Progress and Challenges in the Assembly of W7-X

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Outline

1. The project – Wendelstein 7-X
2. Procurement Status
3. Assembly Status
4. Challenges of next steps
5. Final remarks

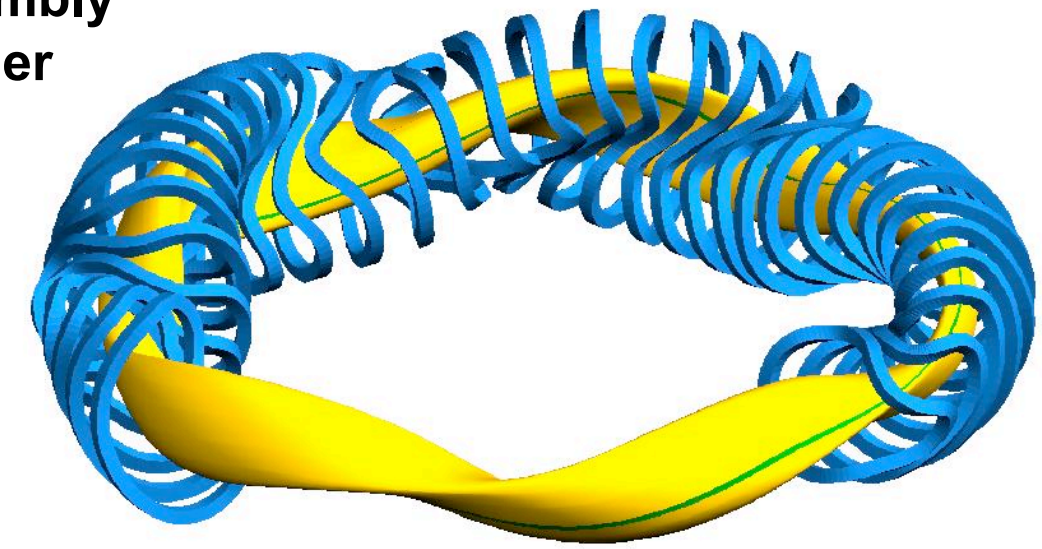
The project – Wendelstein 7-X

Wendelstein 7-X is a modular, optimized stellarator

Properties:
- magnet field is produced only by external coils
- no current driven instabilities
- fivefold symmetry

Physics goals:
- Test magnetic field optimization
- Prove of reactor feasibility of stellarator-principle

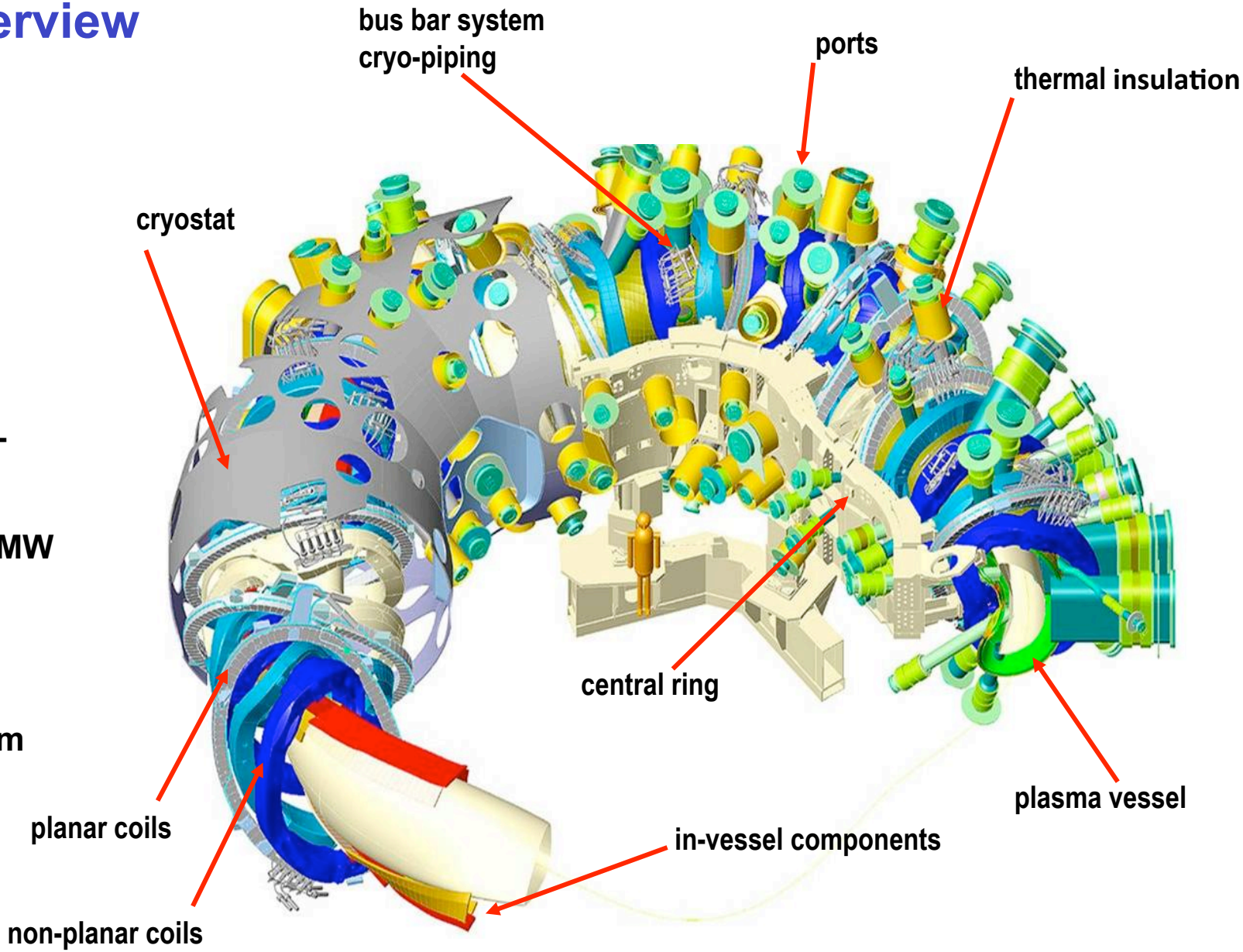
Technological goals:
- steady state operation
- modular assembly
- assembly under industrial like conditions



