The Wendelstein 7-X project and its relation to ITER

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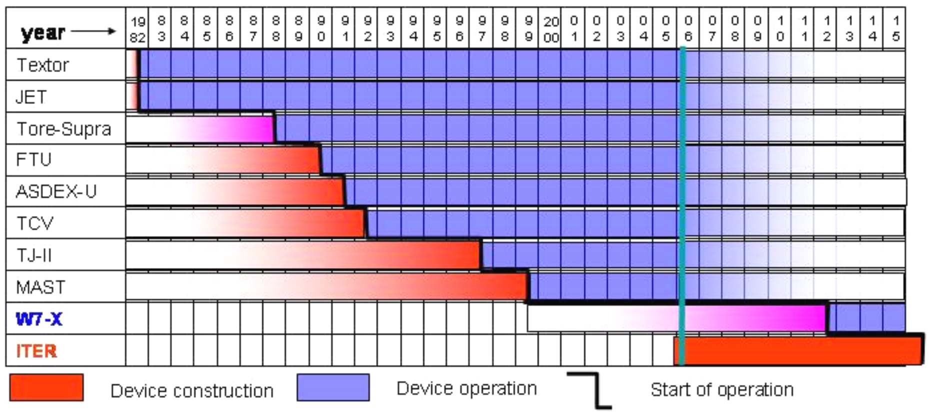
This commented report contains viewgraphs from the development of the W7-X stellarator project addressing all project aspects (scientific targets, organisation, technology, components, assembly, heating, diagnostics, control, data acquisition, software development). The emphasis of this presentation is to highlight the close connection of W7-X to ITER both in technology and in relation to European industry.

F.Wagner

Devices of the EU fusion programme



The last device in the EU programme has been completed 6 years ago
The last superconducting device 17 years ago
W7-X can bridge the gap to ITER

Wendelstein 7-X is a large superconducting stellarator project under construction in Greifswald, Mecklenburg-Vorpommern, Germany. It is the outcome of the research along the Wendelstein stellarator line, developed by IPP over several decades. W7-X should demonstrate the conceptual reactor qualification of stellarators (no tritium operation, however).

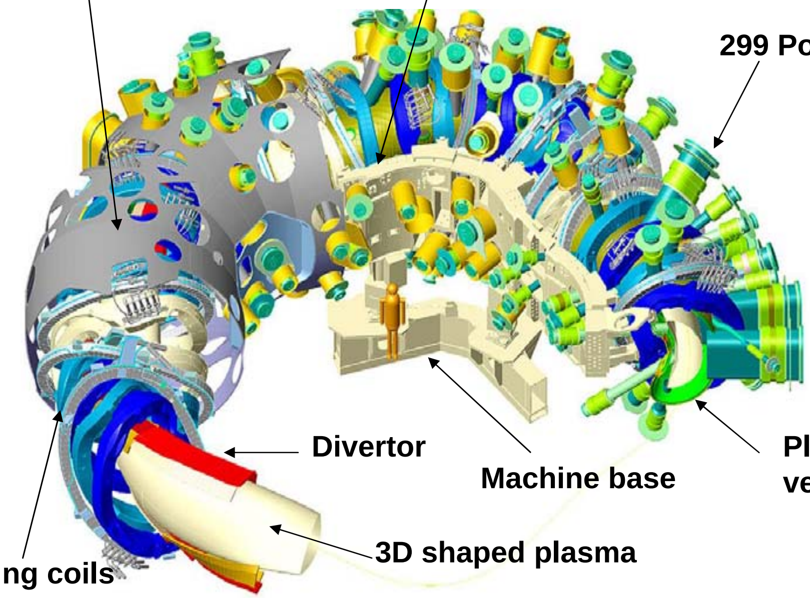
The graph above shows the devices of the European fusion programme and the date they started operation. The red bars correspond to the construction phase; the blue bars to the operation phase. The present date is indicated by a green vertical line. The last device, started in Europe, is Mast which has no technical relation to ITER and whose physics goal is another concept direction.

The last experiment with direct technological ITER relevance is Tore Supra which started 17 years ago. Tore Supra is a superconducting device built to develop steady-state plasma scenarios and to develop the related technology. Many of the people involved in the technical development of Tore Supra (both from industry and CEA) have retired by now.
The gap from Tore Supra to ITER with respect to the relevant long-pulse technology is bridged by W7-X.

The Wendelstein 7-X device

key 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:	900 MJ
heating power	15 - 30 MW
pulse length:	30 min
energy turn around:	18 GJ
machine height:	4.5 m
machine diameter:	16 m
machine mass:	725 t
cold mass:	425 t

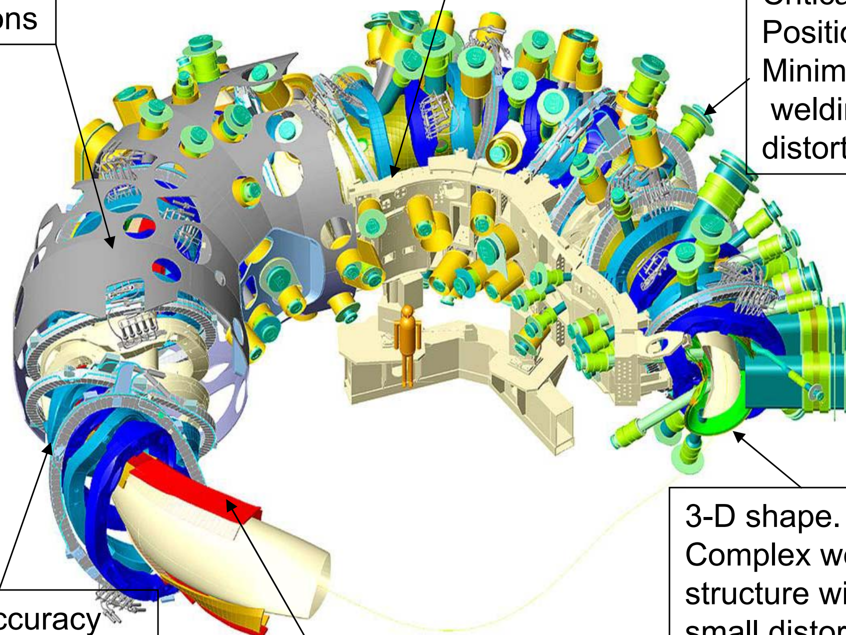


Goal: demonstration of principle reactor suitability of the optimised stellarator

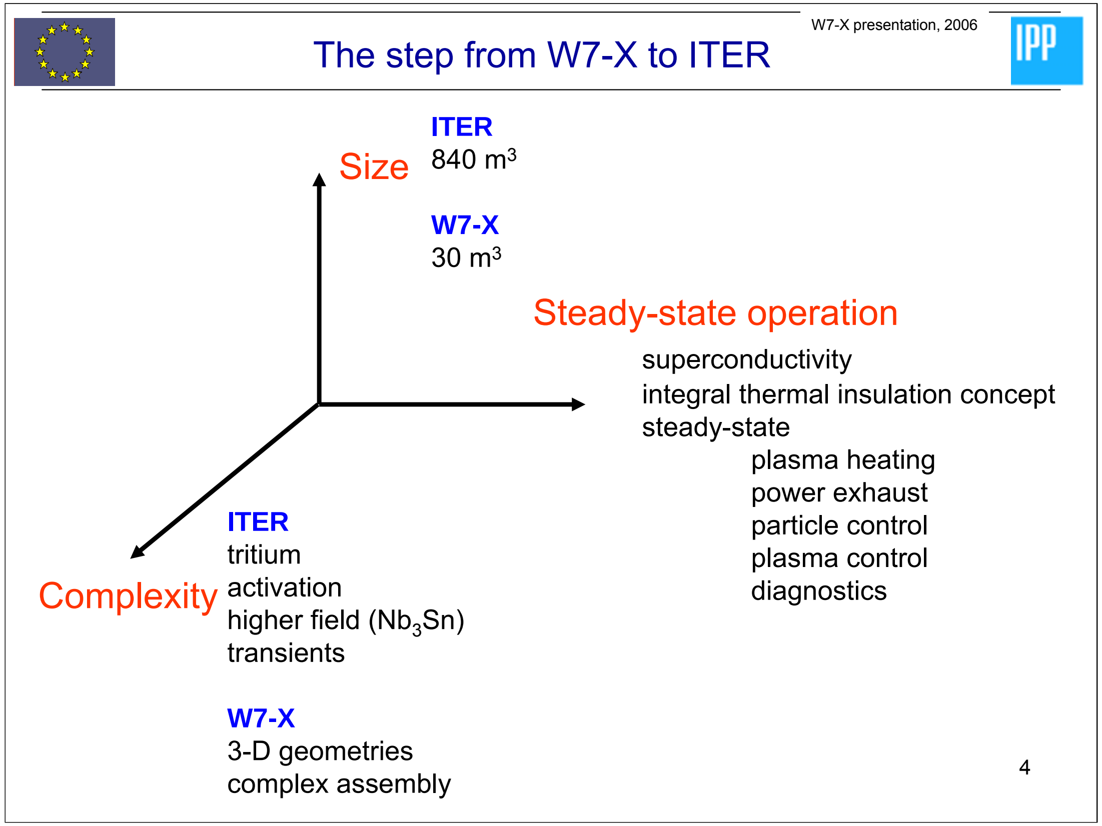
This slide shows the W7-X device and its parameters. The device has two sets of superconducting coils,50 non-planar coils, which produce the confining field and a set of 20 planar coils, which allow to change the field properties.

The function of the divertor is to provide the only wall contact with the plasma. It accommodates the major energy and particle fluxes. The divertor panels are equipped with cooling and the divertor chamber with pumps.

The Wendelstein 7-X device



The texts summarize some of the technical challenges connected with the different components.



W7-X can be used as an example on smaller scale about the challenges of building a demanding fusion device. ITER is substantially larger and more complex because of the radiological aspects. It also uses more challenging superconducting materials. In addition, it has to stand the transients, which can appear during tokamak operation.

The complexity of W7-X is in the 3D geometry of all components and in the complex assembly of a small cryogenic device.

A major issue for the future fusion programme is steady-state plasma operation (the 3rd co-ordinate). This goal affects both physics and technology. Most plasma states are developed up to now in short pulses whereat the surrounding materials are involved through their inertial properties. For steady-state operation, plasma states have to be developed, which are optimised under the pre-requisite of a technical boundary condition - that the surrounding material and technology must be able to accommodate high energy loads and particle fluences. The technology for this purpose is still under development.

W7-X is like ITER based on superconductivity with a complex thermal insulation system and has the goal of steady-state plasma operation necessitating the development of long-pulse plasma heating, exhaust technology, long-pulse plasma control and diagnostic techniques.

This slide shows the two toroidal concepts – tokamak and stellarator. Main aspects are the coil systems and the fact that the tokamak is axi-symmetric (no variation in toroidal direction) whereas the stellarator is 3-dimensional. The 2-D or the 3-D character, respectively, have major impact on the features and properties of the two devices and leads to an attractive alternative.

Stellarators are an independent reactor line but they share all the technology with tokamaks and they contribute, in a unique way, to the physics of toroidal confinement. The conceptual advantages of stellarators are the potential of steady state operation without current drive and the lack of current - driven instabilities, specifically no disruptions and no conventional or neo-classical tearing modes. The reason is that the confining magnetic field originates exclusively from currents in external helical and toroidal coils. Stellarators are free of inductive current; their equilibrium is not established in a self-activative way. Stellarators do not need an active control (like positional feedback) and therefore cannot suffer from its failure. Second order pressure - driven currents (diamagnetic, Pfirsch-Schlüter, bootstrap) appear also in classical stellarators.

The intrinsic properties of stellarators, which provide their advantages, also give rise to their drawbacks. As a consequence of net-current-free operation, stellarator plasmas are 3-dimensional and they tend to have a large aspect ratio. The consequences are that (1) particle drift orbits strongly deviate from the flux surfaces with the corollary of large neo-classical fluxes, that (2) trapped energetic particles are not confined, and that (3) the equilibrium beta is low. Technical disadvantages of a stellarator reactor, based on the classical concept, are the large helical coils.

Because of the above-mentioned factors, stellarators need optimisation. Stellarator optimisation towards an integrated design has been a major goal of the IPP stellarator research. The most rigorous form led to the concept, which underlies Wendelstein 7-X. The theoretical background of the optimisation is (1) that the deviation of particles from the flux surface as well as equilibrium and stability properties depend on the variation of the magnetic field strength |B| in the flux surface and (2) that |B| can be made 2-dimensional in an otherwise 3-dimensional toroidal geometry. Systems with these properties are called quasi-symmetric systems. The design of Wendelstein 7-X closely follows the quasi-isodynamic principle, which allows - in addition to good particle confinement, equilibrium and stability properties - the near elimination also of pressure-driven parallel currents. W 7-X will test the viability of the optimisation.

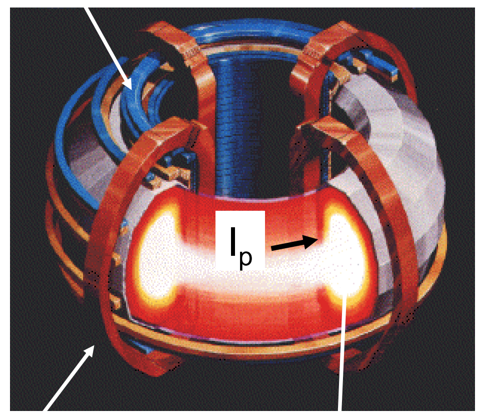
Tokamak and Stellarator

Two toroidal confinement concepts

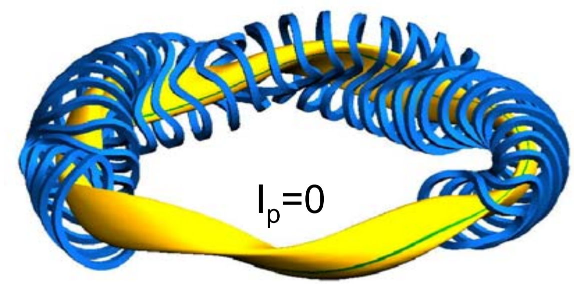
tokamak
toroidal and poloidal field coils
the plasma is symmetric
there is a strong current inside the plasma

stellarator
modular coils;
the plasma is 3-dimensional.
current flows in the coils only

poloidal field coils



toroidal field coils plasma



Plasma and 50 non-planar coils of W 7-X

ITER will be a tokamak

Advantages and disadvantages of the two concepts

Tokamak and stellarator are complementary

- in the tokamak, the current flows in the plasma
- in the stellarator, it flows in the coils
- the tokamak is pulsed
- the stellarator is for steady-state operation
- the tokamak can develop detrimental instabilities
- the stellarator is not 2-dimensional: the classical stellarator has insufficient confinement

→ Stellarators need optimisation: effectiveness demonstrated by W7-X

Goal of stellarator development:

the same confinement quality as tokamaks
steady-state operation
no current driven instabilities

Alternatives in toroidal confinement:

3D system with geometrical complexity but quiescent and steady-state

or:

geometrical simplicity but external current drive + current driven modes

Summary

Technical challenges of W7-X

W7-X is at the edge of what can technically be realised

Superconducting coils, pulse length of 30 min
energy turnover:

Tore Supra:	1 GJ
W7-X:	18 GJ = O(ITER)

Components subject to forces of 450 t have to be placed with mm accuracy and to remain there during operation (symmetric deformations up to 10 mm during operation, however);

3-D shapes have to be constructed, produced, welded and measured;

Some components are heated up to 1200 K, others - close to - are cooled down to 3.5 K;

Components are subject to pressures of 170 bar at a quench whereas the vicinity remains at high vacuum;

Components carry 3 V during regular operation and are subject to 6 kV at a quench;

There will be about 1 Mill pieces of 20000 different types mounted inside the vessel
about 100 000 pieces are custom-made;

DC-power supplies with (130 kV, 50 A) or (30 V, 20 kA), respectively, with low ripple.

