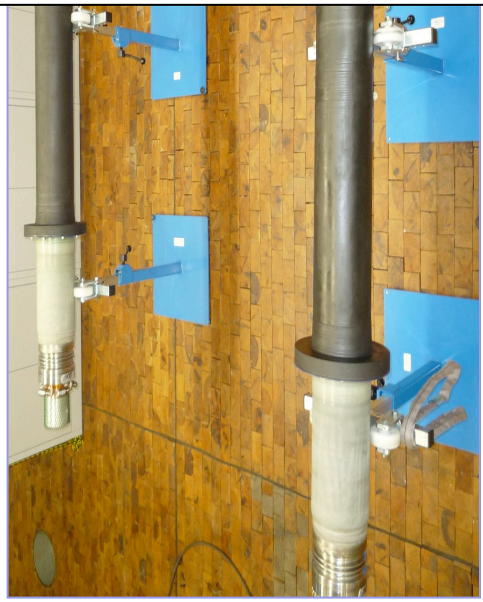
delivery of first coils in 2004

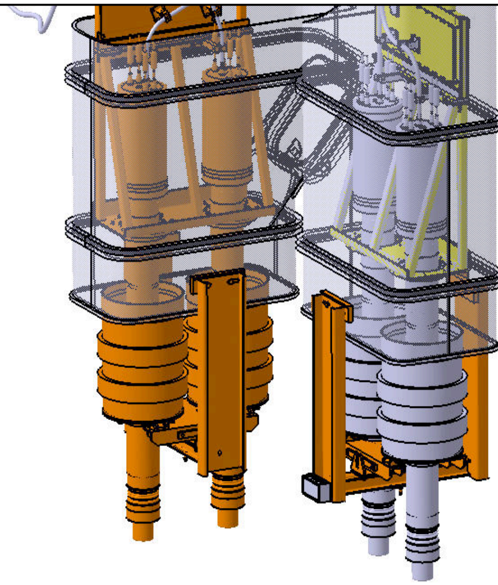
- 50 non-planar and 20 planar coils
- 243 NbTi strands Al cable in conduit
- 18.2 resp. 16kA and 6 resp. 4kV
- contract 100M€
- completed, tested, assembled

14 current leads

the superconducting magnet system of Wendelstein 7-X
T. Rummel et al. Wednesday 16:20 SO3D-3





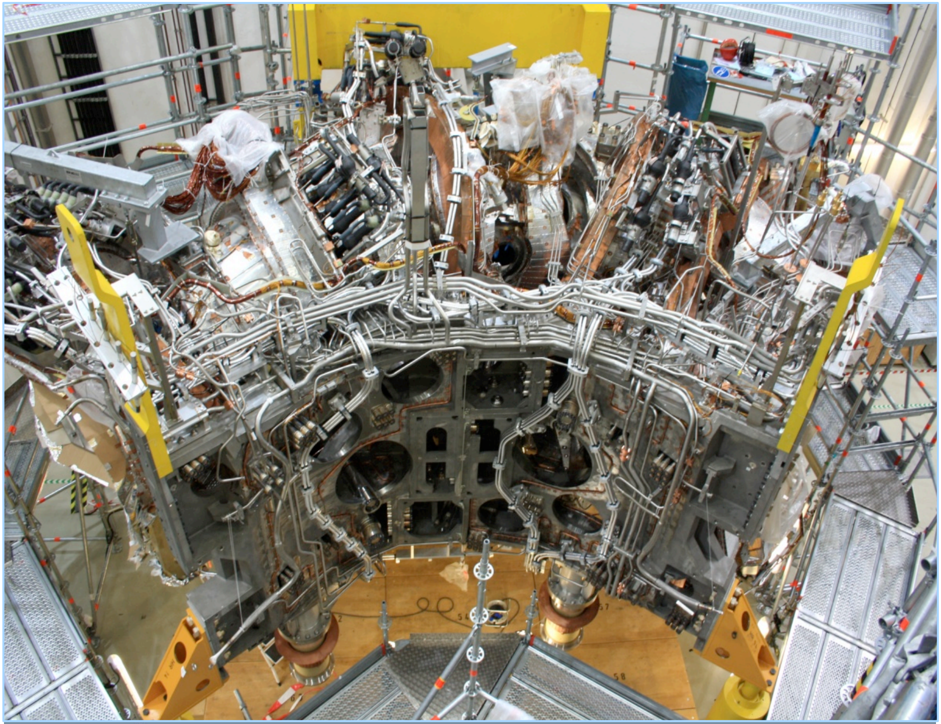


- **HTSC based concept**
- **„upside down“**
- **test successful**

- **series manufacturing KIT**
- **test cryostat ready**
- **delivery acc to schedule**