Schematic Overview

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:254
rot. transform:5/6 -5/4
induction on axis:< 3T
stored energy:600 MJ
heating power:15 -30 MW
pulse length: 30 min

machine height:4.5 m
machine diameter:16 m
machine mass:725 t
cold mass:425 t



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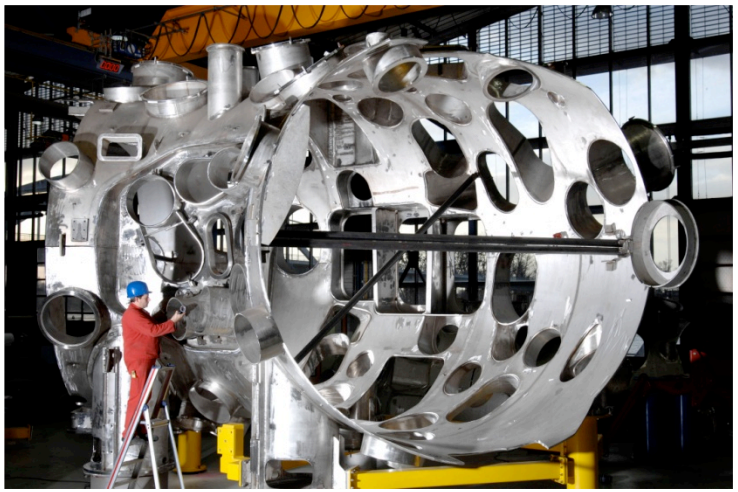
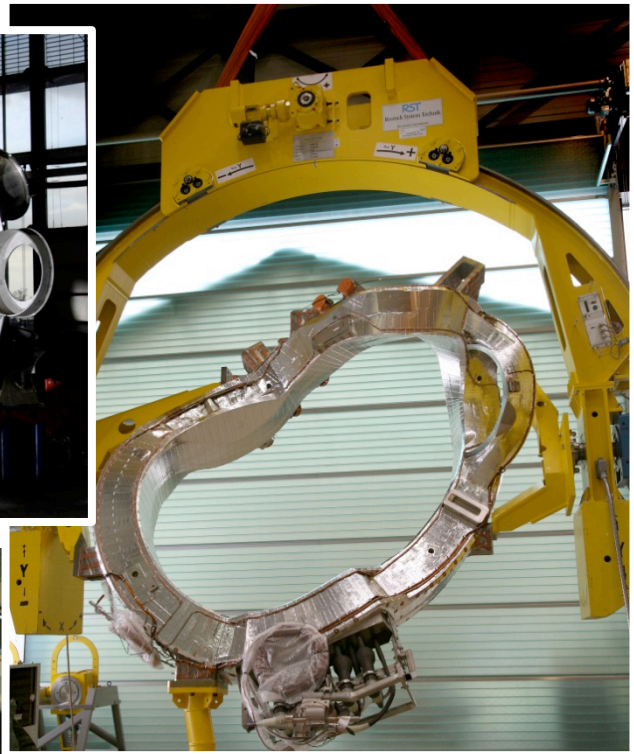
Procurement Status

Most of the basic device components have been delivered

- 1 machine base
- 50 non-planar coils
- 20 planar coils
- 10 central support ring segment
- ≈ 300 support elements
- 20 plasma vessel sectors
- 10 outer vessel sectors
- 254 ports
- ≈ 1700 cryo pipes and supports
- 15 cryo legs
- ≈ 113 bus bars and 400 supports