Summary

The strategic value of W7-X

W7-X is the last large superconducting device in Europe before the start of ITER

It shares with ITER the long-pulse capabilities:
SC coils, st-state heating, energy handling techniques,
st-state operation, st-state diagnostics

- Development of technical solution with direct relevance for ITER

- Training of engineers and (later) physicists

- Training of industry (technologies, documentation, quality assurance)

- Network building

  between technology oriented associations and institutions
  between SC devices under construction or in operation

Scientific value: EU gets a novel scientific device to satisfy the academic standards of the programme with an option for disruption free operation and steady-state capability

Summary

The project is supervised by IPP´s **Board of Directors**, the **Project Council**, dealing with all issues of the project, the **Steering Committee**, dealing with all EU aspects and the **Kuratorium**, with a responsibility for all aspects of the institute.

The Project is headed by Prof. Klinger and Dr. Haange as Technical Director. It is organised in 5 sub-divisions

Project Coordination, headed by Dr. Bosch; Basic Device in charge of the various components, is split into two subdivisions, headed by Dr. Wanner and Dr. Nielsen; System Engineering, headed by Dr. Schauer; Assembly, headed by Dr. Wegener; Physics, headed by Prof. Wagner.

Each sub-division is further organised in departments.

The rest of the presentation is organised in

-a chapter with examples of the work of the various departments (not an complete documentation !) . The header indicates which sub-division and which department does present itself;

- a chapter which summarises the technical innovations via W7-X, mostly achieved in the cooperation with industry.

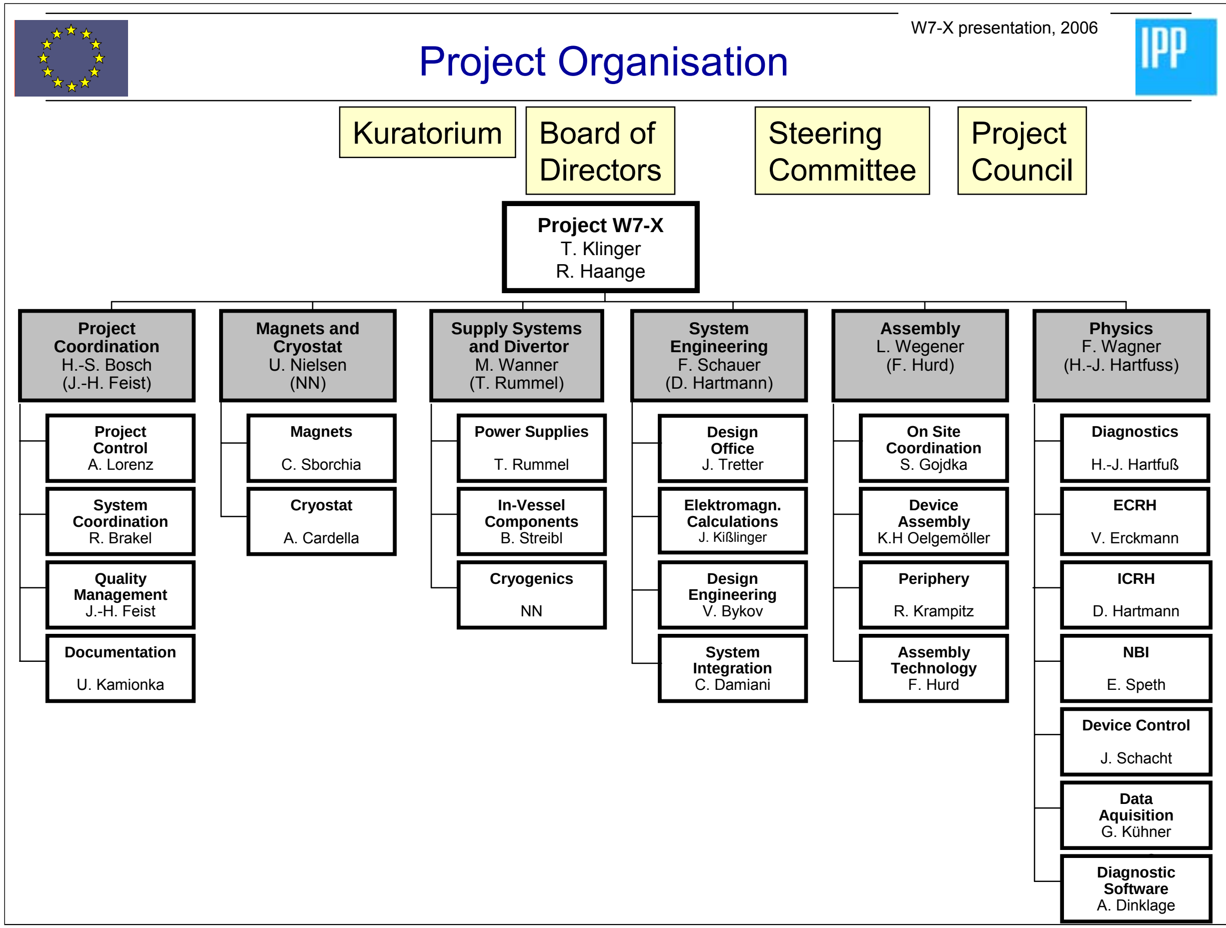
- Thereafter, the relevance of W7-X for ITER is discussed

-as the purpose of this presentation is to attract interested people to work with W7-X a picture of the institute is shown.

- The time schedule gives the completion date of the various components and shows where it is still time to join.

- A chapter addresses the work within the institute, the internationality of the team and describes the city of Greifswald.

- The final slides summarize some aspects.



Project Coord.
H.-S. Bosch
(J.-H. Feist)

Sub-division: Project Coordination

Tasks

The tasks of the subdivision project coordination are based on the scientific-technical concept of WENDELSTEIN 7 X and on the procedures for the preparation of products
determined in the appropriate standards (DIN EN ISO 9000 ff).

The sub-division ensures that W7-X will be realised according to state-of-the-art science and technology.

Project Control develops and follows the financial and time planning. Its aim is to recognise – in advance – any kind of deviations, to identify essential measures for correction and – if necessary – to update the schedule. This is achieved by regular monitoring of workflow, milestones and expenditures of the entire W7-X project. Other tasks are quality management and documentation to guarantee the performance of all tasks in the preparation of W7-X according to quality standards and to document the complete project.

One special aspect of quality management is System Coordination, including setup and update of the W7-X system specification, management of all changes to this specification, and system studies with respect to operational and safety aspects of W7-X.

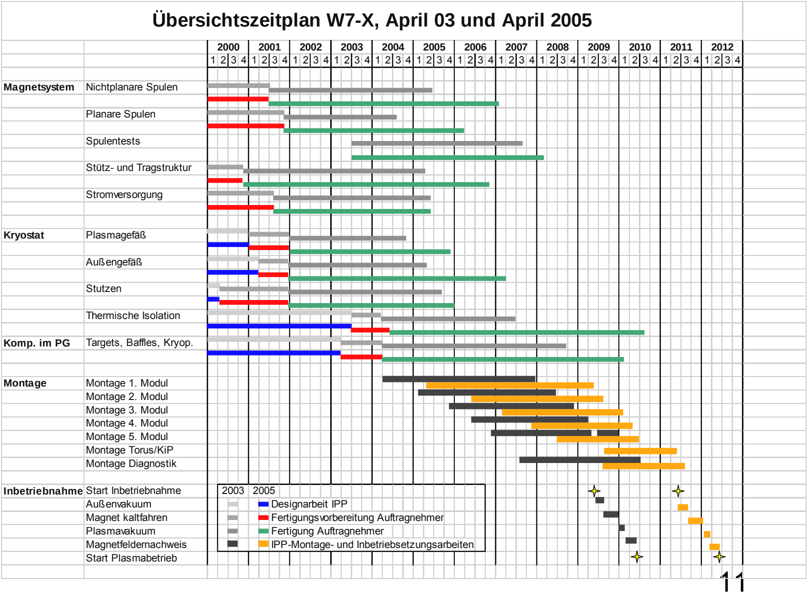
In the following, we describe the task of the 5 sub-divisions and their departments. Besides a general text, introducing the sub-division, examples of their work are presented.

Project Coord.
H.-S. Bosch
(J.-H. Feist)

Project Control
A. Lorenz

Project Control

- **Project Organisation,** Management Plan, work specifications etc.
- **Finances**, Planning, Monitoring, Controlling
- **Contract Monitoring**
- **Schedules**, Planning & Monitoring of
  - contracts, component delivery
  - assembly of W7-X in Greifswald (project schedule)
  - work within the project
    (Work Breakdown structures)



Overview-Schedule
of W7-X (example)

Self-explanatory

System Coordination

- **System specification**
  - preparation and update of system specification and ringbook
  - change management (scientific objectives and technical realisation)
  - documentation of the complete design
  - compatibility of all components with scientific and technical requirements
  - Materials database

- **Control of interfaces**
  - geometry, mechanical, electro-mechanical and thermal issues
  - safety aspects

- **System studies**
  - operational aspects
  - safety analyses
  - operation license

Self-explanatory

Project Coord.
H.-S. Bosch
(J.-H. Feist)

Quality Management
J.-H. Feist

Documentation and QM

Documentation and QM

Documentation
U. Kamionka

- Documentation of all relevant Office documents
- Documentation of all CAD models and technical drawings
- Final check of all CAD-models, harmonisation of the data
- Definition of guidelines and process instructions
- Introduction and maintenance of an electronic documentation system (Agile PLM)

Quality Management

Quality Management
J.-H. Feist

Quality management

- QM manual based on ISO 9001
- process instructions
- standards and regulations
- test instructions
- internal and external audits

Quality assurance

- control of QA in external companies
- support of responsible officers
- Non-destructive testing

Self-explanatory

Quality Management

Visual testing - videoscopy

weld seams in cooling pipes

Eddy current testing

Thickness measurement of the winding package insulation of non planar coils

Self-explanatory

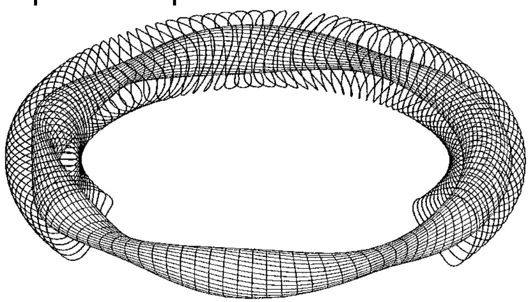
Basic Device
M. Wanner
(T. Rummel)

W7-X presentation, 2006

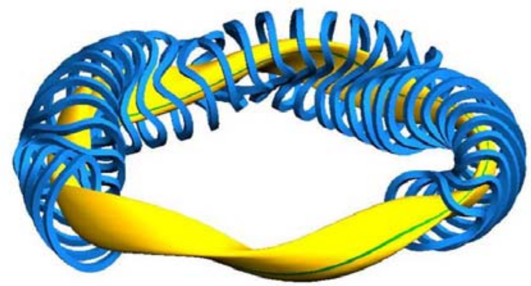
Sub-division: Basic Device

The non-planar coils: From the idea to the realisation

Current filaments which produce optimised plasma



The filaments are grouped into coils.



CAD drawing of a coil

Industrial coil production

Coil assembly

With this slide, the various components of W7-X are presented. In addition, this slide demonstrates the route from the idea and the numerical design to the realisation of the coil system. The first picture shows the plasma (flux surfaces) which is optimised to yield optimal plasma properties and the current filaments on a control surface which would produce the optimised field distribution. In the next step, the current distribution is lumped into coils.

The rest is self-explanatory.

Coil fabrication

Cable production

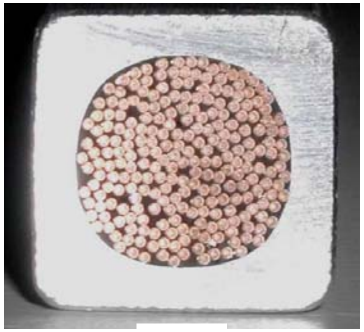
The individual filament

0,58 mm

VAC
Europa-Metalli

243 filaments give a cable

Alu casing for the cable



16 mm

AluMenzingen

Cable on a drum

The pictures show the production of the W7-X conductor from the filament to the complete conductor. The upper left picture shows a strand where the NbTi filaments are embedded in a copper matrix. The upper right pictures shows a cable composed of 243 strands during a check for broken strands. The lower left shows a Al-jacketed cable. The lower right shows a cable on a drum ready for delivery.

Non-planar coil fabrication

Coil winding

Initial stage

progressed stage

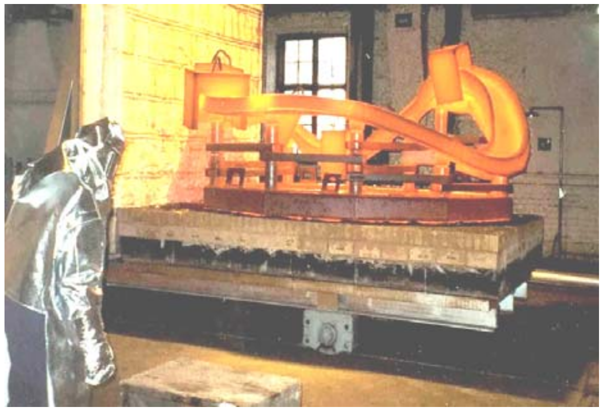
Accuracy of winding body

The upper two pictures show the winding form for a non-planar coil with the hasp for the conductor above and different stages of winding. The lower right shows a winding package with integrated joints which is subjected to a dimensional survey.

Non-planar coil fabrication

Coil casing

Cast half-casing



Accuracy of half-casing

Insertion of a winding body in casings

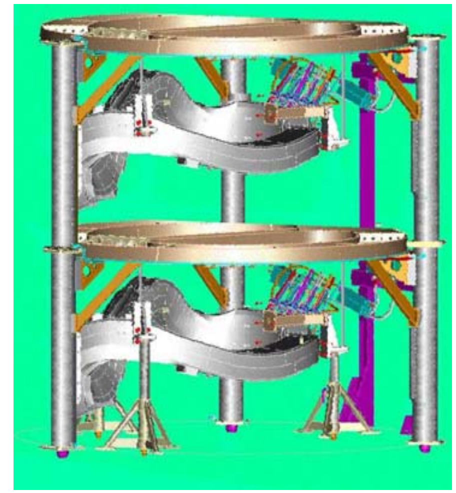
Welding of two half-casings

The casings are cast as halves, heat treated and precision machined (upper left and right). Next the winding package is introduced, and the halves are welded together.

Coil testing

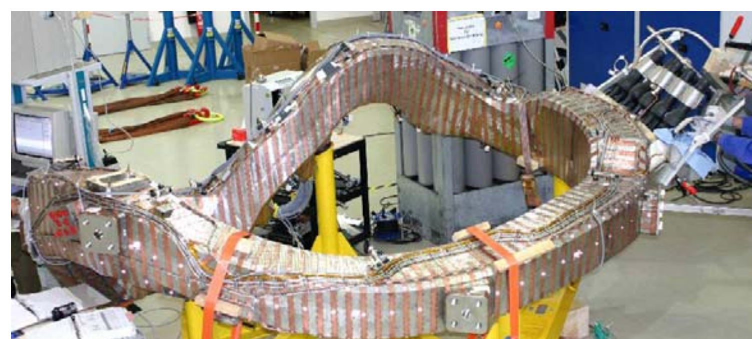
Test equipment in Saclay (CEA)

Rack for coil support



A coil arrives in Saclay

Final coil in Greifswald



Upper left: two cryostats each capable to hold and test two coils in one run. upper right: test rig for assembly of two coils in the cryostat. lower left and right: a non-planar coil is received and prepared for the test.