- **ORNL/PPPL concept**
- **tooling and mock-ups**

Cryo piping & bus bar design & assembly



- 120 SC bus bars and joints
- 300 low Co steel Helium pipes
- clamps and (semiflexible) holders

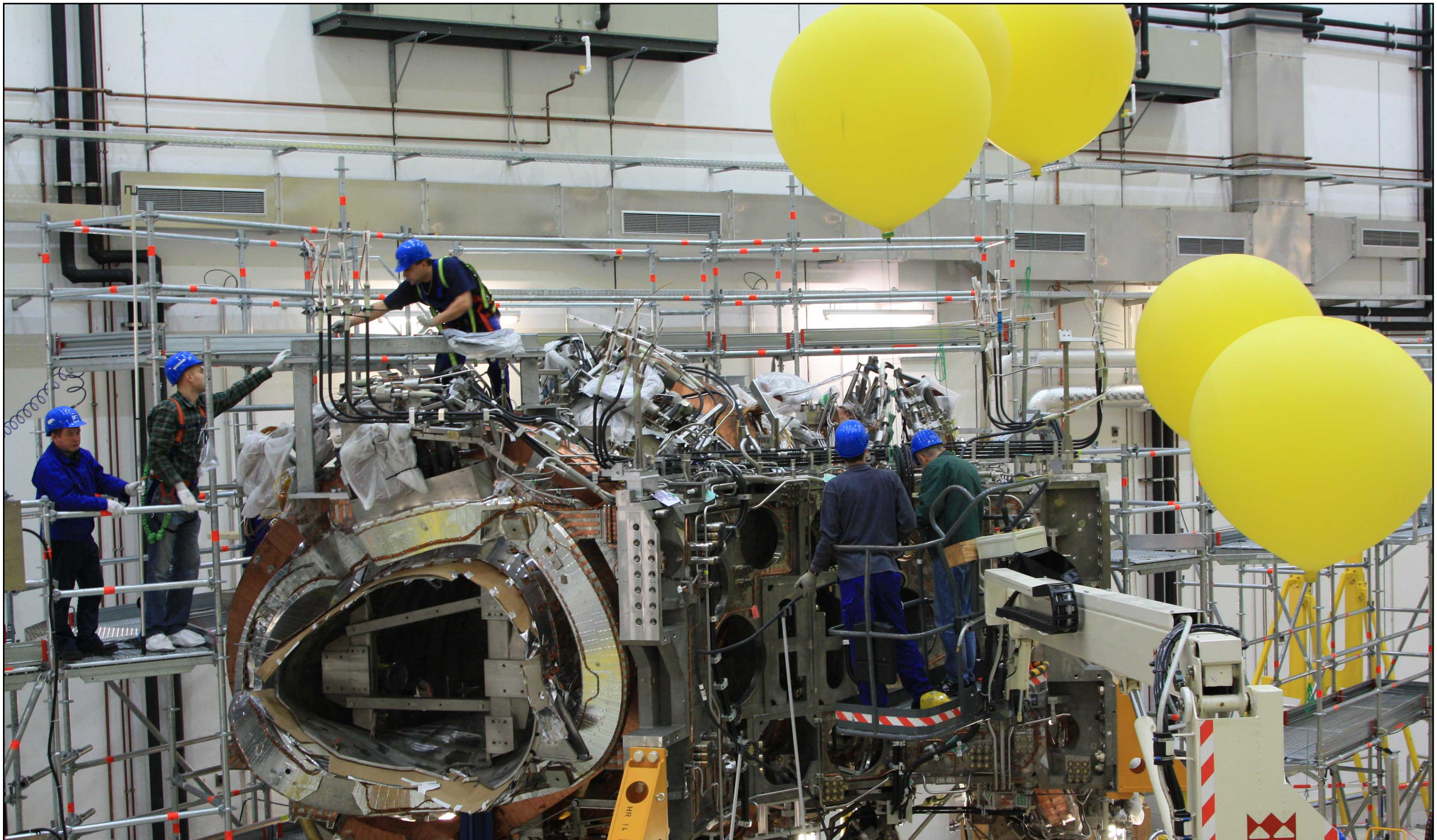
- cryostat volume minimized
- extremely tight space conditions
- three-dimensional design
- collision control and mitigation
- pre-manufacturing and assembly

Forschungszentrum Jülich

- all bus bars and cryo pipes have been manufactured and delivered
- all five modules have both bus bars and cryo pipes assembled