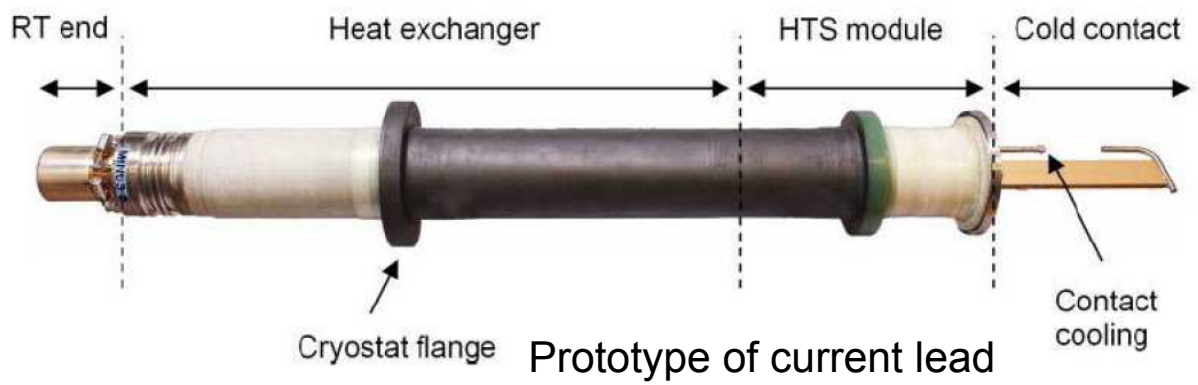


All incoming components were intense checked:

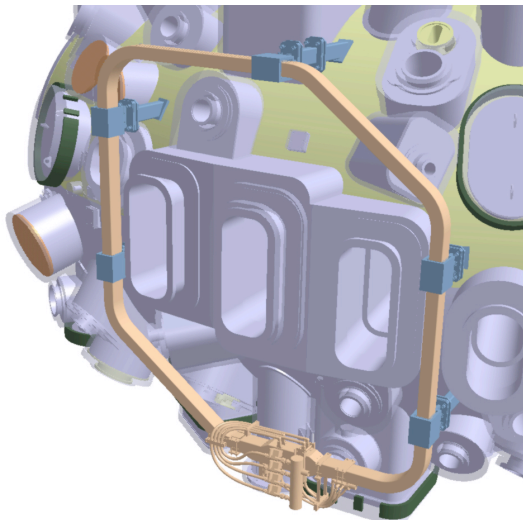
- **geometrical checks**
- **leak tests**
- **cryogenic test for main field coils**

Basic device components in manufacture, test or design

Thermal insulation (ports)	delivery according to assembly progress
In vessel components	most delivered; partly in series production
Current leads	prototypes successfully tested, series production started
Trim coils	in production, partly in design
Peripheries components (platforms, pipes, cables)	manly in design, partly in production or delivered



Prototype of current lead



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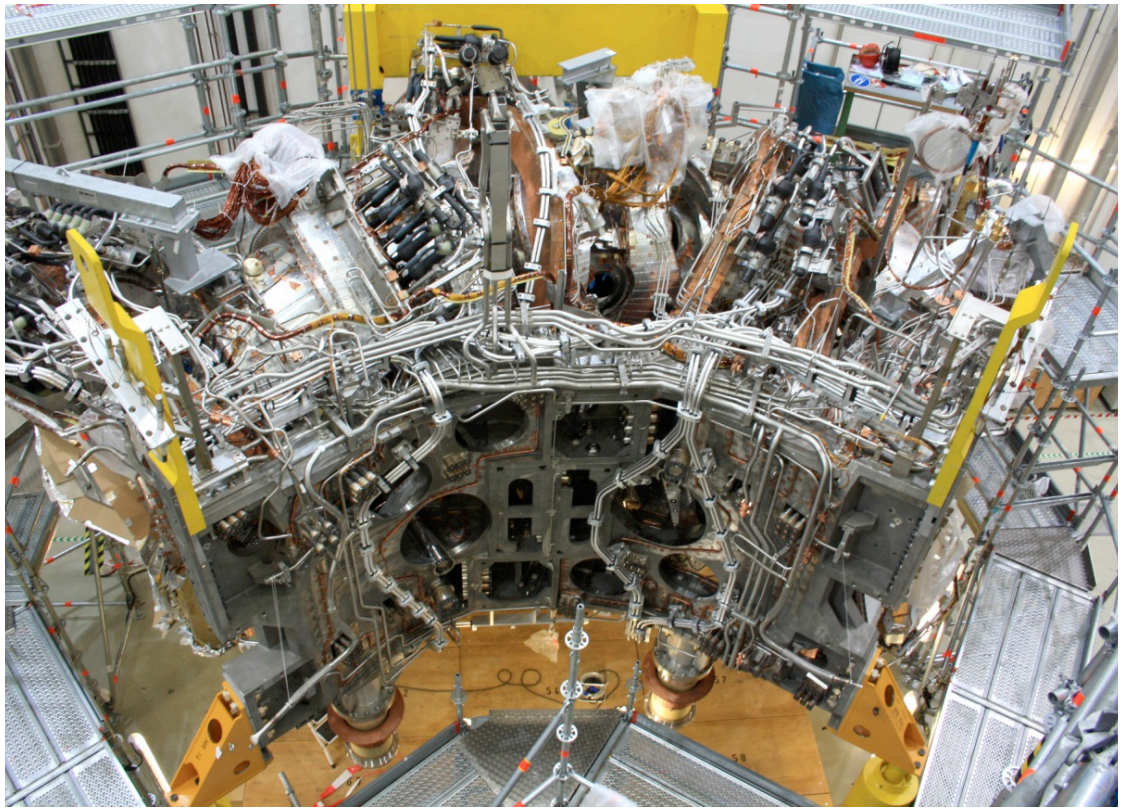
Pre-assembly of magnet system modules:

- Pre-assembly of 5 x 2 half modules
  - Connection of 5 non planar coils, 2 planar coil and support structure
  - Inserting vacuum vessel with thermal insulation
- Alignment of two half modules
  - Bolting of support structure flange
  - Welding of vacuum vessel
- Installation of bus bars, cryo pipes and sensors (last step of last module)



4 of 5 magnet system modules finally pre-assembled

5th (last) magnet system module in final pre-assembly phase

Pre-assembly of magnet system modules:

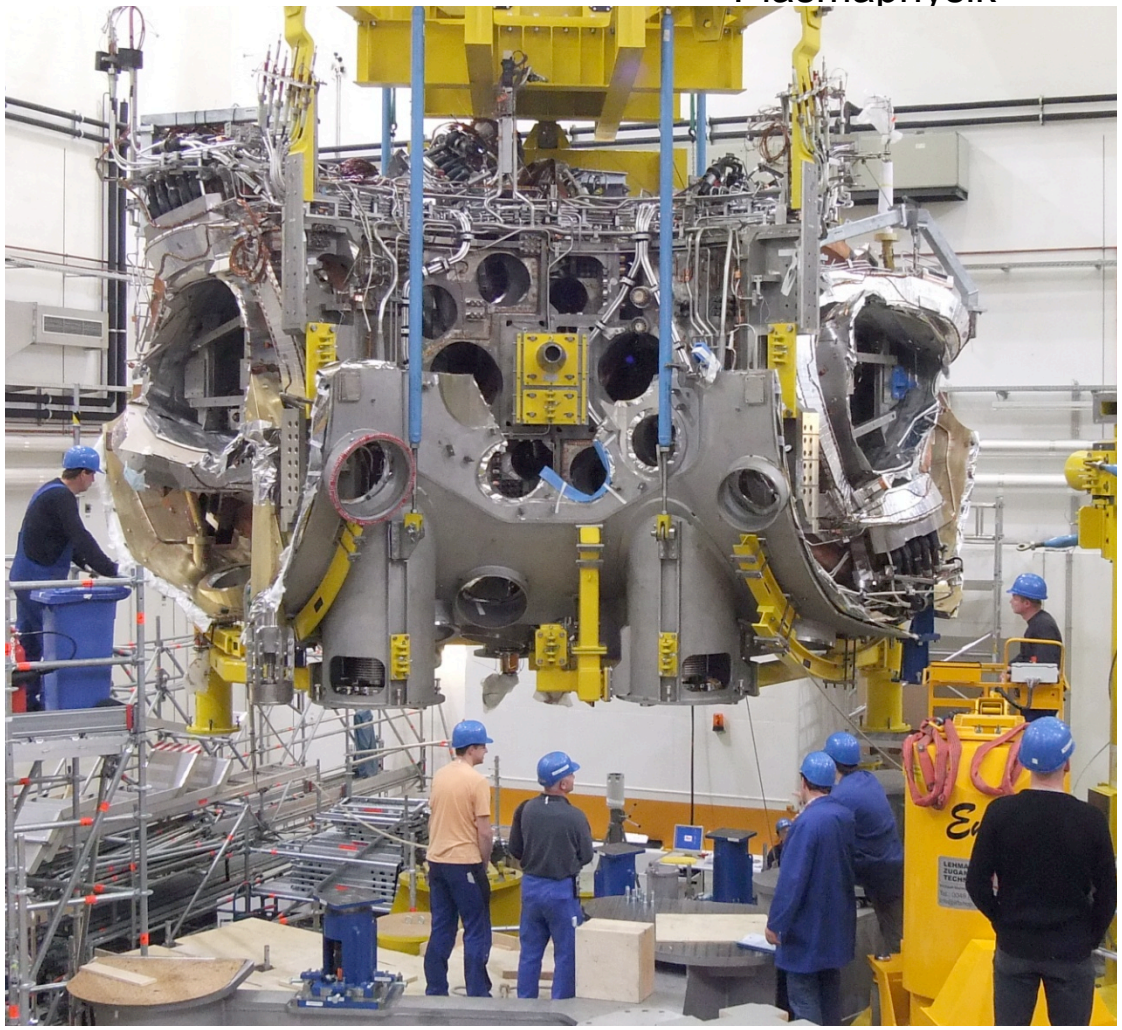
Main experience:

- requirements on coil positions are achieved
  - no part of any coil shows deviation of >3.2mm in comparison to nominal
  - Expected, that magnet field quality will be fulfilled ($2 \cdot 10^{-4}$)
- All other parts of module are inside geometric tolerances too
  - In only a few cases rework was necessary to avoid collisions
- All super conductor joints and cryo pipe were successfully leak and high voltage tested up to now

Assembly Status

Final assembly in torus hall:

- Adjustment of magnet modules into there final position
  - Field calculations have delivered optimized co-ordinates
- Adjustment of vacuum vessel
- Adjustment of lower and upper shell of outer vessel and welding of both shells
- Port assembly (in progress, next slides)
- Connection of modules (MS, VV, OV)
- In vessel assembly (starts end of the year)
- Assembly of periphery (started)