Coils: lessons learned

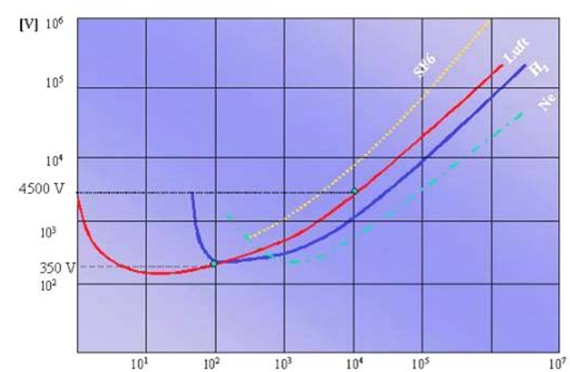
Coils in Greifswald

Preparation of a Paschen test

Experience gained

- Ic/strand (>150 A → 170 A)
- accuracy of winding pack/casing → as specified
- no degradation of the conductor → margin
- R&AC- measurements → interlayer shorts
- LINAC inspections → lack of fusion, cracks
- HV test → exchange of QD cables, insulation
- Paschen test → improvement of insulation

Paschen curve

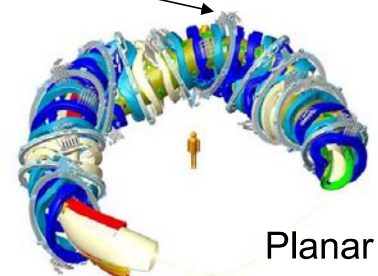


Upper left: a planar and a non-planar coil is being prepared for assembly at Greifswald. lower left: a large vacuum vessel at Greifswald allows to perform leak and Paschen tests of coils and other large components.

Coils and/or winding packs are subject to Paschen tests. This is a crucial test which shows all defects in the insulation. High voltage is supplied and the pressure is varied. The Paschen curve is shown. The Paschen curve has a minimum breakdown voltage at a pressure range of a few millibars.

Planar Coils

Planar coils



Planar coil
(test assembly)

Experience gained

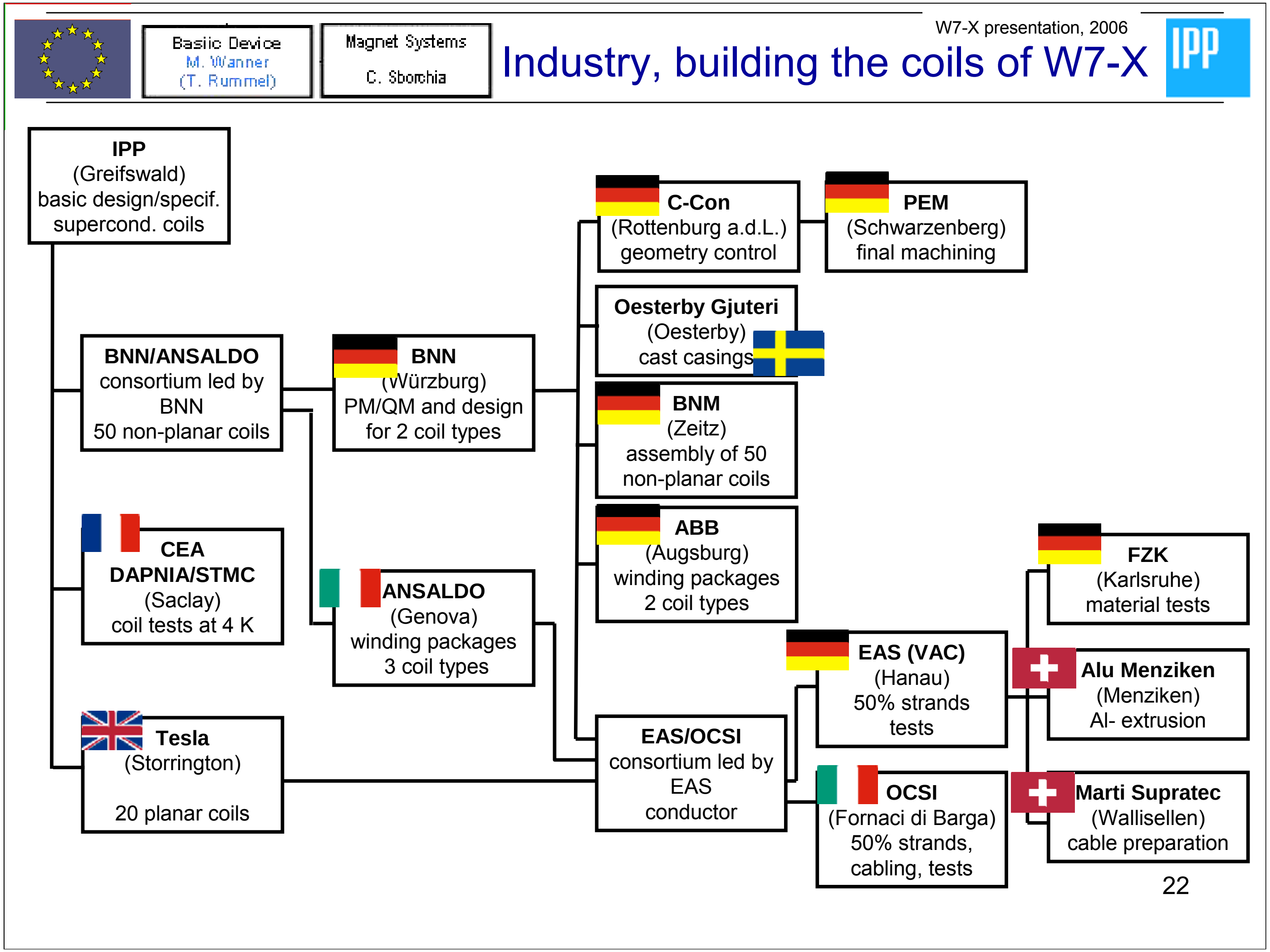
-SF_6 method → integral leak testing
(sensitivity 10^{-7} mbar*l/s)

- cold leak → pitting corrosion on SS tube

-cold leak → re-qualification of Al-welding
of superconductor

-HV tests → quality of insulation had to
be improved

Upper left: the casing cooling of a planar coil is being mounted, it serves to conduct the heat onto the casing to the helium cooling loops.
lower right: a planar coil is strung across the non-planar coil.



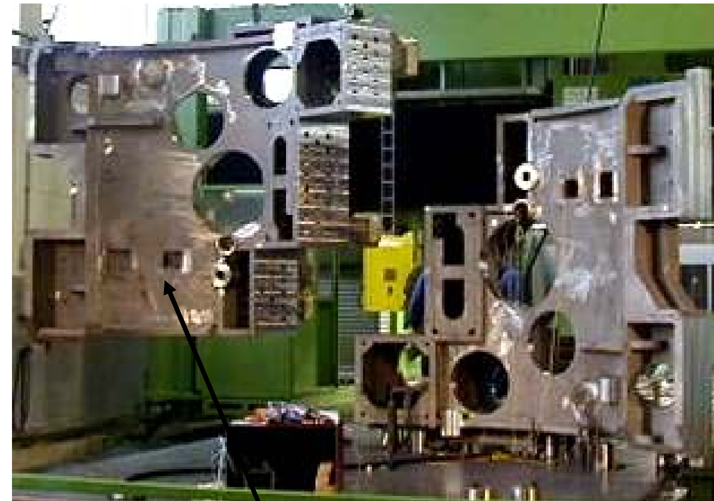
Structure of the contractors for the non-planar and planar coils showing main contractors and subcontractors.

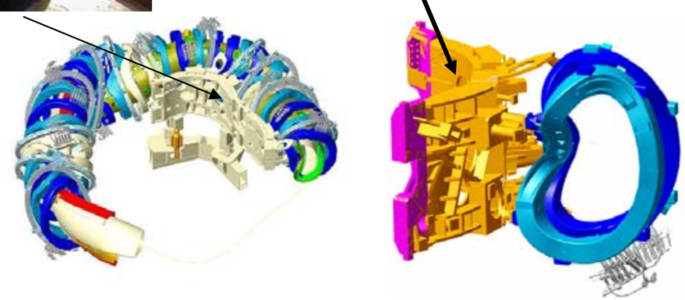
Basiic Device
M. Wanner
(T. Rummel)

Cryostat
A. Cardella

W7-X presentation, 2006

Central Support Structure





Experience gained

- precise machining and fitting of half-module flange interfaces (0.05 mm)
- trial assembly → high repetition accuracy achieved

The pictures show the two sectors of a module of the coil support structure during final machining at the Italian subcontractor Rovera. The step flange connects two half-modules.

Basiic Device
M. Wanner
(T. Rummel)

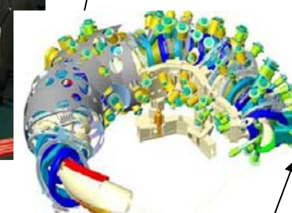
Cryostat
A. Cardella

W7-X presentation, 2006

Plasma & Outer Vessel & Ports

Plasma vessel

Outer vessel (cryostat)



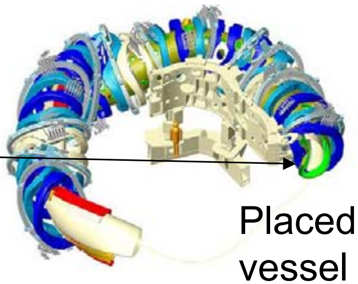
Ports
Incoming inspection

Experience gained

- high precision of port holes → water jet cutting
- integral leak test of vessels → $<10^{-7}$ mbar*l/s
- accuracy of surface → 3 to 7 mm
- shrinkage during welding of half modules → 2.5 mm

Upper left shows the plasma vessel during production and shows the water cooling pipes attached to the surface. The upper right picture shows the outer vessel with several domes and ports already welded to the shell. The lower right picture shows a round port with integrated bellow and cooling pipes during the works acceptance test.

Thermal Insulation



Placed between vessel and coils

Detail of super-insulation and panel

Experience gained

- high insulation quality of aluminised Kapton MLI
  (0.67 W/m² not compressed,
  0.93 W/m² compressed with overlaps)

The upper left picture shows the thermal insulation being fixed to a sector of the plasma vessel. The lower right picture shows a panel of the plasma vessel thermal insulation with attached copper braids.

Basiic Device
M. Wanner
(T. Rummel)

Cryogenics
n.n.

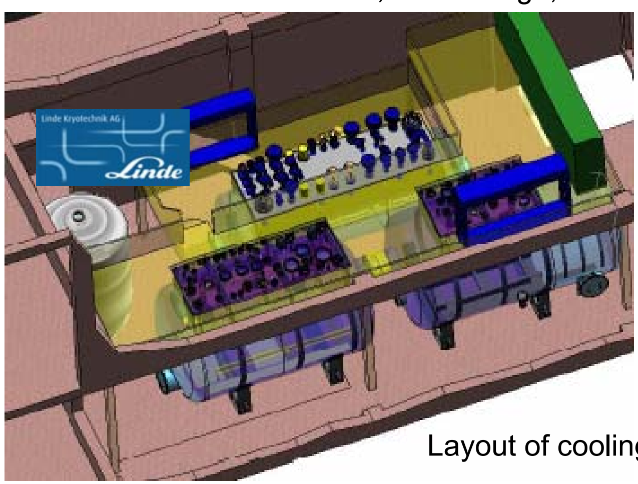
Layout Cryoplant

Refrigeration System

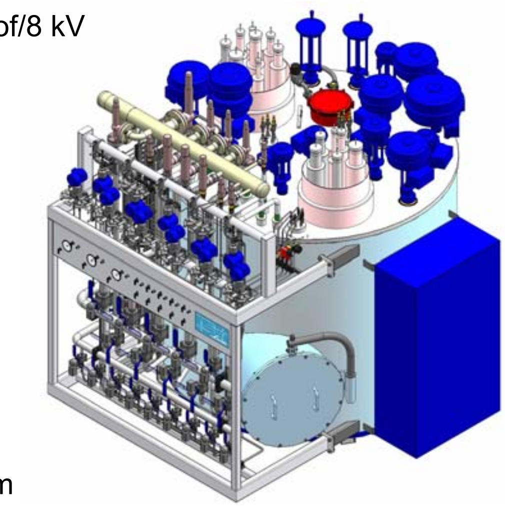
cooling power: appr. 7 kW@4,5 K (equivalent)

components: cycle compressors (1→18 bar, P_{el} =1.65 MW) & cooling water towers
cold box (heat exchangers, turbines, cold compressor, adsorbers) subcooler
(4.5 …. 3.4 K, cold circulators 250 … 400 g/s)
LHe tank (10.000 l), LN2 tank (30.000 l), GHe storage (4x250 m³/20 bar)
transfer lines (L=60 m, shield supply, LHe-supply, GHe return)
magnet valve box & transfer line
cryopump distribution box & 10 transfer lines

Current leads Current 20 kA, HTS-design, Paschen proof/8 kV



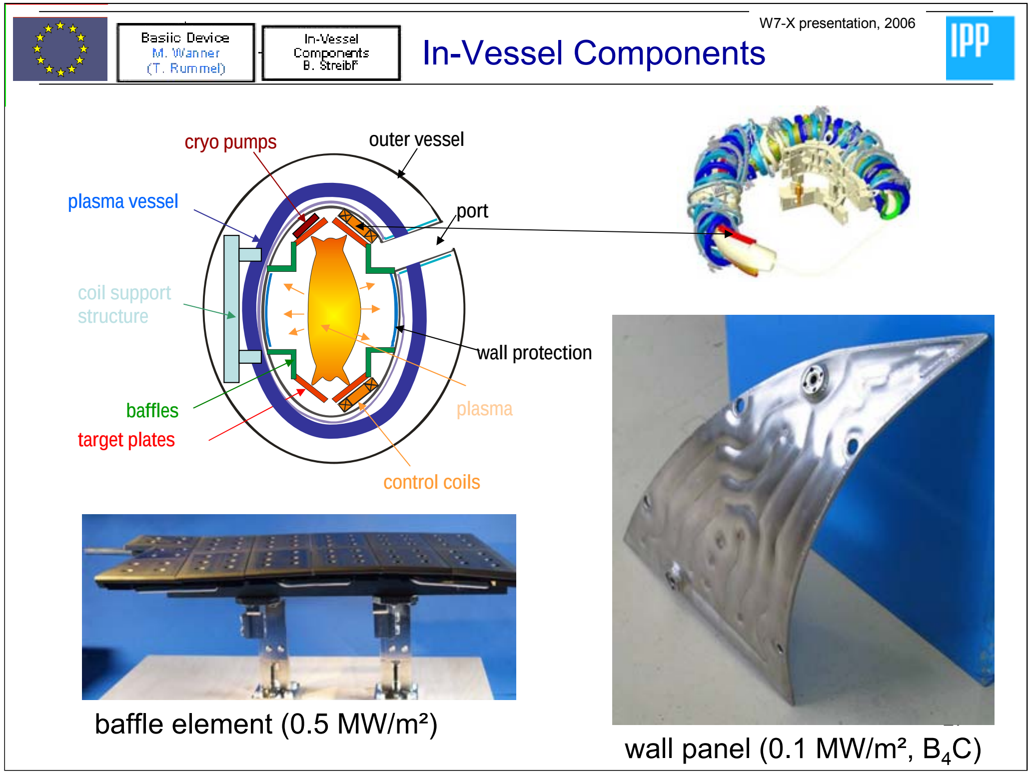
Cold box



Layout of cooling system

Self-explanatory

W7-X will have 2×5 divertor modules placed at the bean-shaped poloidal cross-section. They comprise target and baffle plates. The target plates (19 m^2), which are formed by 890 elements, are made from flat CFC tiles bounded to the CuCrZr cooling structures bonded with a copper interlayer to the cooling structure. Four cooling channels, equipped with swirl tapes, provide a sufficient heat exchange for the expected target load. (For W7-X, the mono-block concept has been discarded mainly due to geometrical problems.) Target plates are designed for 10 MW/m2 steady-state heat fluxes. The baffle plates (33 m^2) form a somewhat closed divertor chamber to increase pumping efficiency. They are made out of flat fine-grain graphite tiles (~2900 elements) screwed onto CuCrZr cooling structures. They are designed for up to 0.5 MW/m^2. The wall protection is split into the protection of the high-field side (45 m^2, ~3400 graphite tiles) and the low-field side (70 m^2; B4C coated stainless-steel panels).