- systematic change management turned out to be extremely important

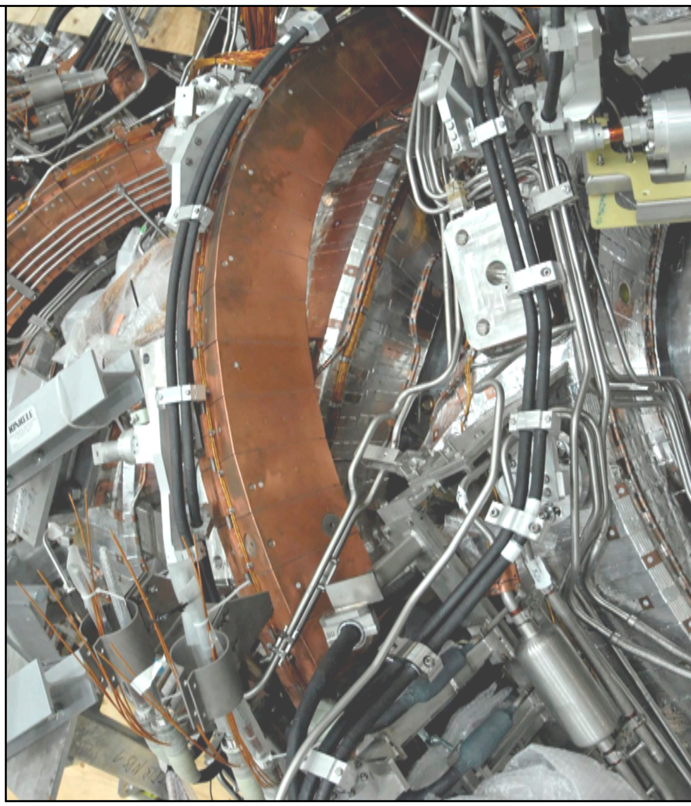
Assembly of the bus bar system

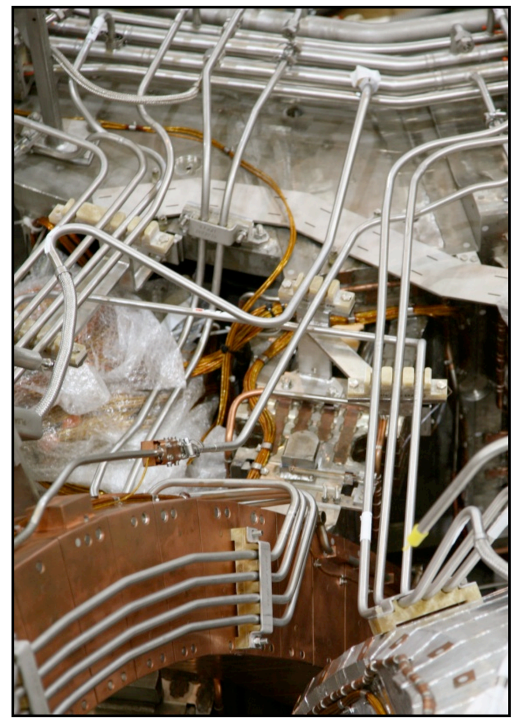


Helium-filled baloons to support the (up to 14m long) bus bars.

Helium pipework

configuration control inside the W7-X cryostat
C. Baylard et al. Thursday 11:30 SO4C-5