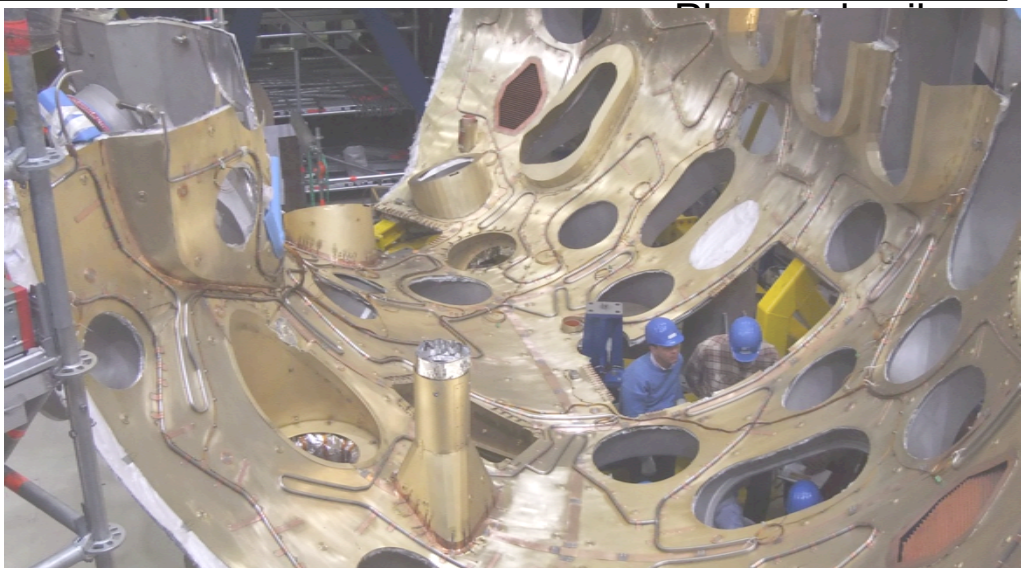
4 of 5 modules are inserted into outer vessel

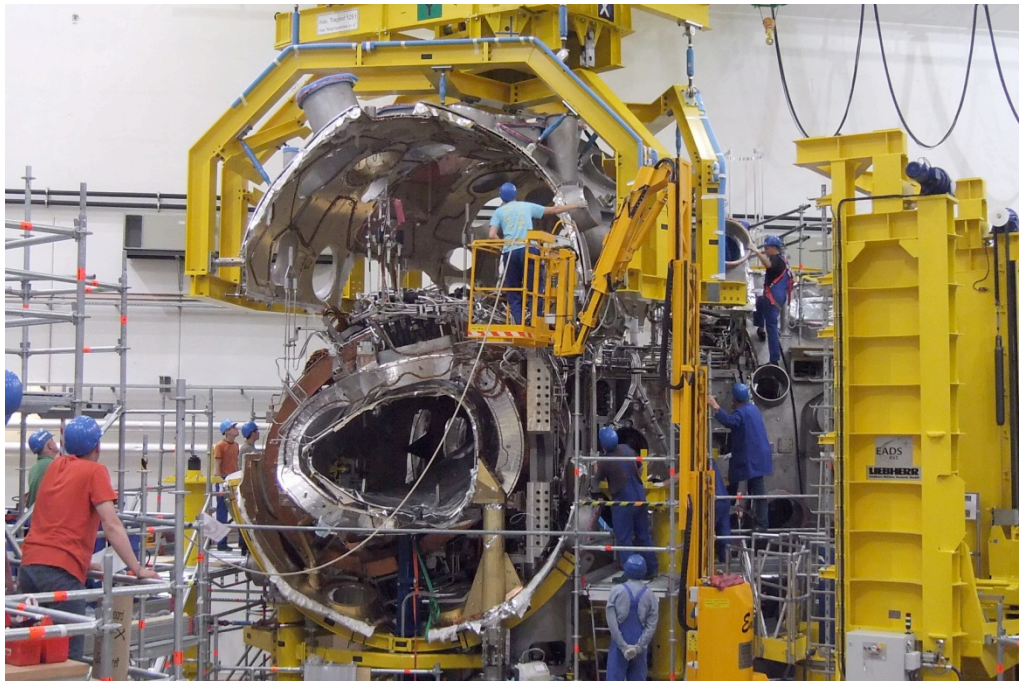
4 of 5 modules on there final position on machine base

Final assembly in torus hall:

Main experience:

- Adjustment of magnet system modules (weight ≈ 100t, dimension ≈ 7x5x5m³) was possible in r ≤ 1.5mm
- Adjustment of outer vessel shells and vacuum vessel in r < 1.5 resp. r < 2 mm
- Deformation of outer vessel due to welding and death weight up to 15mm considered in the clashes-free design