The design of all protection areas is finished. Prototypes of target elements have been successfully tested up to 12 MW/m2 steady-state and 15 MW/m2 for short pulses. The critical heat flux is expected to be ≥ 25 MW/m2. The baffle plates and wall protection panels have passed the critical test under maximal operational conditions. Also the B4C coating programme has successfully be finished in co-operation with industry (not realised for the first experimental phase). All plasma facing components are in industrial fabrication. A high heat flux test stand has been built in Garching to qualify the series production of target elements. This ion beam facility can also be used for PFCs of ITER. Irrespective of the detailed design, the industrial experience with series production and that of non-destructive examination of complex compound structures as employed for PFCs is of high relevance for ITER.

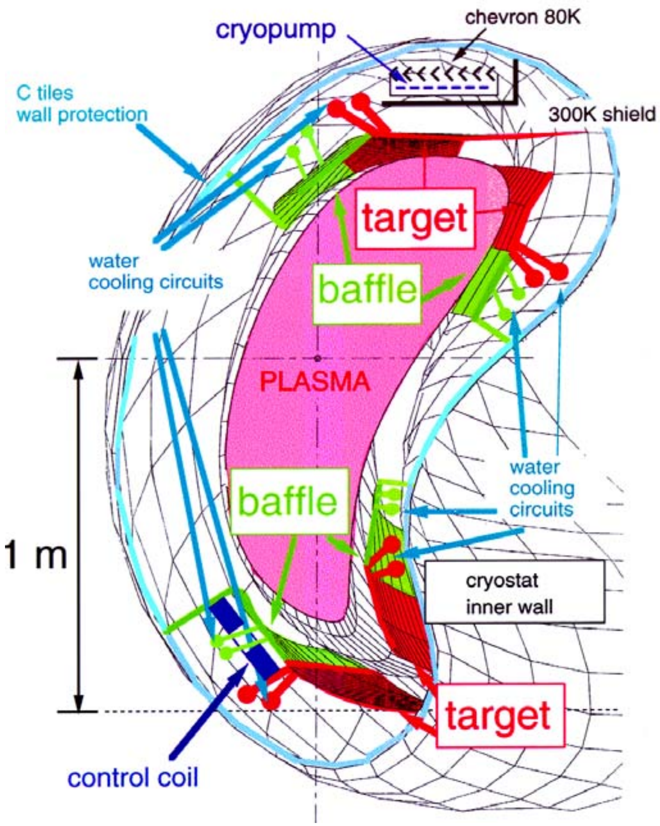
The upper left picture shows schematically the different in-vessel components which surround the plasma. CFC armoured target plates receive the highest heat load. Cryopumps provide a high pumping capacity for the neutralised particles and baffles avoid a backflow of these neutralised gases. Control coils behind the target plates allow modifying the magnetic configuration at the plasma edge to sweep the target area of the diverted particles. The lower left shows a prototype of a baffle which uses graphite tiles clamped to a water cooled heat sink. The lower right picture shows a prototype of a wall protection panel which is made from double walled steel panels with integrated water cooling channels.

Basiic Device
M. Wanner
(T. Rummel)

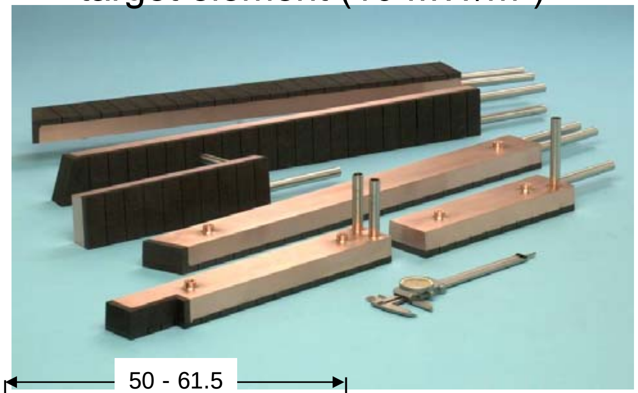
In-Vessel Components
B. Streibl

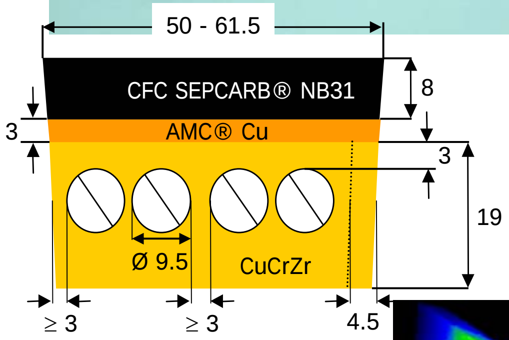
W7-X presentation, 2006

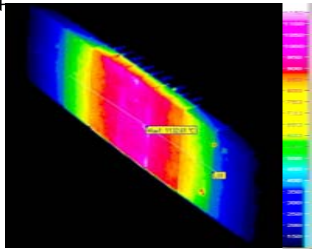
Target Plates



target element (10 MW/m²)







The cross-section on the left side shows the plasma (pink), the vessel (blue) and the divertor installations – targets and baffles. The up-down divertor chambers contain also cryo-pumps and additional control coils to allow optimal divertor operation. The upper right picture shows prototype target elements with the cooling water connections. As shown in the graph underneath the target element is composed of a CuCrZr cooling structure with four cooling tubes which is bonded to the CFC tile by a pure copper interlayer through a patented active metal casting process (AMC®). The lower right shows a CFC target element during a high heat load test.

Components: Major involved industry

High-heatflux-divertor components: SNECMA (F), Plansee (A), MAN DWE (G)

Plasma vessel: MAN DWE (G)

Thermal insulation: MAN-DWE (G) and Linde (G)

Non-planar coils: BNN (G), Ansaldo (I), ABB (G) and sub-contractors

Planar coils: Tesla (GB)

Outer vessel: MAN DWE (G)

Ports: Romabau-Gerinox (CH)

Experimental platform: MAN DWE (G)

Machine base: MAN DWE (G)

Cryosystem: Linde (G)

Power supplies: JEMA (E), ABB (CH), Siemens (G), Thales (CH)

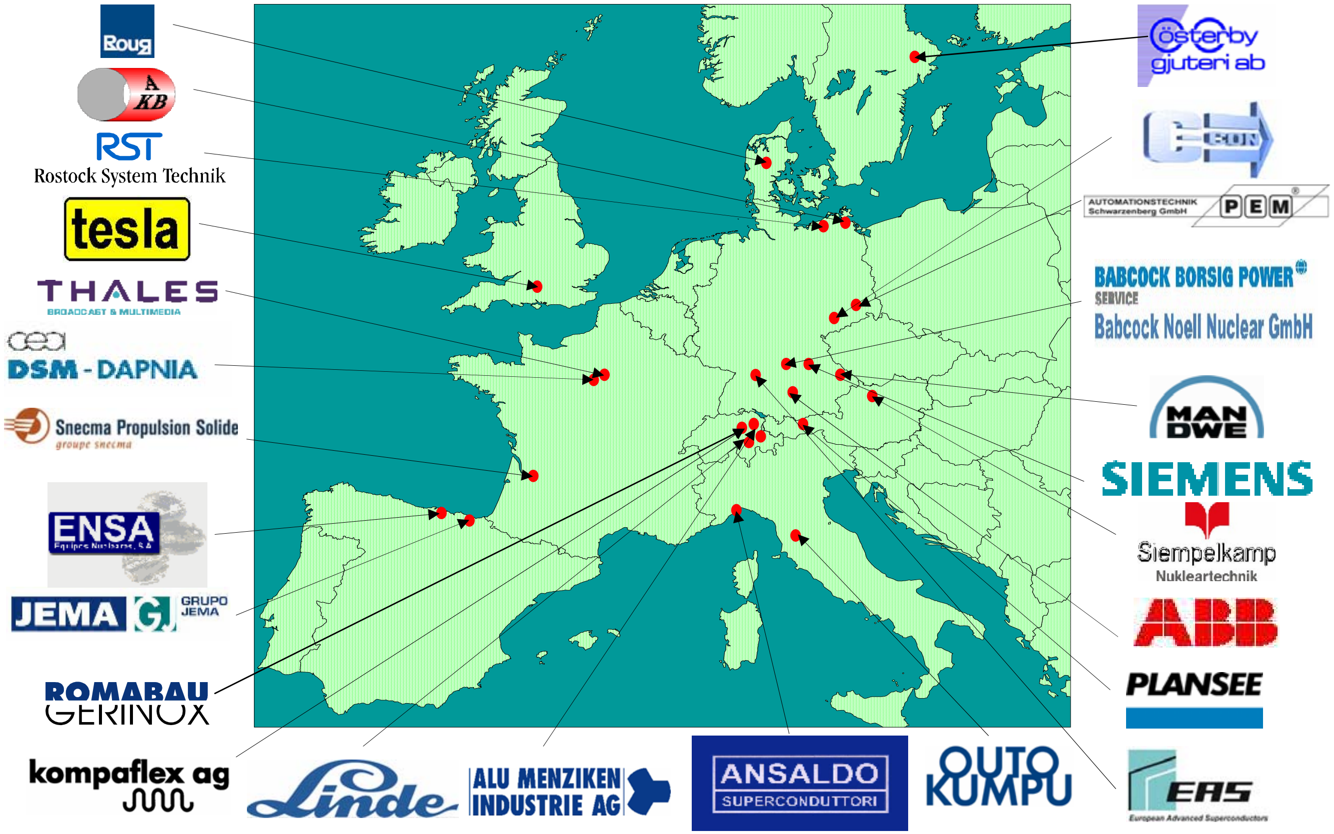
ECRH gyrotrons: Thales (F)

Building: Henn (G)

Summary

W7-X presentation, 2006

EU industry, involved in W7-X



Self-explanatory

Sub-division: System Engineering

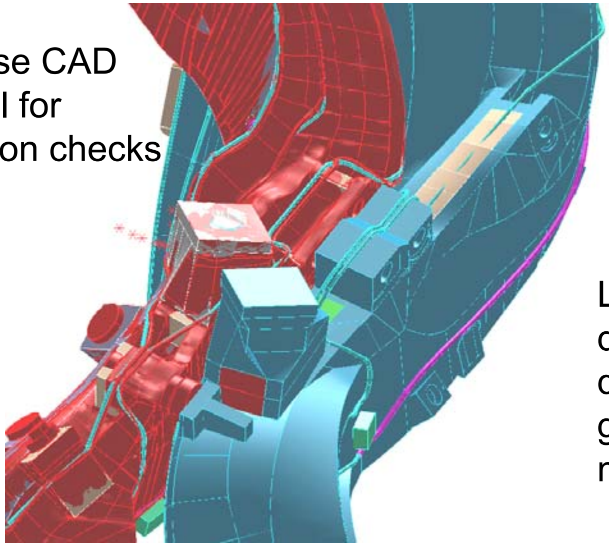
System engineering provides the following engineering support to W7-X:

Design Office, Electromagnetic calculation, System Integration, Design engineering:

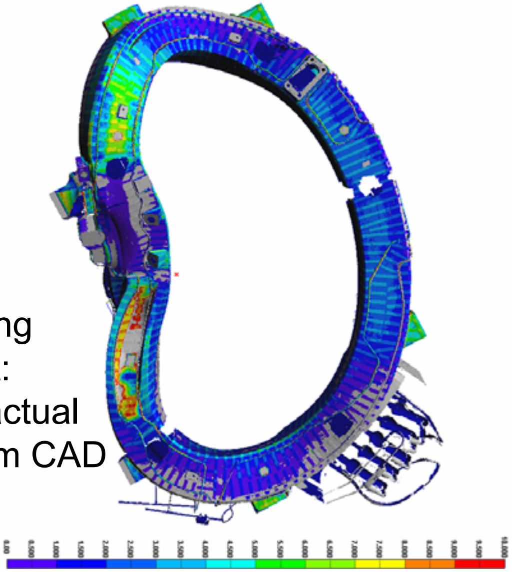
Design Office: Design Office J. Tretter

Component detail design including periphery and start-up diagnostics
Collision analysis of components; CAD-models of the as-built geometry (reverse engineering)

Precise CAD model for collision checks



Laser scanning deviation plot: deviation of actual geometry from CAD model



Self-explanatory

Sys. Engineering
F. Schauer
(D. Hartmann)

Electromagnetic
Calculations
J. Kißlinger*

W7-X presentation, 2006

Sub-division: System Engineering

Electromagnetic calculations:

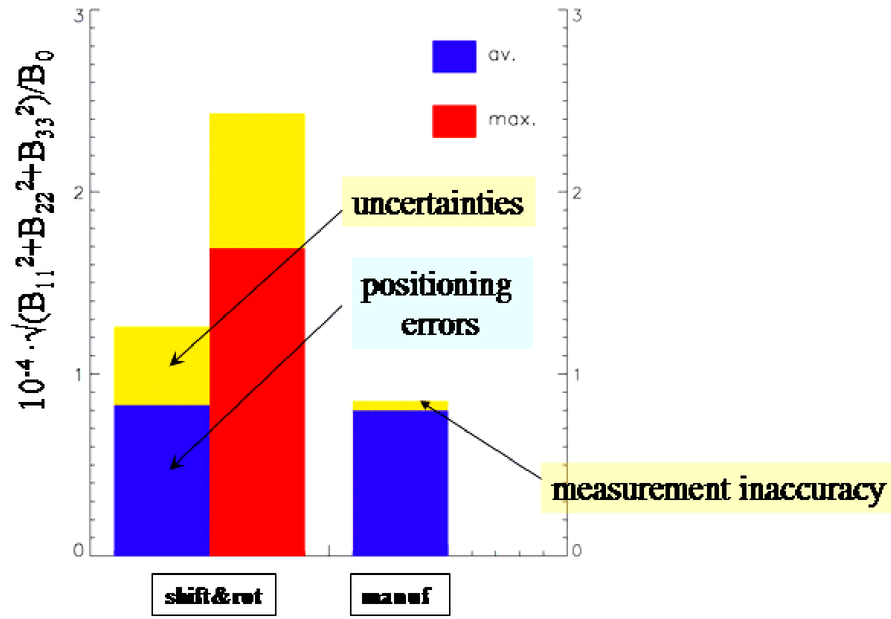
Electromagnetic loads on coils and bus-bar components

Magnetic field perturbations due to manufacturing and assembly tolerances
as well as ferromagnetic materials, and their effects on the plasma confinement

Eddy currents in passive structures

Stray magnetic fields

Relative field errors
due to fabrication
and assembly errors



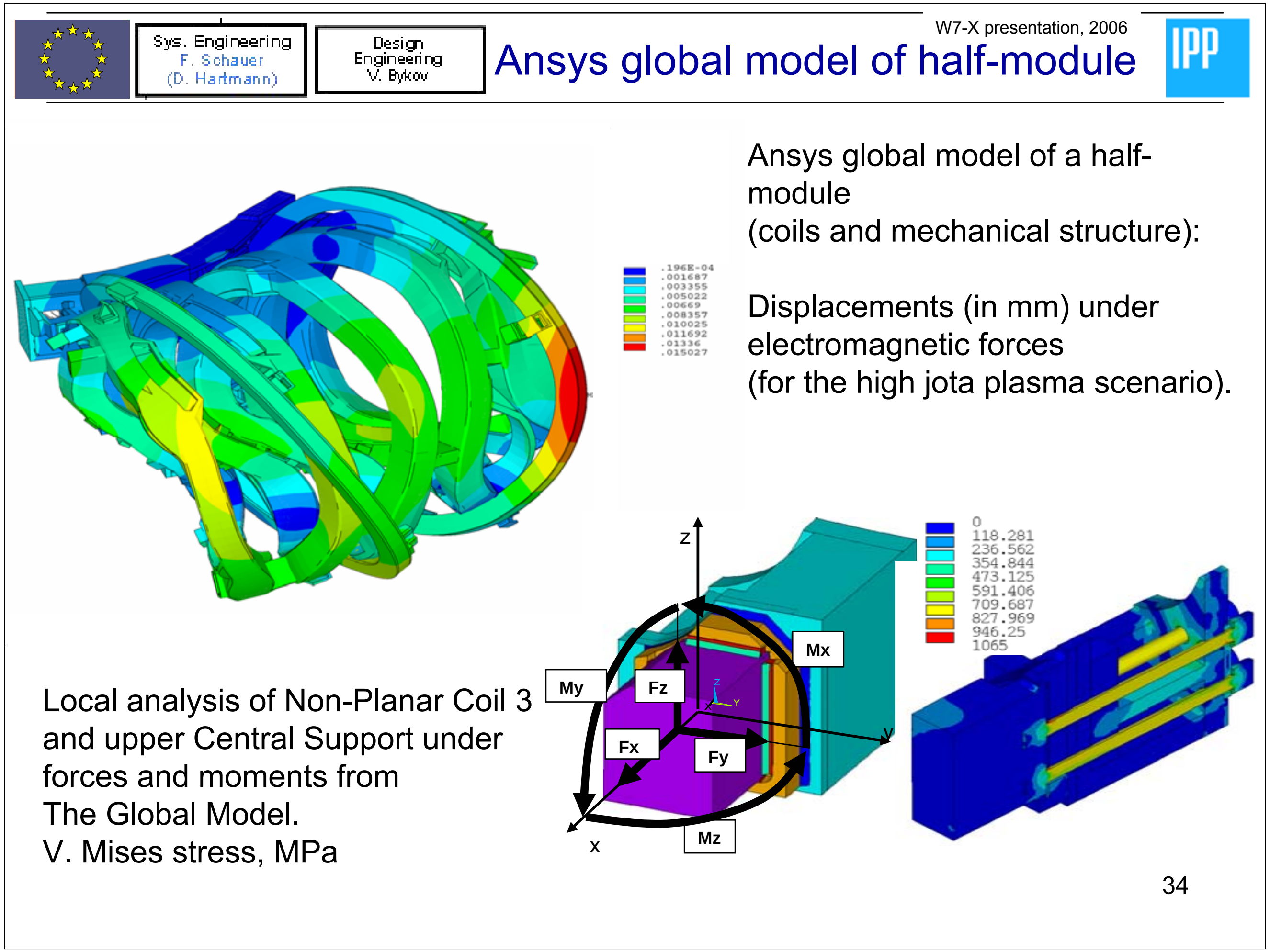
The graph shows the field errors due to fabrication and assembly inaccuracies. The field error is expressed in Fourier-coefficients. Blue is the average error, red the maximal error. Physics requires that the relative field error is kept below 2 10^{-4}.