high demands on the quality of the 500 orbital welds

Cryostat vessel design & assembly

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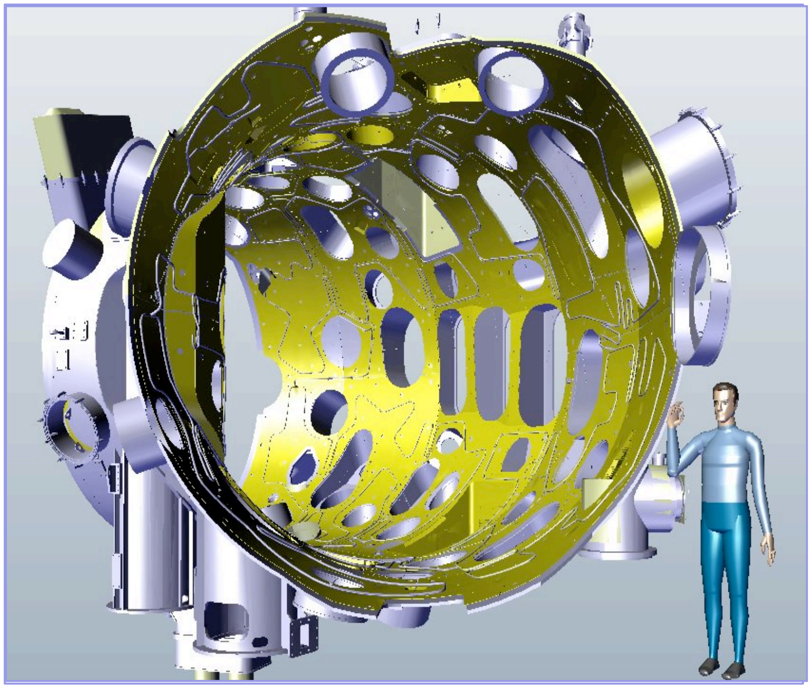
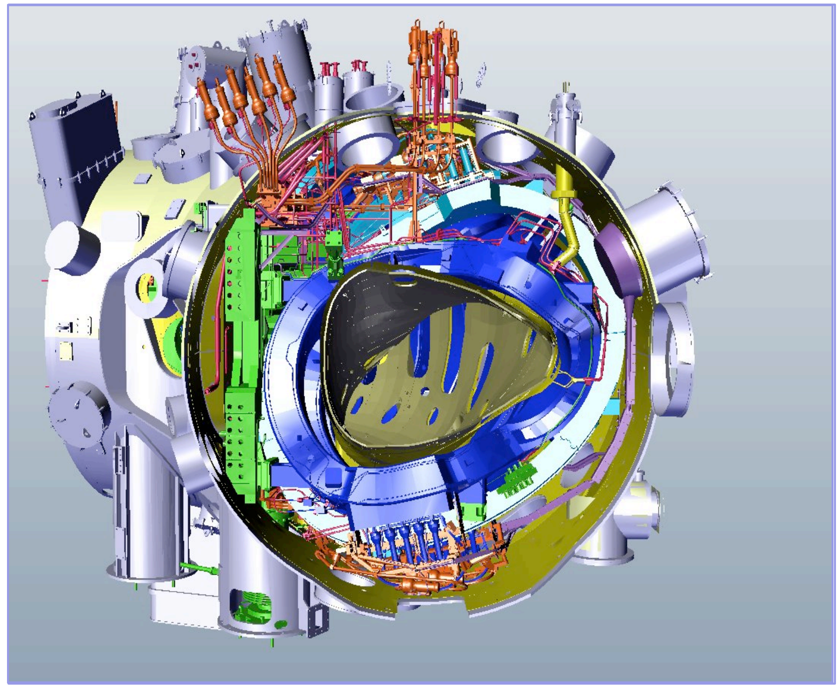