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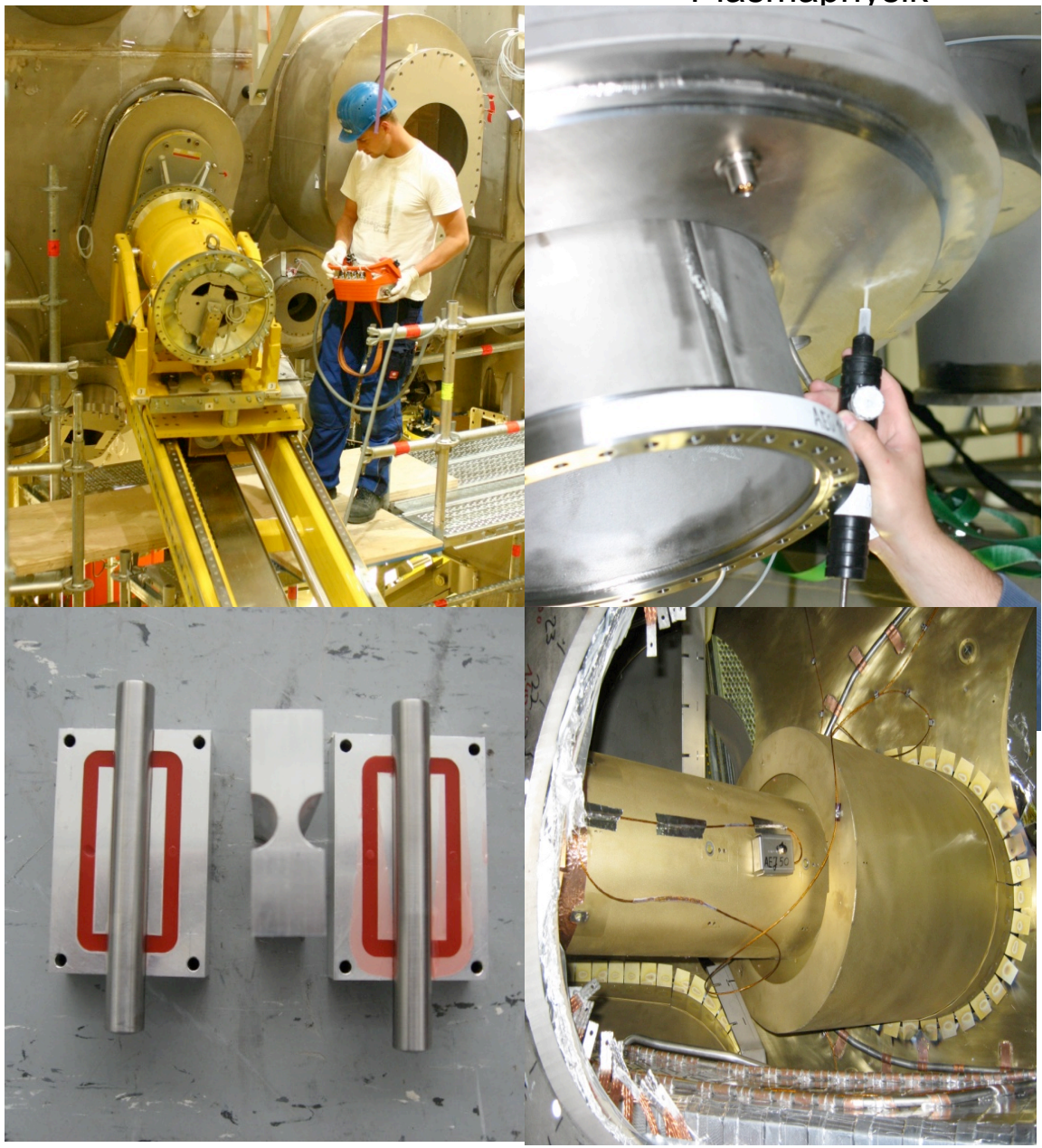
Challenges of next steps

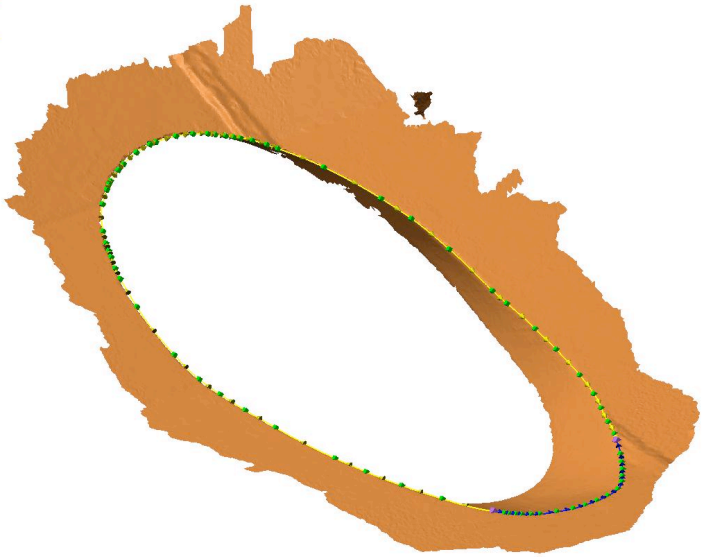
Challenges:

- **Port assembly**
  - 20 support and 22 diagnostic ports per module
- **Joining of vacuum and outer vessel**
  - 5 separation planes
  - Handling of shrinkages
- **In vessel component assembly**
  - Very complex assembly situation
- **Leak testing**
  - All (without some exceptions) seam are tested
- **Current lead assembly**
- **Periphery**