Sub-division: System Engineering

Design engineering:

- Mechanical and thermal analyses mainly based on Finite Elements (FE) models:
  - Global FE models; detailed FE models and sub-models for critical components
  - Reaction forces on components and deformations during assembly
- Identification and analyses of critical components with regard to high-performance plasma scenarios and/or lifetime of the W7-X device under normal operation and fault conditions
- Interface problems
- Analyses of problems identified during fabrication;
- Development, qualification and tests of analytical tools for analyses of the W7-X device behaviour

Self-explanatory



Global models developed for magnet system (planar, non-planar coils, support ring, intercoil support structures) and for cryostat system (machine base, plasma vessel, outer vessel, ports). The magnet system global model consists of one half module with stellarator symmetric boundary conditions. It is used to calculate the deformation and the stresses of the components and to provide the boundary conditions for local, more detailed models. A number of local models exist, for example for the connection between the coils and the central support ring.

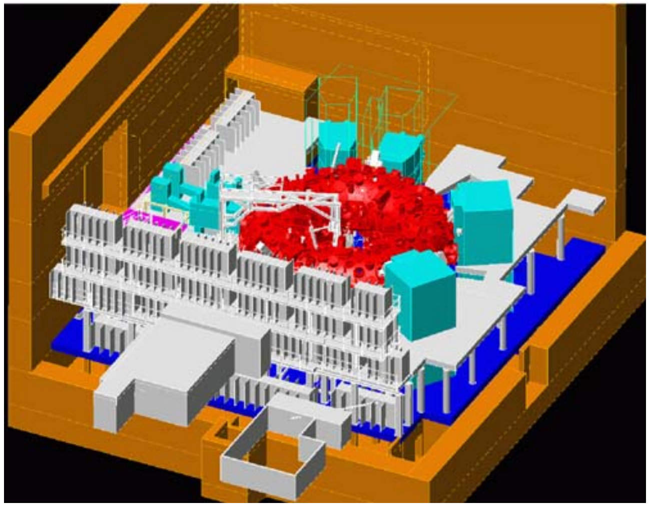
Sys. Engineering
F. Schauer
(D. Hartmann)

System
Integration
C. Damiani

Torus hall layout

System Integration:

Failure mode and reliability studies
System layout
System analyses and operational limits
Qualification of materials and implementation of a material data base
Coordination of mechanical tests



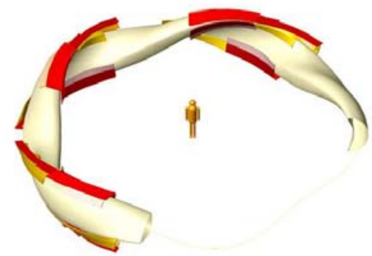
- Coordination and performance of the R&D programme for support structures, e.g. for the intercoil support structures, so called "narrow support elements".
- Development of a data base for material properties, particularly at cryogenic temperatures.
- Performance analysis (crack propagation, failure mode effect analysis, evaluation of non-conformities, ...)
- Coordination of the component layout in the torus hall, definition of accessibility routes, support structures, etc.
- experimental, computational and analytical investigation of technical issues, that arise during the detailed design of components

Torus hall layout is monitored, modified, and updated by System Integration department. The component arrangement is optimized taking into account assembly, repair, and maintenance space.

Sub-Division Assembly

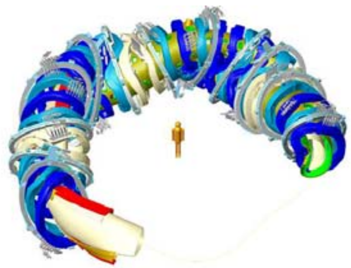
Plasma

Divertor

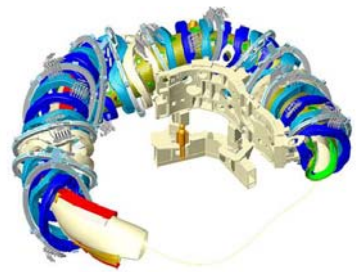


Plasma vessel

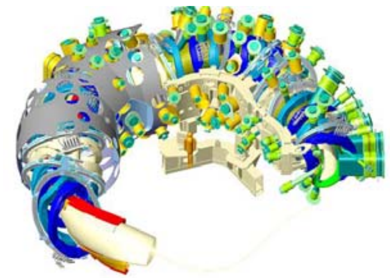
Non-planar and planar coils



Central support ring



Outer vessel + ports



The pictures start with the 3-D shaped plasma, the divertor chambers (2 in each of the 5 modules), the plasma vessel, matched to the shape of the plasma, the non-planar and planar coils, the central support ring to fix the coils and the outer vessel (cryostat) with the ports.

Assembly

Assembly occurs in separate assembly stands where half-modules or modules, respectively, will be put together. The assembled modules will then be placed onto the experimental platform in the final position.

Plasma vessel half-module is split into two pieces for assembly of the first coil.

- After coil assembly, the two vessel pieces are welded.
- The tolerance range for this process is 3 mm (is met).

The 6 t coils have to be positioned to an accuracy of about 1.5 mm.

- The assembly accuracy is monitored by laser tracker (accuracy can be met)

Detailed numerical studies and assembly trials ensure collision-free paths

- for the coils to their final positions
- for the 299 ports
- for the bus-bar system comprising of 25 individual conductors per module.

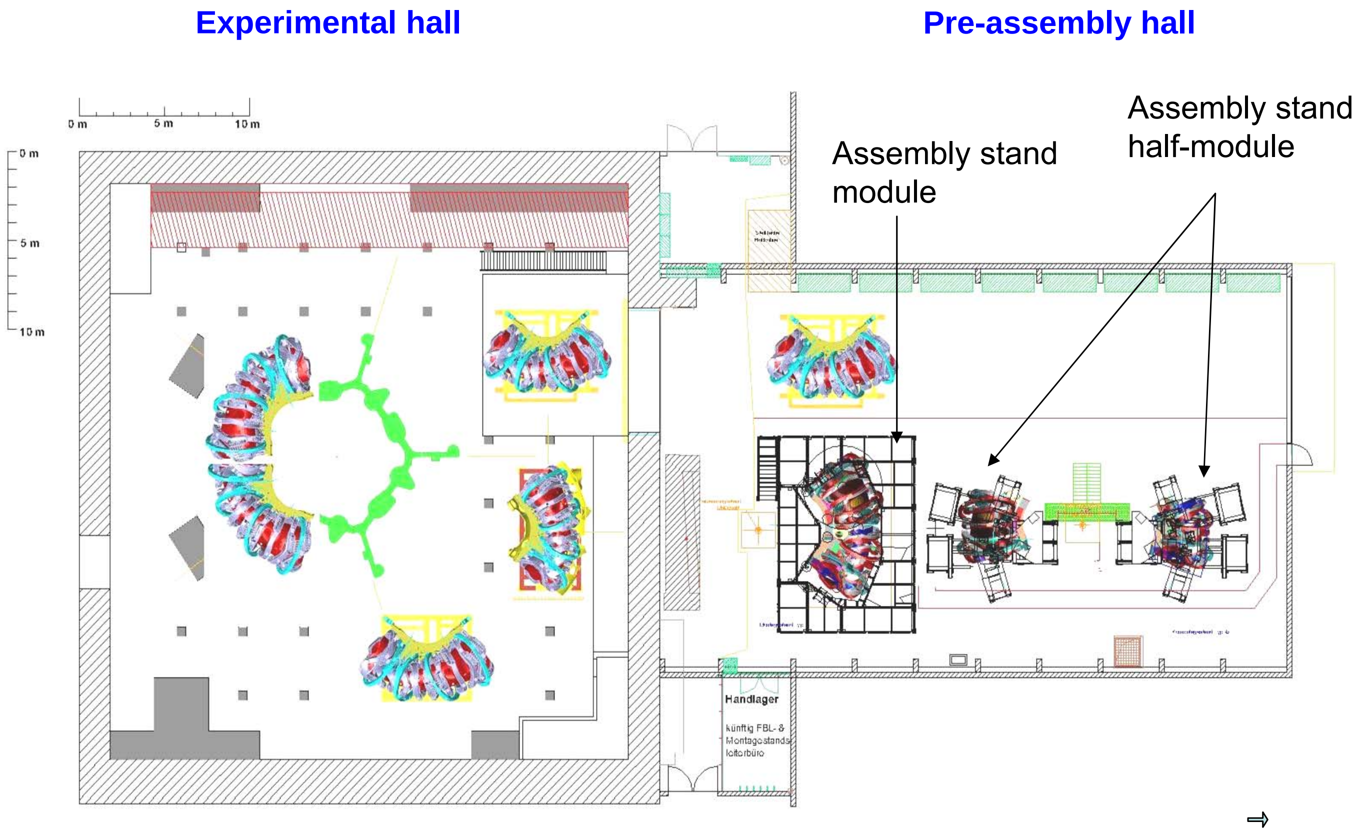
Leak-tightness of all welds, which generally are along non-standard contours.

Insertion of coil support elements under restricted accessibility.

Periphery: optimisation in terms of use of space, assembly sequence, logistics…

Self-explanatory

Experimental hall and pre-assembly hall

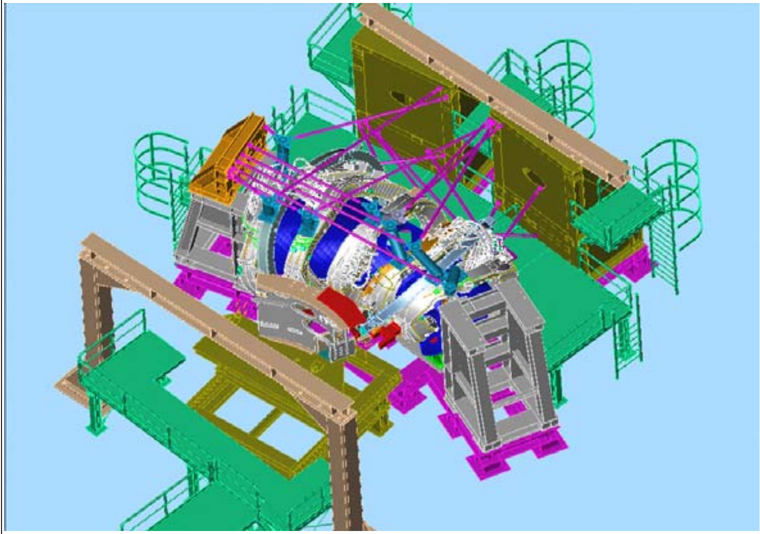


Main assembly steps and work-flow:

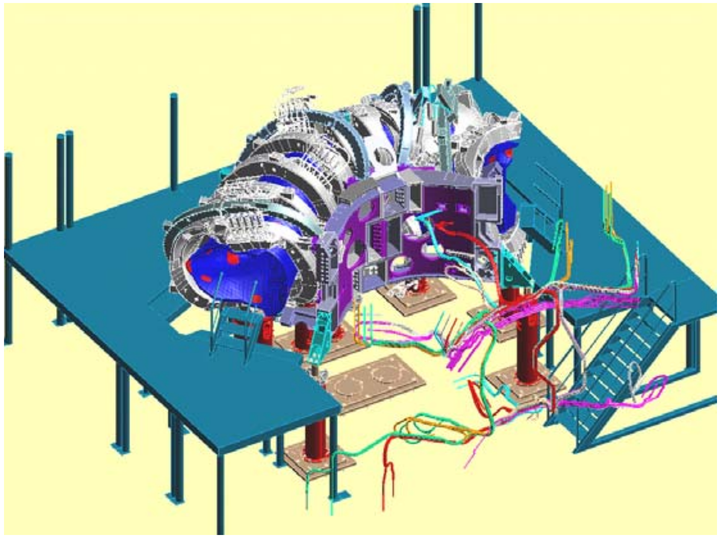
- pre-assembly (half-modules and modules of the magnet system)
- final assembly (magnet modules completed with outer vessel shells, positioned on the machine base and linked with each other

Assembly stands

Half-module assembly stand

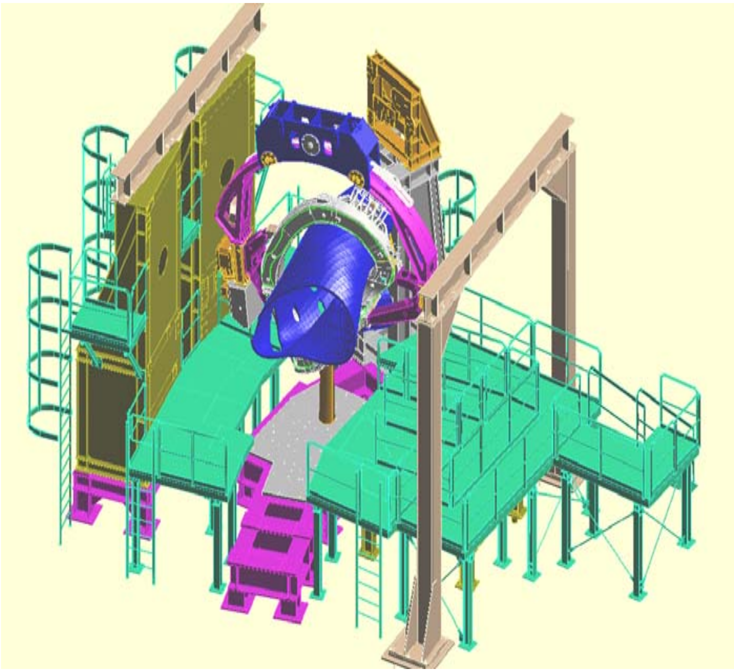


module assembly stand



CAD models of typical mounting stands used during pre-assembly, in total 6 main stands are needed during the entire assembly