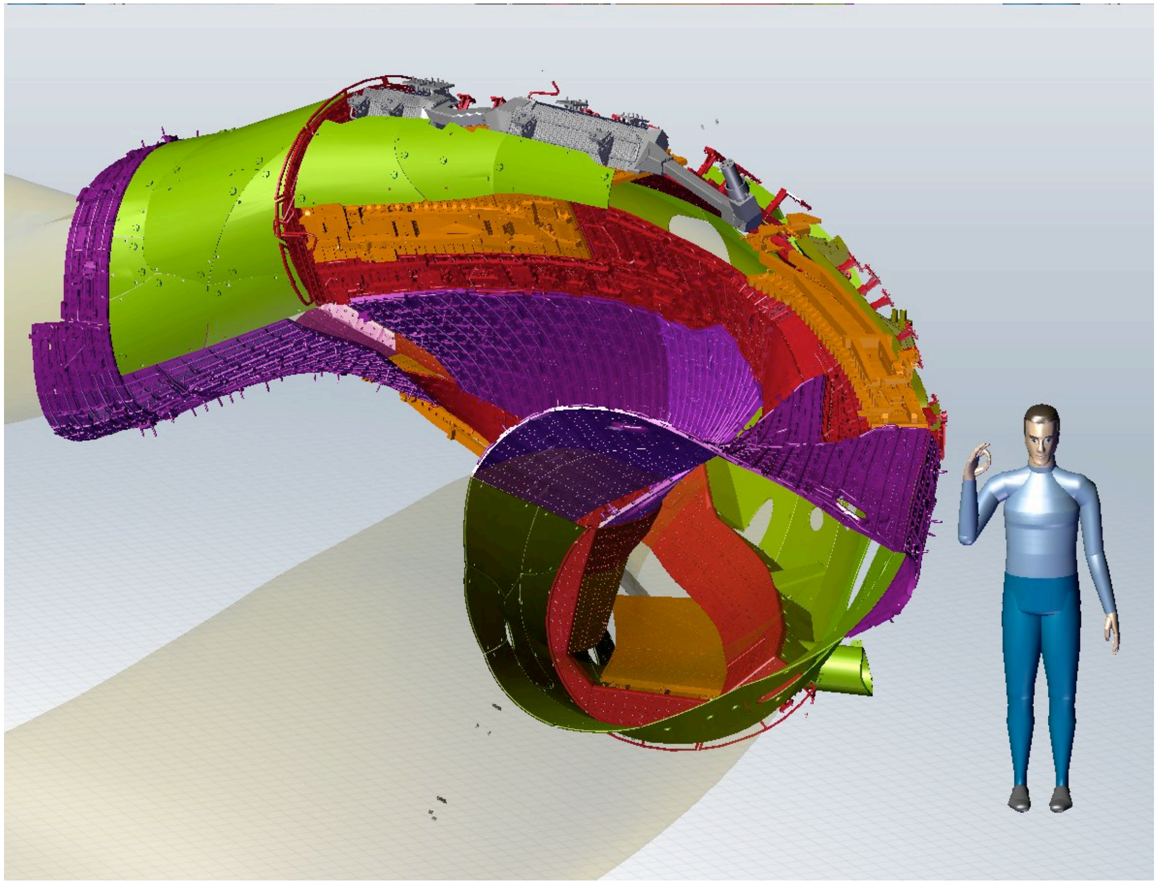


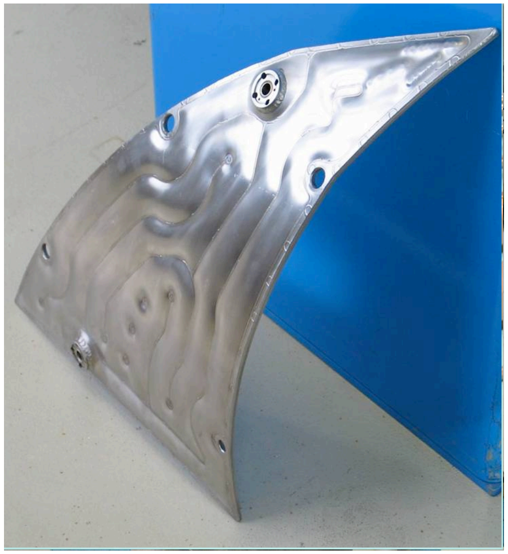
- 10 steel half shells
- 500 openings and domes
- deformation by ist own weight
- MLI and LN_2-cooled shields
- very tight tolerance requirements

- magnet module into lower shell
- upper shell on magnet module
- welding of equatorial gap
- removal of stiffeners
- closing the module separation

In-vessel components

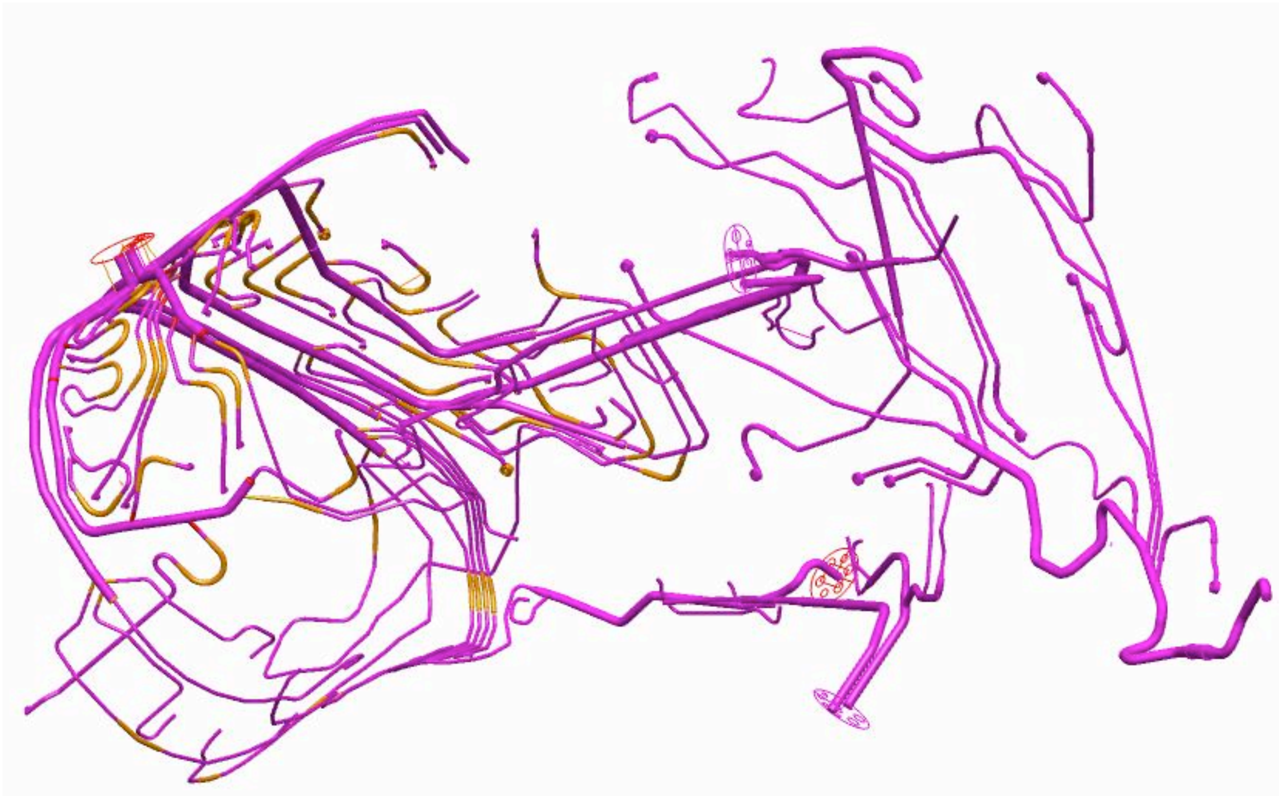
actively cooled wall elements heat load from 100kW/m^2 to 10MW/m^2