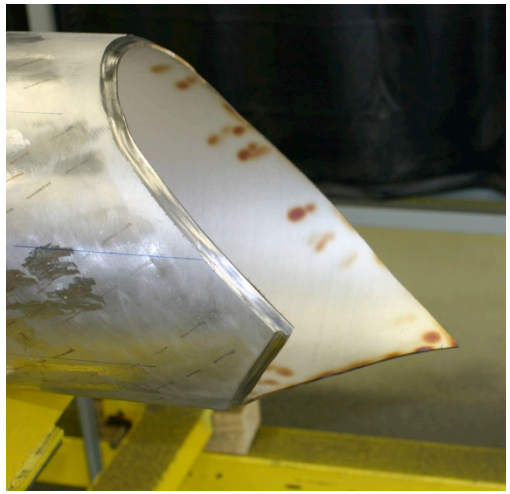


Port assembly: challenges

- High accuracy requirements
  - < 2.5…8.5mm to CAD
  - < 5 mm pipe to pipe
    (for diagnostic ports only)
- Interplay of heavy steelwork and delicate installation of thermal insulation
- Tight schedule
- Huge demand of resources
  - Welding capacity (2 shifts)
  - Permanent Metrology support



Substitution of a trial assembly process by a metrology supported method to find the 3D cut contour



Port assembly: status

- 1st Module:
  - All support and diagnostic ports final welded on vacuum and outer vessel
- 2nd module:
  - All support ports final welded
  - All diagnostic ports tack welded
  - Final welding of diagnostic ports in progress
- 3rd Module
  - Positioning and tack welding in progress (70%)
- 4th and 5th Module
  - No port assembly up to now

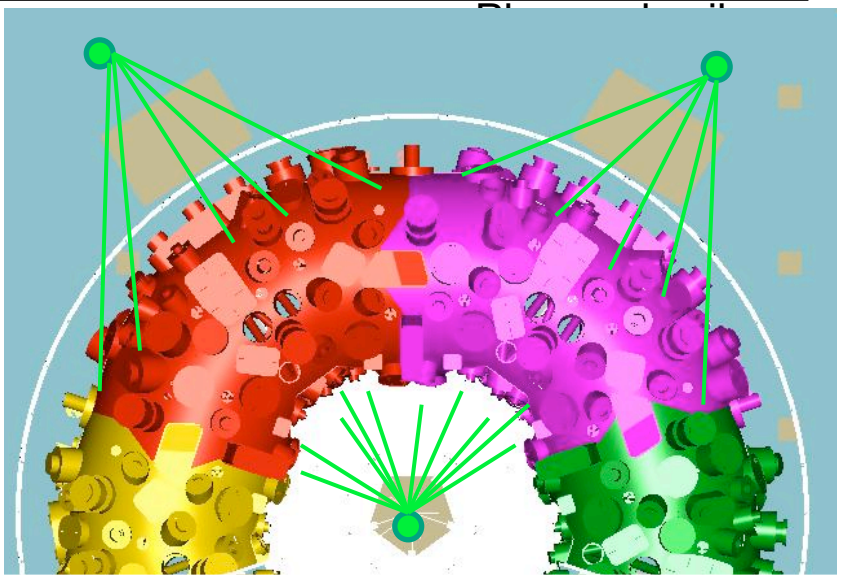
Port assembly: experience

- In 1st module few critical ports due to position deviations
- A full metrology supported welding process is necessary to guide the welder
- welding technology has been optimized; use of supports for death weight compensation and various stop blocks
- Intermediate cooling with CO_2
- Contour taking by metrology can substitute a trial assembly
- In 2nd and 3rd module requirements are fulfilled

- Port welding is more resource consuming than expected !!

Joining of vacuum and outer vessel

- Weld shrinkage force displacements and deformations
- Vessels have to be moved before welding to compensate weld shrinkage
- Gap between vessels (≈ 140 mm) will be measured and individual splice-plates will be manufactured (MDT)
- Welding will be supported by metrology (up to 3 Laser-Tracker simultaneously)
- Welding procedure of last module will be adapted (based on experience of first modules)