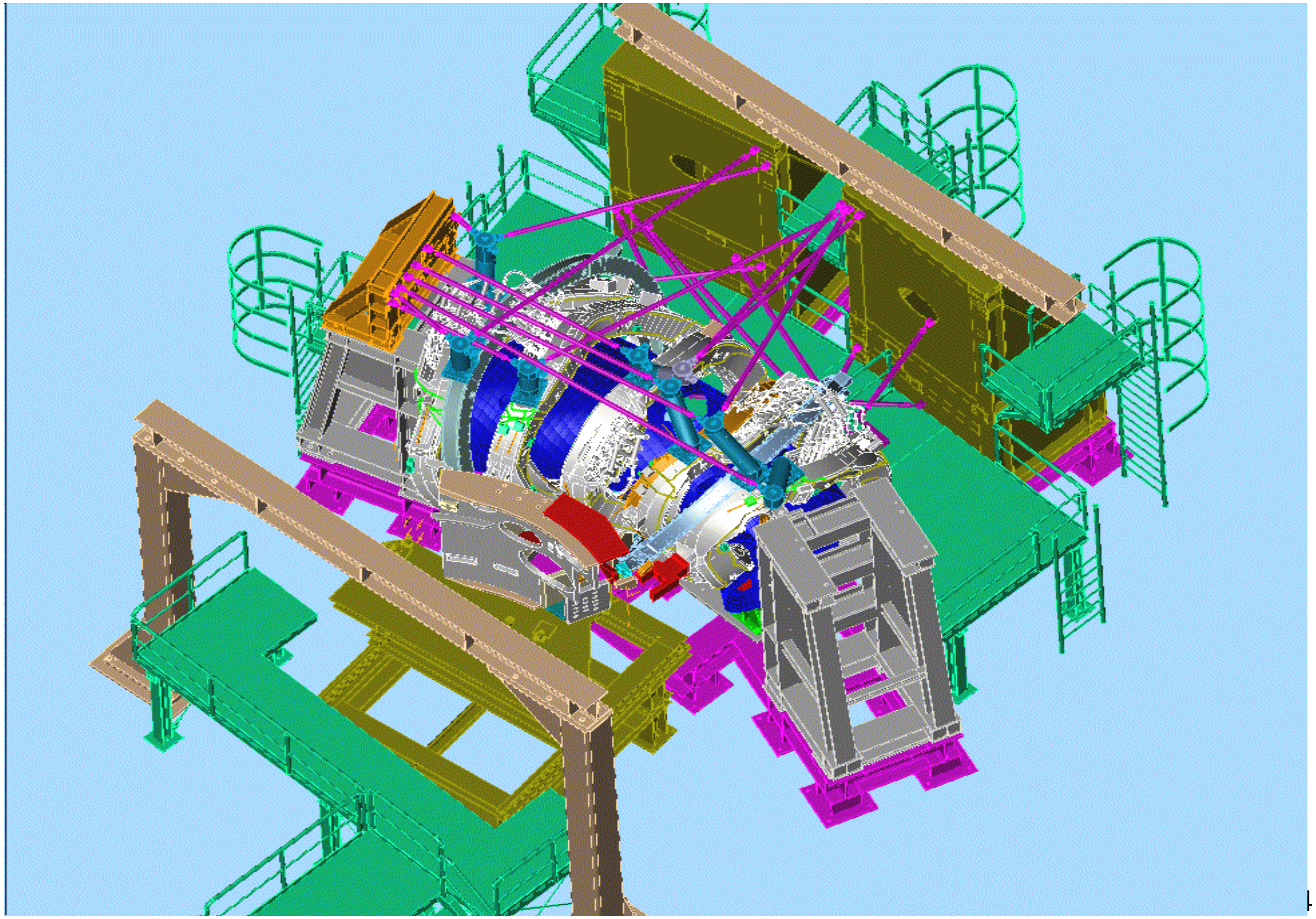
First step: assembly of half-module



The assembly stand 1a is shown with support elements. A half-module will be assembled in this stand. The half-module vessel is shown in blue. A non-planar coil is attached to the coil handling tool (violet in the left picture, yellow in the right slide).

On the right side, a coil is moved over the vessel.

Complete half-module



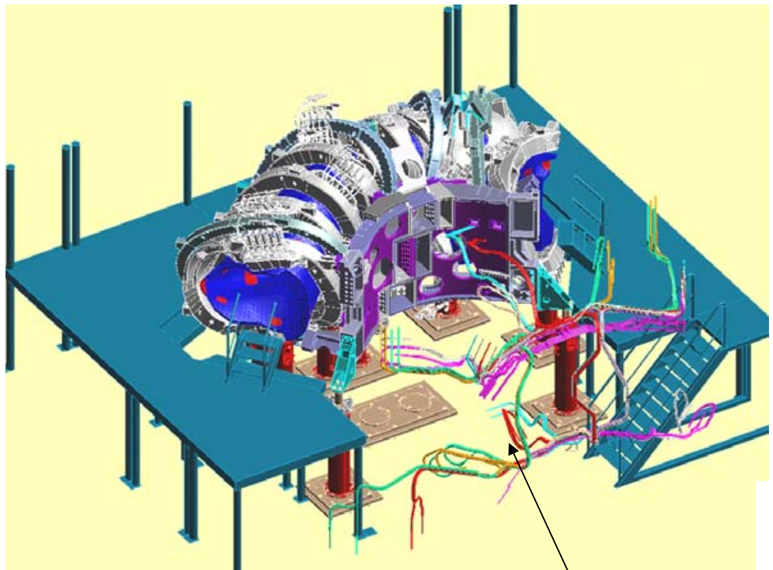
Shown is a complet half-module in stand 1b.

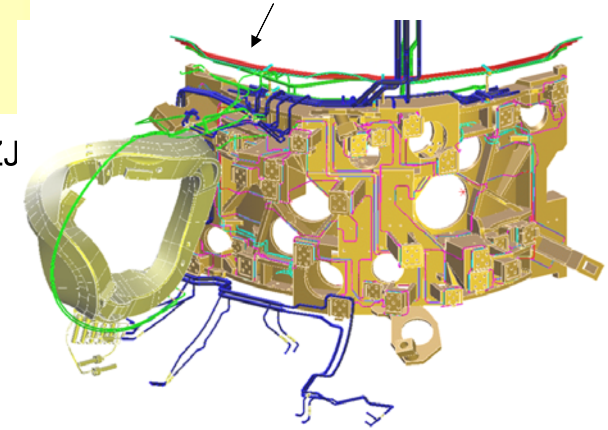
Assembly
L. Wegener
(F. Hurd)

W7-X presentation, 2006

IPP

2nd step: assembly of module



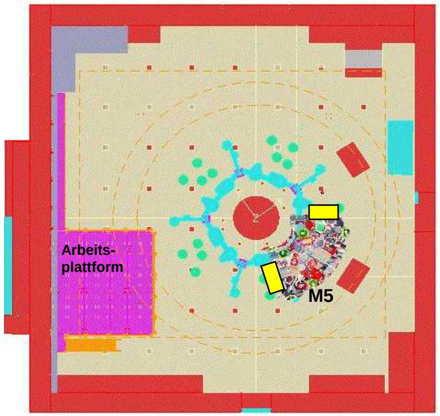


This slide shows the completion of one magnet module on mounting stand II (one fifth of the entire machine): all 14 coils are mechanically linked to the central support ring; plasma vessel parts are welded and insulated; bus-bar system, helium pipe system and instrumentation system are installed

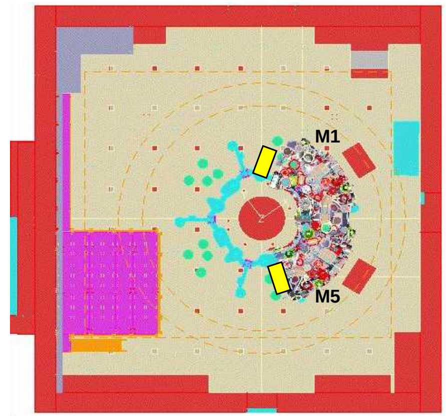
Assembly
L. Wegener
(F. Hurd)

W7-X presentation, 2006

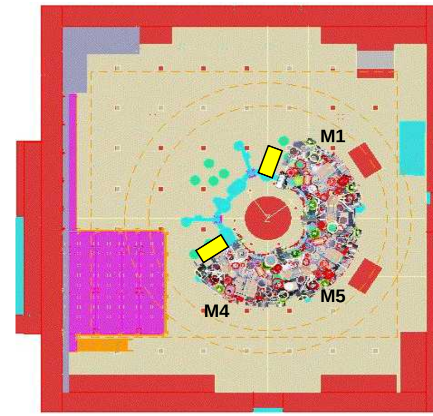
3rd step: assembly of modules



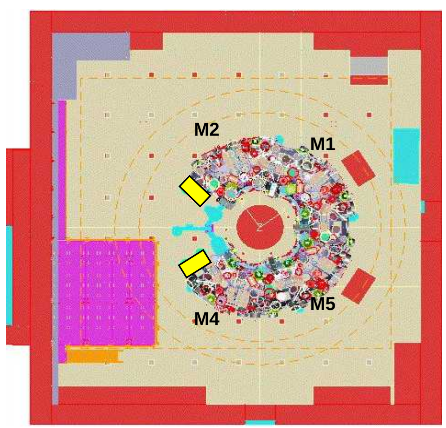
Schritt 1: Modul 5



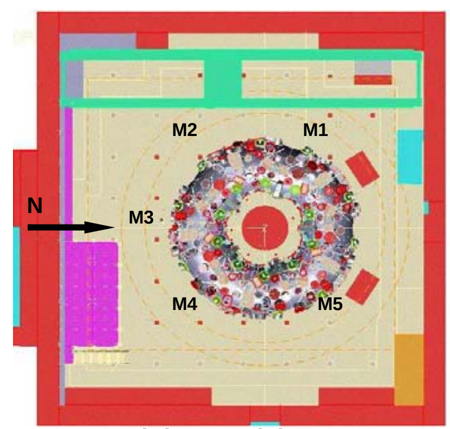
Schritt 2: Modul 1



Schritt 3: Modul 4



Schritt 4: Modul 2



Schritt 5: Modul 3

Sequence of the final assembly; view in the experimental hall: each pre-assembled module will be moved from its assembly position onto the experimental platform.

Assembly
L. Wegener
(F. Hurd)

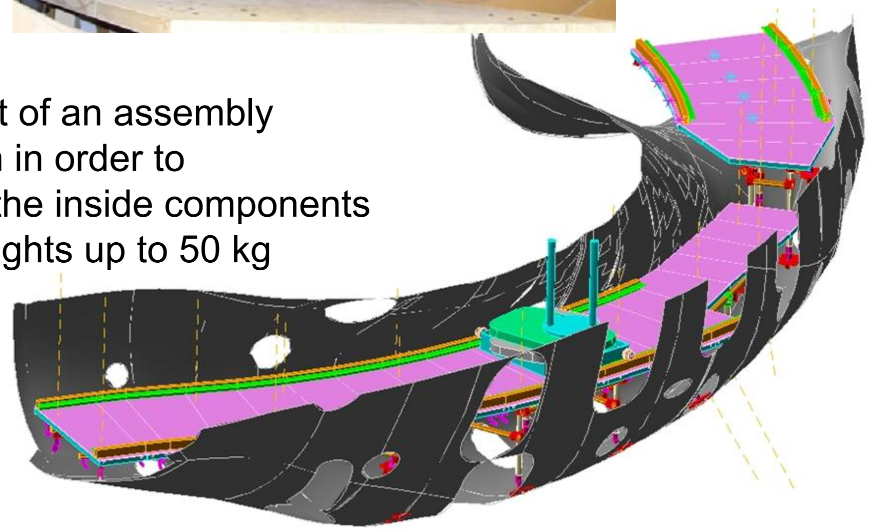
W7-X presentation, 2006

Assembly inside vessel

View into plasma vessel

Model to test assembly inside vessel

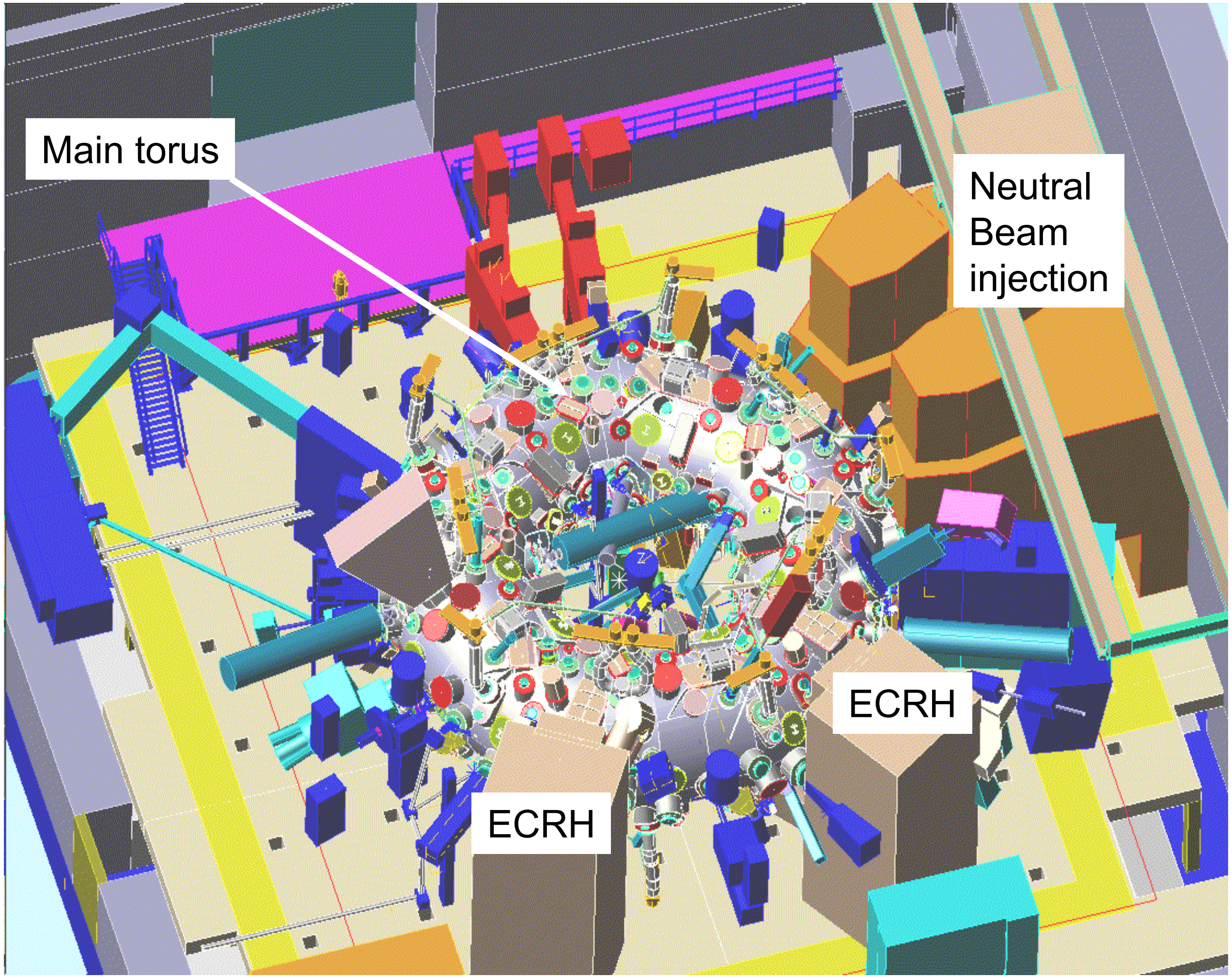
Concept of an assembly platform in order to handle the inside components with weights up to 50 kg



The installation of the “In Vessel Components”; studies of assembly principles

Assembly
L. Wegener
(F. Hurd)

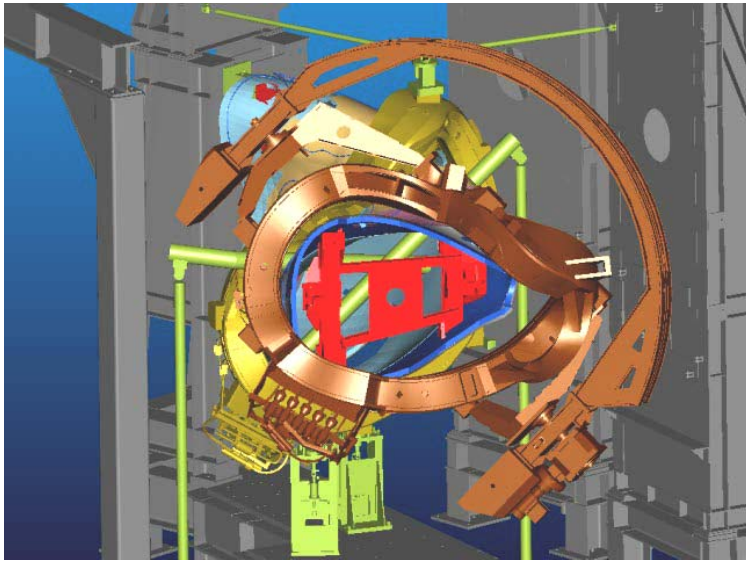
4th step: periphery (heating, diagnostics)



The assembled torus is shown; the reserved space for diagnostics is indicated. NBI is represented by the two brown boxes on the left side, the ECRH coupling towers are shown on the bottom.