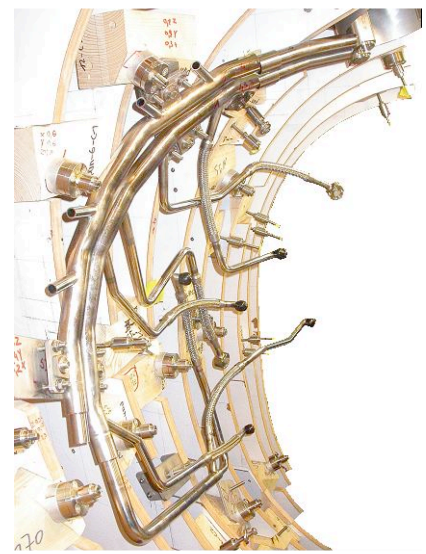




60m^2 heat shields graphite bolted on CuCrZr and 60m^2 steel panels

Water cooling of in-vessel comp's





- about 100 port plug-in units for supply
- about 4km in-vessel water pipe lines
- manifolds manufactured with collaring technique

High-heat flux elements and assembly

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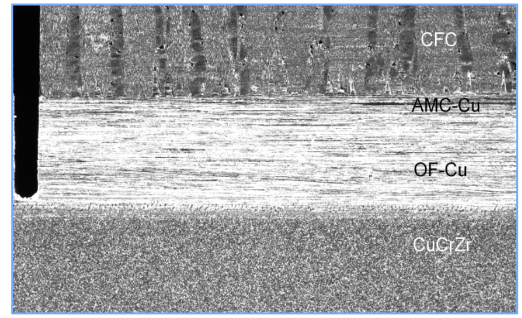
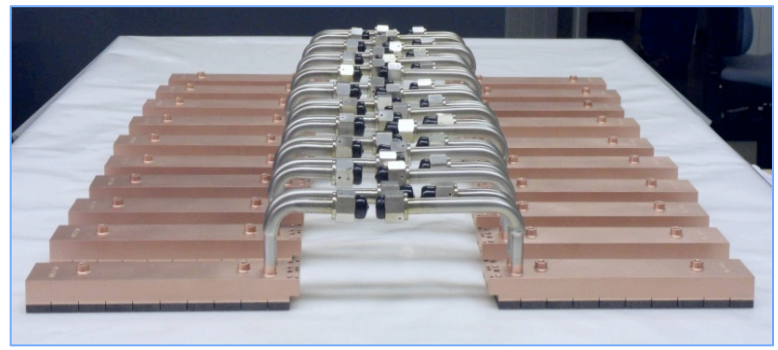
Status

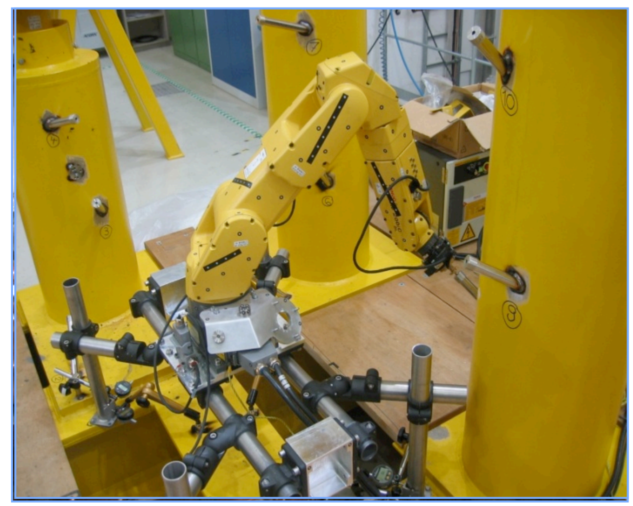


- Plansee contract with significant R&D
- CFC HIPed and e-beam welded on CuCrZr
- 100 (out of 890) HHF elements delivered
- HHF test of 20 elements full success
- series manufacturing of first lot released