Challenges of next steps

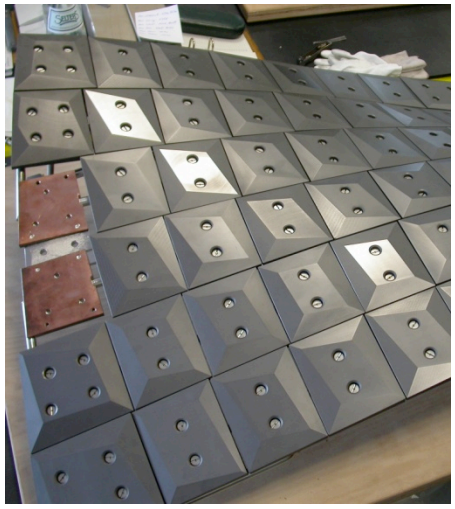
In vessel component assembly

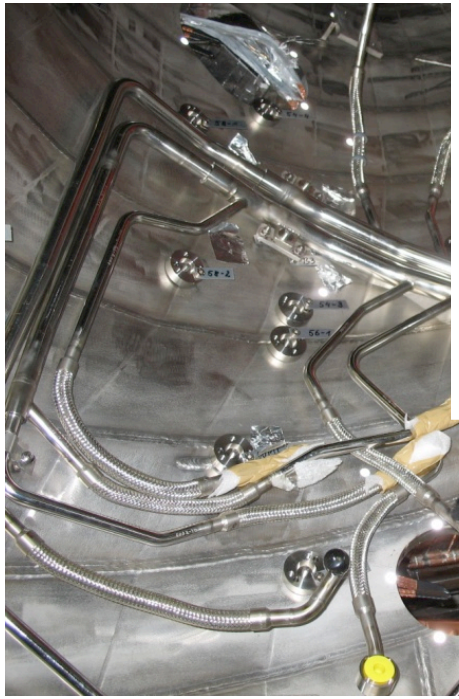
- Lots of mounting parts, e.g. ≈ 1000 weld studs per module, to be adjusted and welded on vessel surface
- Lots of 3D-shaped parts to be very precise 3D adjusted
- Lots of (water-) pipes to be welded inside of vessel

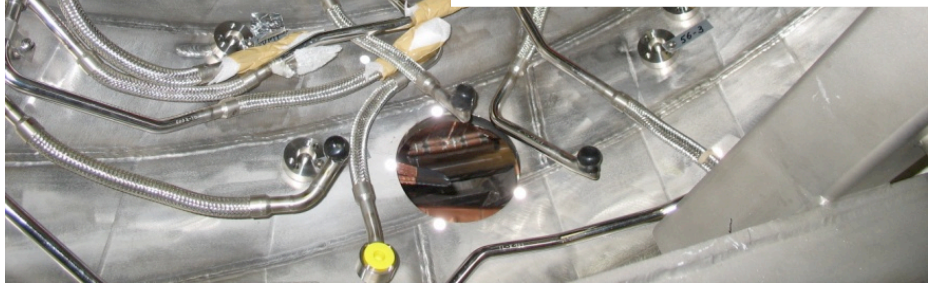
- Very tight assembly space
- Most of components have to be transported through a man-port
- Entrance for staff only through man-port

- High demands of leak test capacity

- Clean room requirements

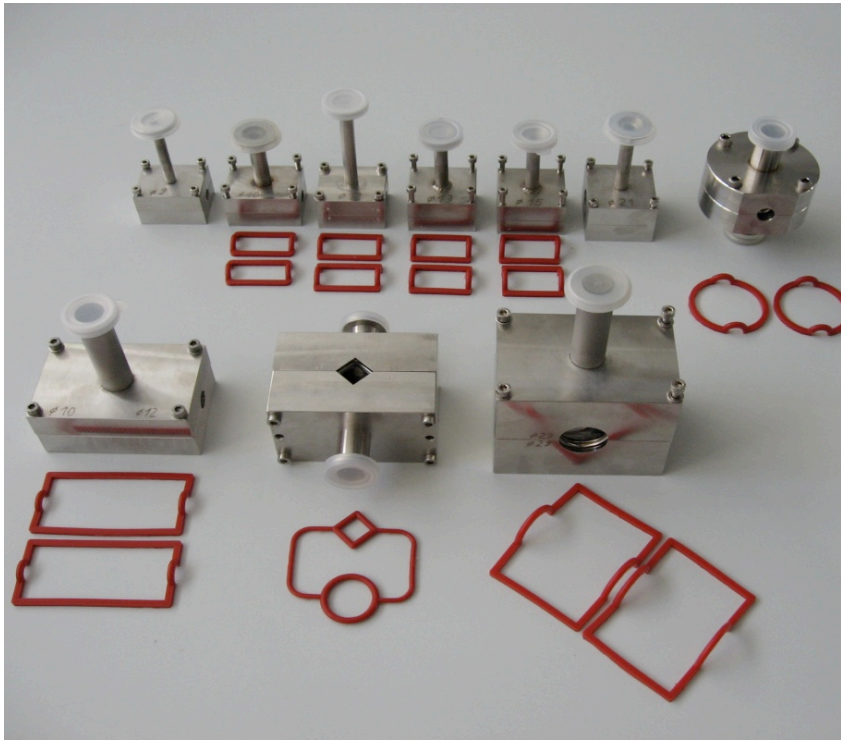






Leak testing

- Weld seams are routinely tested to a leak rate < $1*10^{-9}$ mbar*l/s
- Meanwhile there is a stock of about 100 different leak-test chambers available
- Welding seams at He-pipes made in assembly rigs are thermally shocked (77K) and leak tested
- Joints of busbars and coils are tested locally at RT
- Assembly welds at water pipes in plasma vessel will be leak tested at 430K (ohmic-heating heating)
- HV tests are performed under Paschen conditions



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Final remarks

- Pre-assembly of magnet system modules nearly completed
- 4 of 5 modules on their final position on machine base
- Port assembly runs routinely

- No serious quality deviation occurred
- effective QM-system

- Mock ups and trial assemblies are essential prerequisites to ensure a smoothly running work on the assembly sites

- Higher resource needs of some work packages, complex logistic and a increased work density
- High qualified workers were hired from industry
- In the assembly a 2-shift system (up to 88h/week) was and is used

- Advanced weekly and 4-weekly plans are necessary for an efficient work planning

- Since schedule update in 2006 all milestones were met

Commissioning date is still on the middle of 2014

Thank you for attention !