Assembly status

planning



status

Presently first coils have been threaded across the plasma vessel sectors, the pre-assembly worked as planned without severe problems; two half-modules are in work (mounting stand Ia and Ib)

Assembly
L. Wegener
(F. Hurd)

On Site
Coordination
S. Gojdka

On-site Co-ordination & Work Safety

IPP

•Observance of the tasks and responsibility of the safety coordinator in conformity with the § 4 labour protection laws and § 6, BGV A1

•Implementation of the laws and rules for safety, health and environment protection

•Coordination of the different activities of the firms and persons who are on site, so that possible mutual dangers are prevented.

•Technical consultation for safety of the assembly subdivision leader and supervision of the employees in the assembly subdivision in all matters concerning work safety (compliance with the specifications of the assembly handbook)

•Contribution to Assembly Documents from the point of view of the work safety (quality assurance and assembly plans (QAAP), work and inspection instructions)

•Definition and care of the assembly handbook (part A safety, part B organisation)

•Significant collaboration in the enforcement of the regulations of part A (assembly-safety) of the assembly handbook in planning, preparation and during assembly

•Regular safety inspections on site during the assembly

•Creation and assessment of the dangers for the activities during the assembly

•Creation and assessment of the operating instructions (dangerous materials, machines etc)

•Delivery and availability of proper personal protection equipment

Assembly
L. Wegener
(F. Hurd)

Device Assembly
K.-H. Ölgemöller

Device Assembly

W7-X presentation, 2006

IPP

Main tasks:

- Component Preparation
- Setting up of Half-Modules, Modules, Torus… (e.g. all practical assembly works; about 60 to 70 technicians and engineers at peak load estimated)
- Entire Metrology
- Welding Shop (including practical qualification of special welding procedures)
- Vacuum Technique (leak tests and setting up of vacuum systems)
- Assembly control (work preparation and planning, assembly documentation, QAAP…)
- Operating the shift system, managing all interfaces
- Quality checks (DIN/ISO 9001)

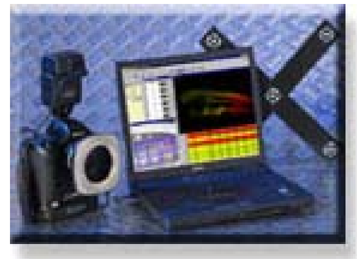
Assembly consists of 3 main departments: Device Assembly, Assembly Technology and Periphery

Device Assembly comprises all crafts, practical works and organisation to set all parts of the W7-X basic machine up

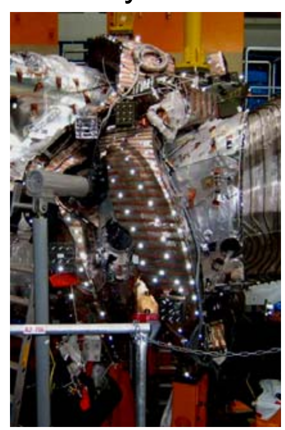
Device Assembly, Metrology

Equipment and applications

Leica LTD800 with T-Probe



Photogrammetry-System



FARO-Scanner with FARO-Arm

Metrology is part of Device Assembly. It is required during all assembly steps, it accompanies all alignment works and it provides the final geometrical inspection of mounted units and sub-units

The Leica Laser Tracker is used to survey single datum points on components and units. The data are compared with CAD-models.

Photogrammetry is used mainly for the final survey of assembles sub-units.

Laser Scanning is used to scan the “as built” geometry of components and to create “as built” models for the reverse engineering.

Periphery

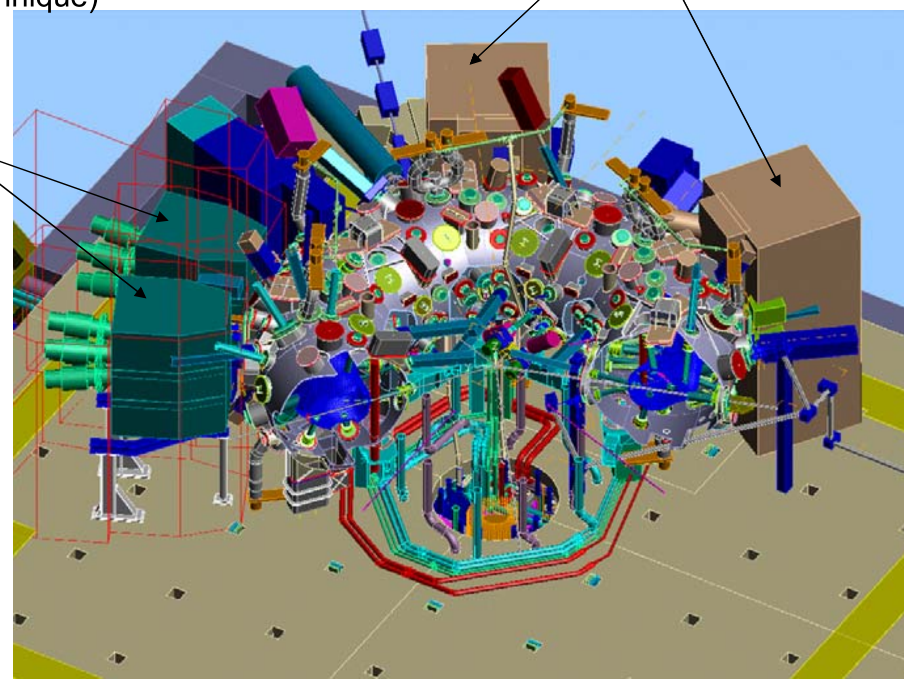
Main tasks:

Components to integrate (design, qualification, procurement, installation):

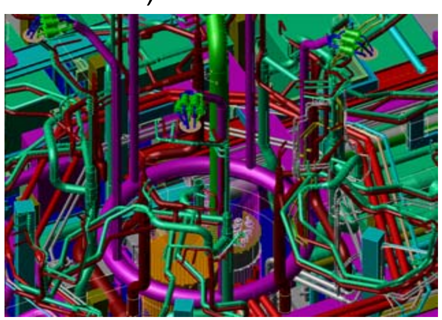
- Water cooling circuits
- Electric (supply voltage)
- Instrumentation cabling (inside and outside the cryostat)
- Cubicle shelves, experimental platforms etc.
- (Vacuum lines by Vacuum Technique)
- (Cryo lines by Basic Device)

ECRH towers

NBI-boxes



Detail:
Cooling water and cryo lines (machine itself and floor are not shown)



Periphery deals with the installation of the auxiliary supply systems: 400 V power supply and power distribution system; cooling water system for all components; compressed air system and the cabling system for the sensor instrumentation. The basic layout is made by the Division “System Engineering”; the qualification, procurement and installation is made by Assembly Periphery.

The installation of the vacuum system is separately made by the department “Device Assembly”; the installation of the main helium supply system is mad by the division “Basic Device”.

Power supplies

Power supply module (with transformers, interphase reactors, thyristor rectifier) during a test

Power supplies of the control coils

Control room of the power supplies

Test of a circuit breaker in the magnetic field (test bed in Greifswald)

The high current power supplies for the superconducting magnet system are provided, installed and handled by the division “Basic Device”.

The high voltage power supplies for ECRH and other systems are provided, installed and handled by the division “Technical Services”.

Both systems have successfully passed the final acceptance tests. They are ready to be put into operation.

Technology

Main tasks:

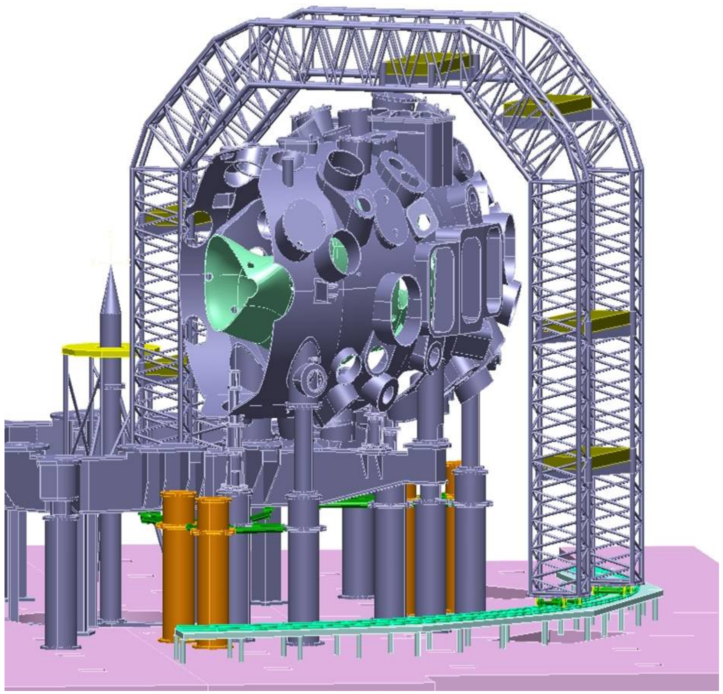
- Design, qualification, procurement and commissioning of assembly equipment and tools
- Qualification of all assembly procedures including work instructions
- Design and procurement of the machine fundament
- Design and procurement of the entire bus-bar system
- Engineers assistance to assembly works, optimisation of assembly procedures

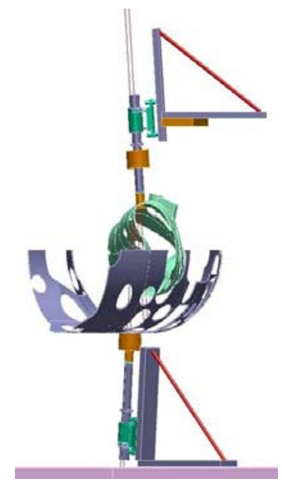
Design and procurement of different coil stringing tools and mounting stands

Assembly Technology has to work and qualify all equipment and tooling which is needed to carry the entire assembly out as well as the belonging assembly procedures. Main objects are: 6 mounting stands, coil-threading tools, assembly of support elements, bus-bar assembly, alignment of both inner and outer vessel sectors, port handling tools, procurement of bus-bars and machine base, installation procedures and tools for “In Vessel Components”

Technology

Design and procurement of assembly tools for port installation





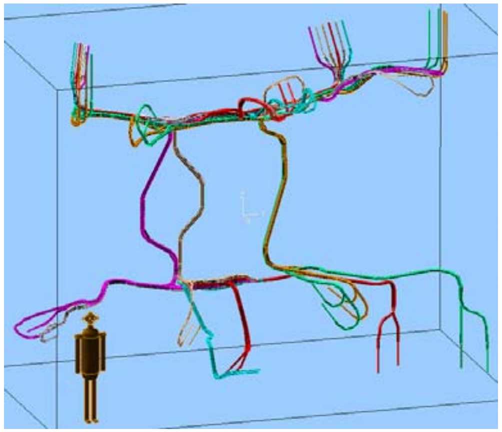
Port assembly support; can be moved in all directions. The ports will be positioned between the inner and outer openings with the help of a movable sledge.

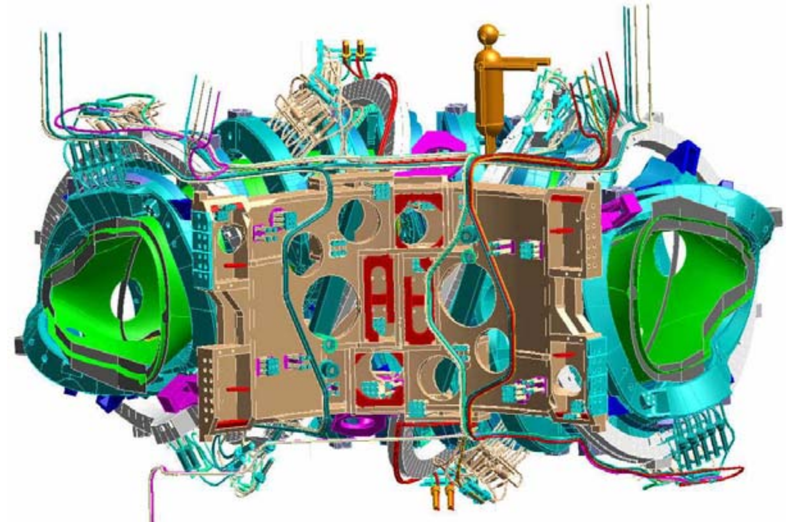
Bridge to mount the ports with platforms to accommodate the port-assembly supports

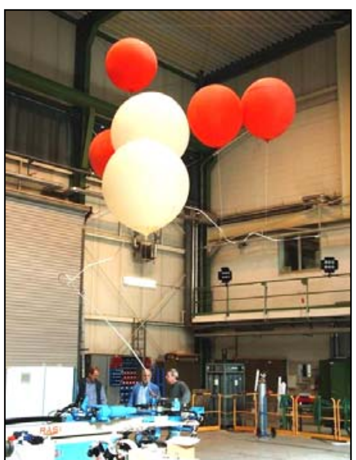
Port assembly supports (ramps) and bridges are presently planned to enable the port installation. The devices must be operated in all three directions of space. Ports can weight up to 1.5 ton, position accuracy must be below 1 mm. To save time, port installation must be done as much as possible in parallel.

Technology

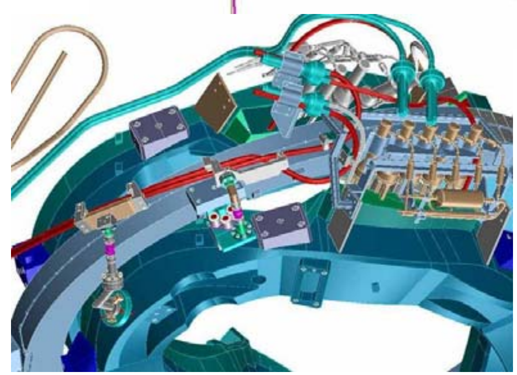
Design and procurement of the bus-bar system, built by FZ-Jülich







Winding of a connector



Detail of the connection to a coil

The bus-bar installation is challenging: 3D bent conductors up to 14 m long, low resistance joints, high pressure prove joint housing, helium tightness and high voltage prove insulation. The mechanical supports must both resist the magnetic loads and tolerate the structure deformation during operation.

The manufacturing of the parts in FZJ has already started.

Physics
F. Wagner
(H.-J. Hartfuß)

Sub-Division: Physics

IPP

Main tasks:

Diagnostics: To develop the start-up diagnostics

ECRH: To develop a 10 MW, 140 GHz, 30 min system in collaboration with FZ-Karlsruhe and IPF-UNI Stuttgart

ICRH: In the 1st step the goal is to develop an efficient system to condition the plasma vessel wall in the presence of a magnetic field.

NBI: To develop a 5-10 MW plasma heating system based on the injection of energetic hydrogen.