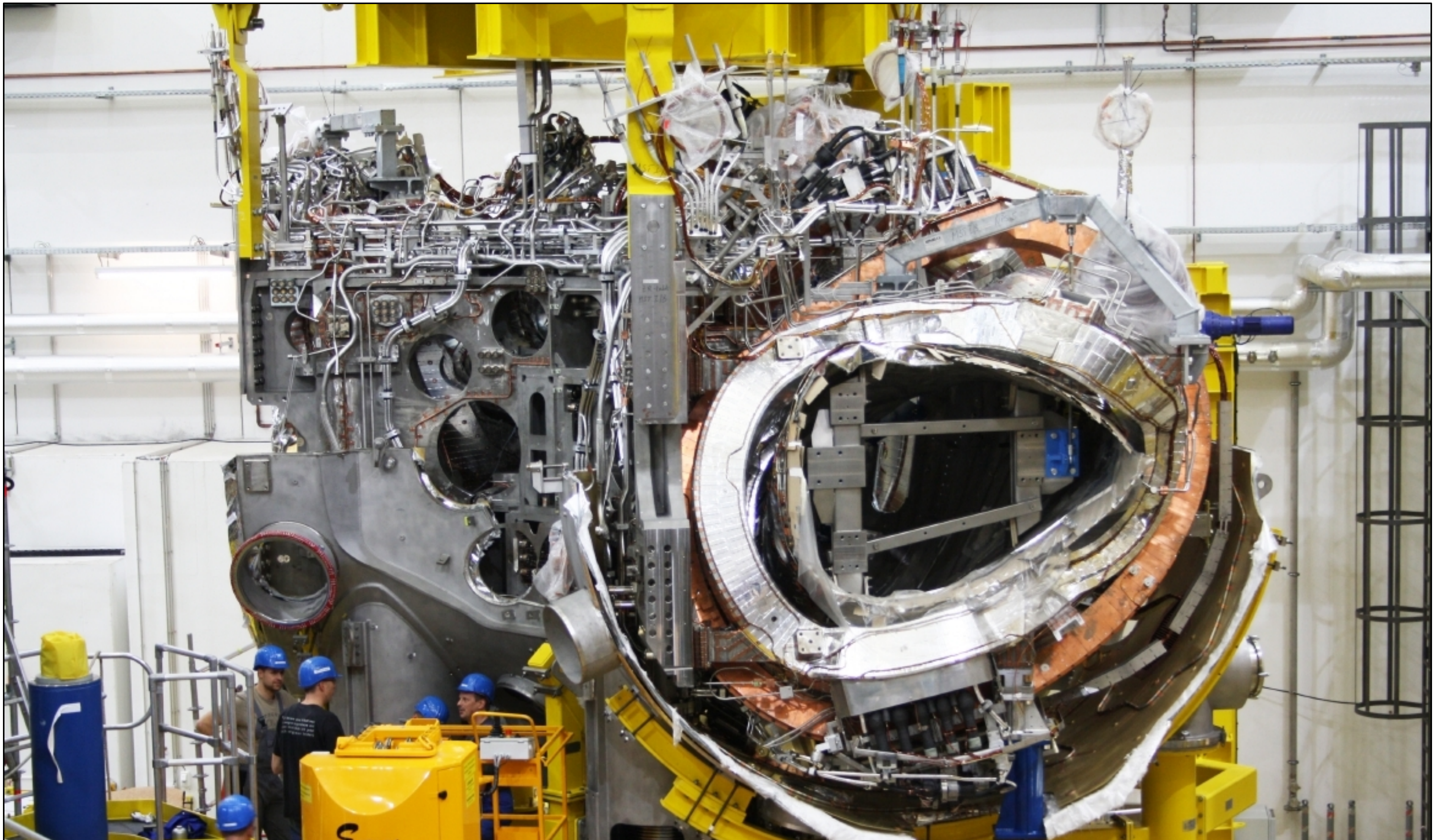


Assembly preparation

- assembly test program in one magnet module
- precision requirements mostly met
- up to now no show-stopper found
- positioning tools developed
- logistic planning (assembly v 5 man ports)
- increase of personnel resources

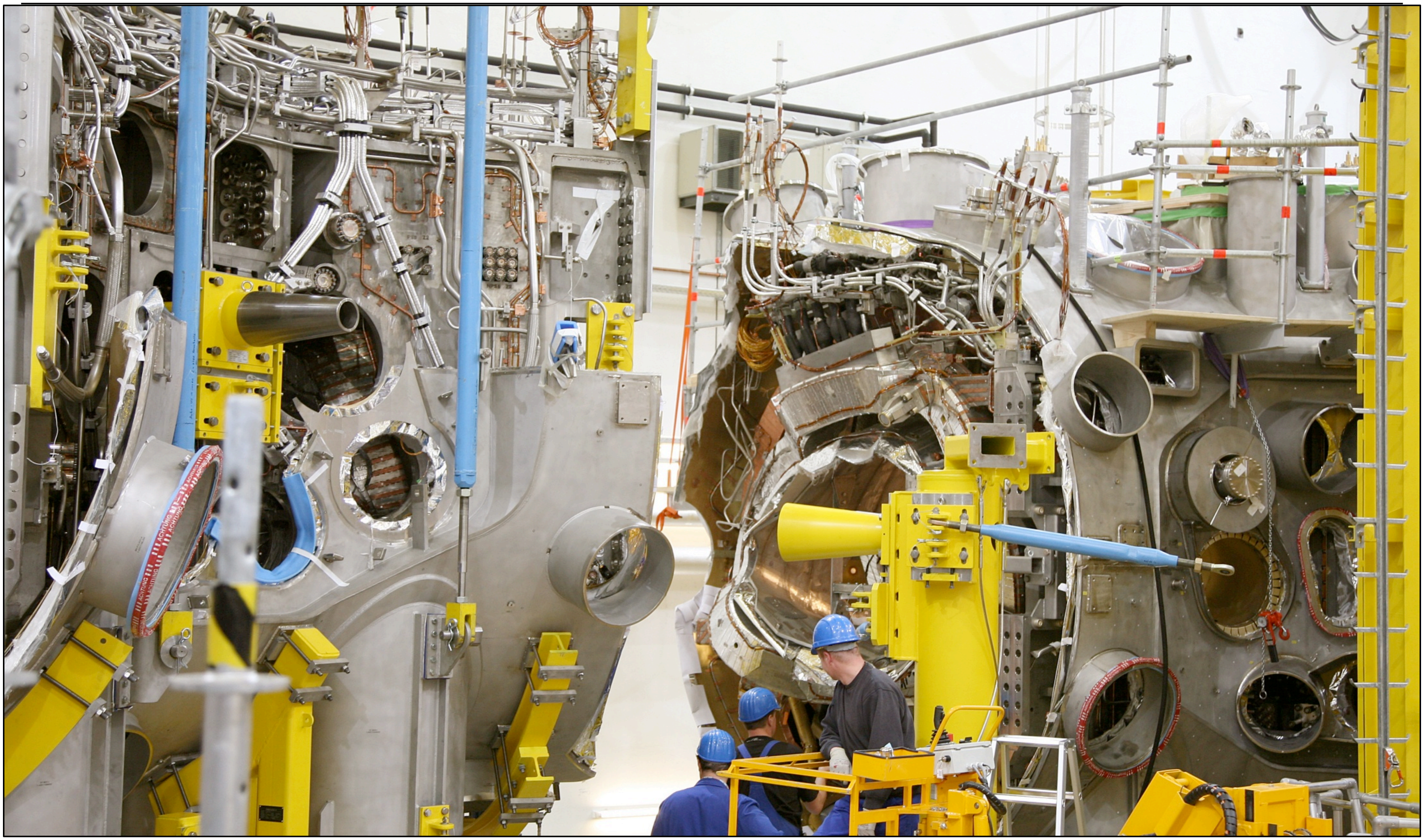


Module assembly



Magnet module inserted into lower shell of the outer vessel.

Joining completed modules



Main task: The assembly of the 253 ports with about 100 versions.

Port assembly

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Progress and challenges in the assembly of W7-X
T. Braeuer et al. Wednesday 15:30 SO3C-1

Lessons learned from fabrication and assembly of W7-X
H.S. Bosch et al. Thursday 10:00 SO4C-1

Earned value management in the W7-X project
A. Lorenz et al. Thursday 11:15 SO4C-4

Posters Tuesday 10:00-12:00

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Lessons learned from design and manufacturing of the coil support structure of W7-X

SP 2-3: D. Chauvin

Space reservations for the peripheral components of W7-X

SP2-7: S. Renard et al.

Purpose and design of trim coils for the W7-X stellarator experiment

SP2-11: K. Risse et al.

Overview of main mechanical components and critical manufacturing aspects for the W7-X cryostat

SP2-15: T. Koppe et al.

A proposed scraper element to protect the end of the W7-X divertor target elements

SP2-41: A. T. Peacock et al.

Conclusions

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- after the crisis 2003-2007 the project is now well on track since 4y
- stellarators are by nature more complex than tokamaks – no surprise
- one needs the right tools: 3d physics codes
  3d CAD design
  3d FEM
  3d metrology
  3d manufacturing
  3d assembly tools
- the benefit will be most likely much tamer operation incl. steady-state
- goal is to demonstrate the reactor potential of the optimized stellarator
- many possibilities for simplification have been found already now
- to be developed: 3d blanket solutions
  3d remote handling

Thank you!