Machine control, data acquisition, software:
To develop the control and data acquisition systems and the necessary software for machine operation and plasma diagnostics

Overview

Start-up Diagnostics

MACHINE OPERATION
Flux surface measurements
Pressure gauges divertor
Divertor calorimetry
Divertor thermography
Visual inspection, video

CORE TEMPERATURE, DENSITY
Thomson scattering, bulk
Multichan interferometry
ECE radiometer
Diagnostic beam
CXRS

MHD, E/B FIELDS
Magnetics
X-ray multi camera system

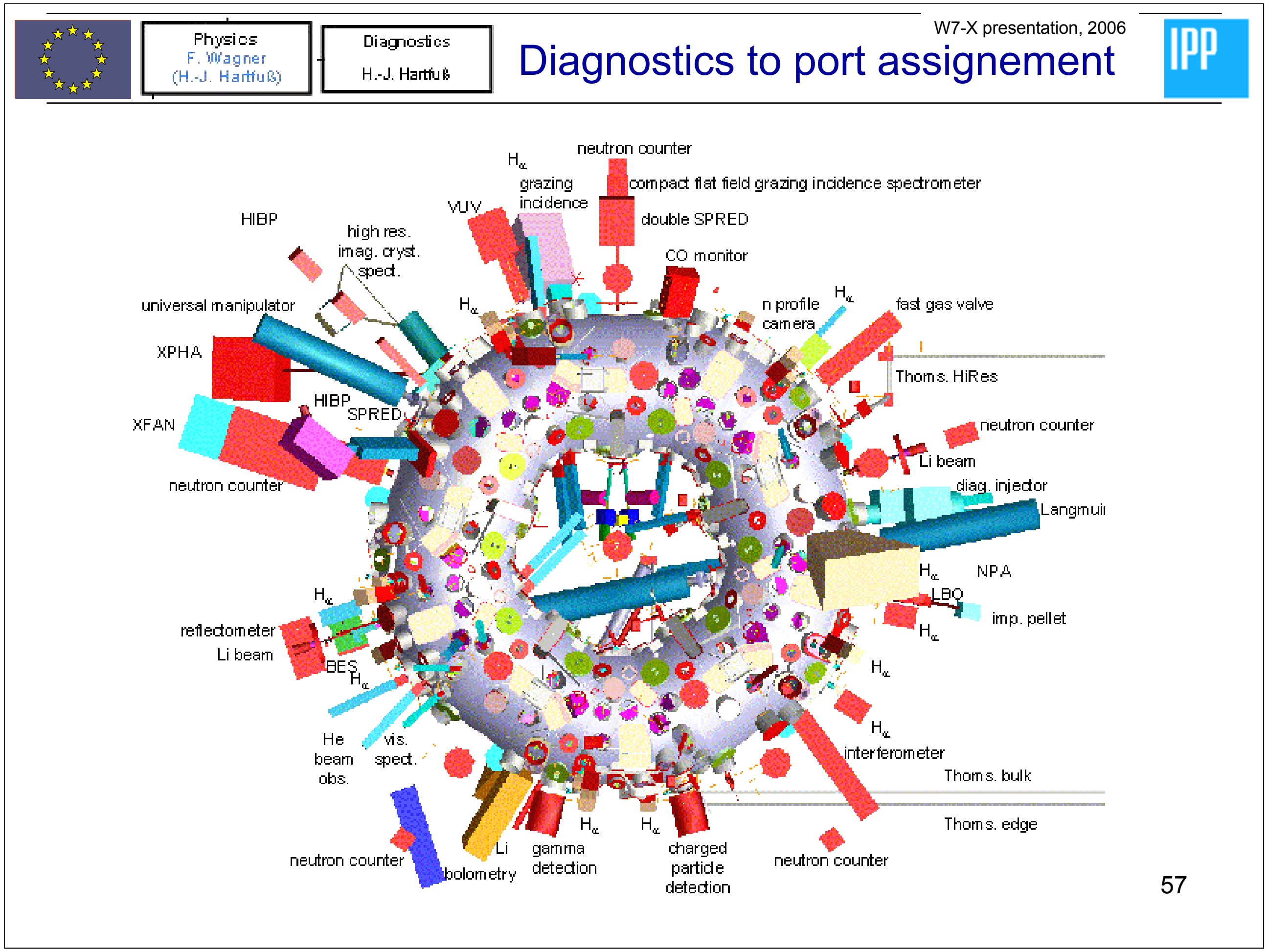
EDGE/DIVERTOR
Langmuir probe arrays
H-alpha

SPECTROSCOPY/IMPURITIES
Bolometry, bulk
Visible spectroscopy
C-, O-monitors
Zeff
HEXOS
X-ray PHA system

FAST PARTICLES
Neutron counters

FLUCTUATIONS
Langmuir-probes, reflectometry,
ECE correlation, Li-beam, Mirnov coils

The start-up diagnostics concentrate on the basic measurements for plasma characterization and machine control. For the latter the diagnostic systems marked in red are foreseen. In a next more physics oriented step following the start-up phase of W7-X, the start-up diagnostics set is complemented by polarimetry, CX-NPA analyzers, HIBP, manipulator, He- and Li-beams, reflectometry, and a fast ion loss detectors. This full set of basic diagnostics is called level-1 system.



The full diagnostics set defined is assigned to about 100 out of 140 diagnostics ports of the W7-X machine. The star-up set occupies about 70 to 80 ports. Simple geometrical bodies are defined as placeholders for the individual diagnostics. No supporting structures, platforms, and connecting paths are included for clarity.

Overview of the distribution of diagnostics around the machine is given in slide 45.

Diagnostics strategy, status

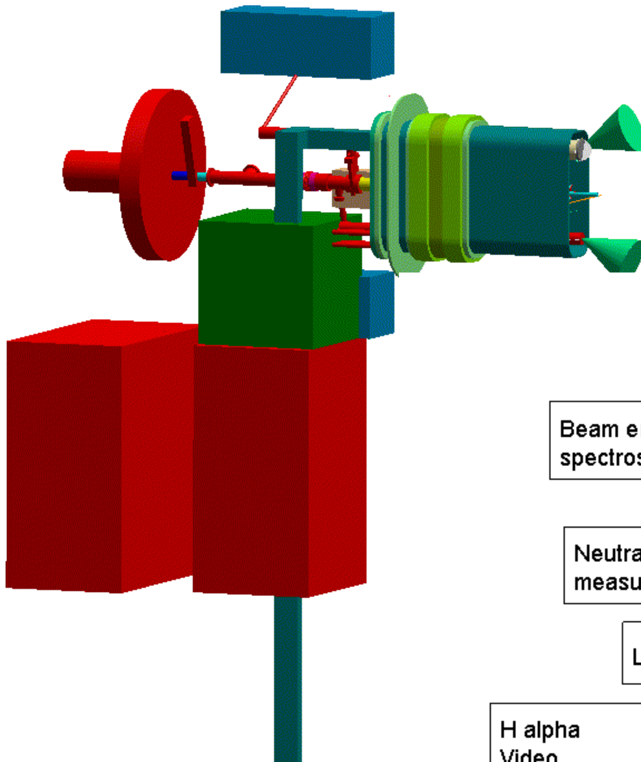
- PHYSICS PROGRAM: DIAGNOSTIC NEEDS, optimization, ...
- DEFINE FULL SET OF DIAGNOSTICS, range, resolution
- PORT ASSIGNEMENT FULL SET
- CONCENTRATE ON “START-UP DIAGNOSTICS“ SET
- DEFINE INFRASTRUCTURAL DEMANDS

STATUS 2006

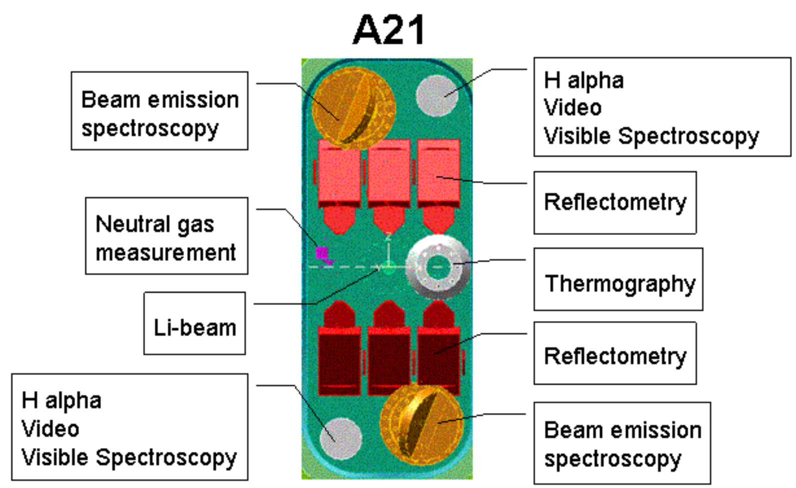
FEASIBILITY	flux surface measurements
DETAILED DESIGN	video, SX, Thomson, interferometry, probes,
R&D	diagnostic beam, X-ray camera, PFOC
CONSTRUCTION	magnetics, windows
TEST	manometers, thermography, HIBP
INTEGRATION	magnetics, HEXOS (Textor)

The strategy adopted in defining the diagnostics set, started from the aims and the mission of W7-X and the physical parameters their spatial and temporal resolutions demanded. The status of diagnostic development in 2006 covers a wide range. While some diagnostics are still in the definition phase others are being tested while others are being mounted at the machine vessel.

A-port diagnostics, feasibility

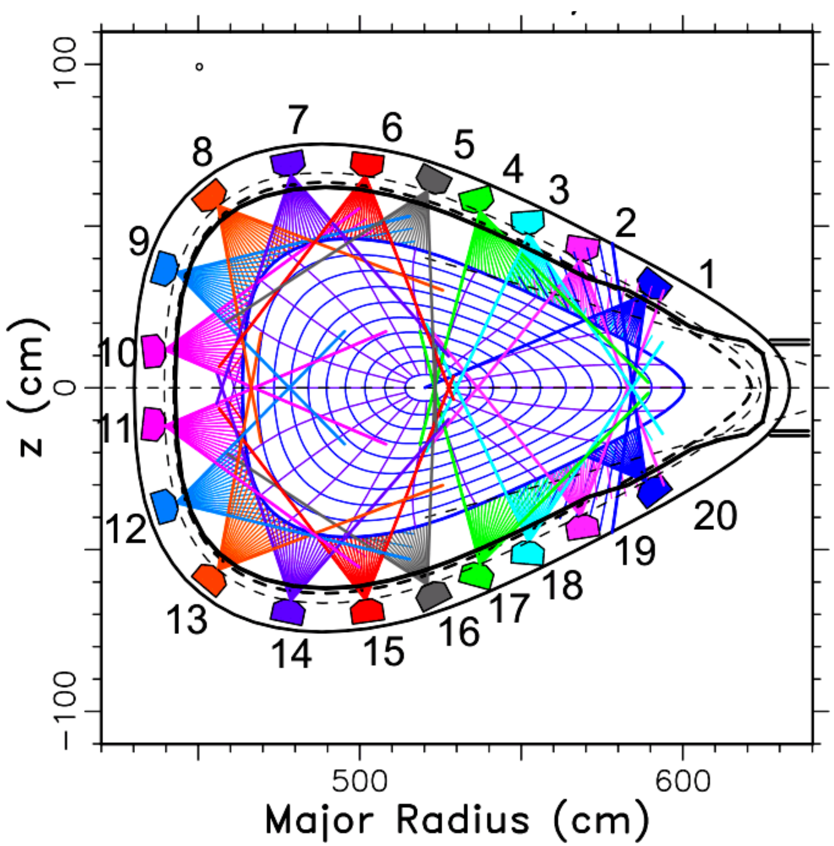


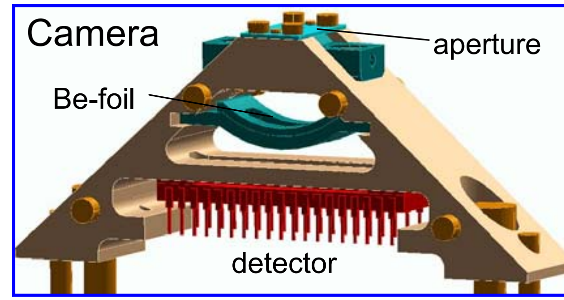
large number of diagnostics to be integrated

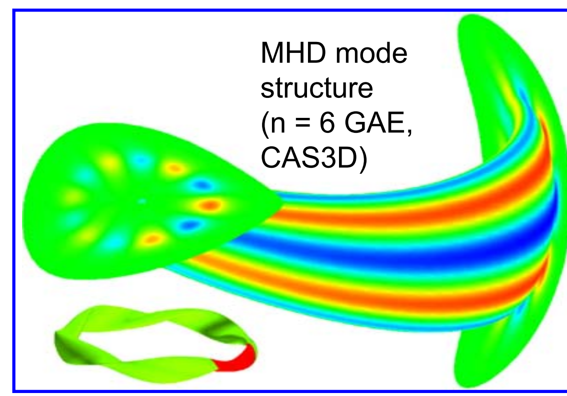


Example of feasibility studies at one of the larger diagnostic ports where a number of diagnostic systems have to be integrated in close neighbourhood.

X-ray cameras, design, R&D



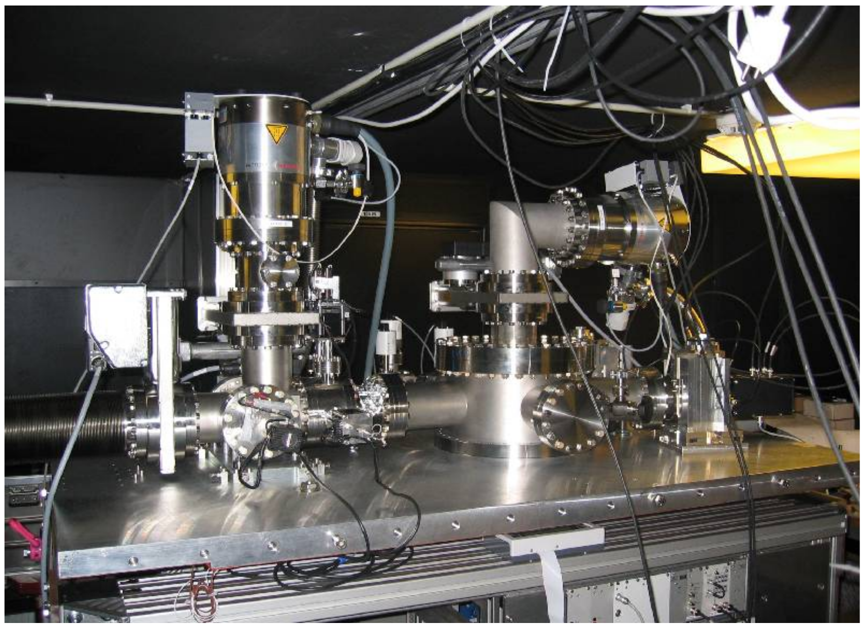


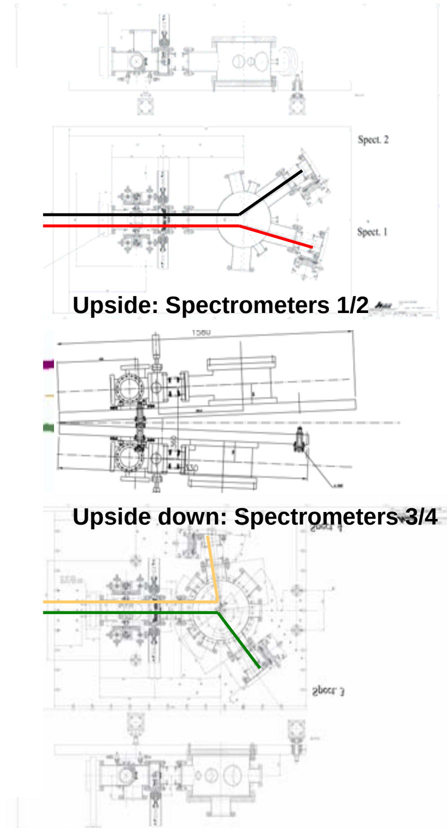


Detailed design of one of the SX-cameras foreseen for in-vessel mounting.

VUV/EUV spectrometer, test

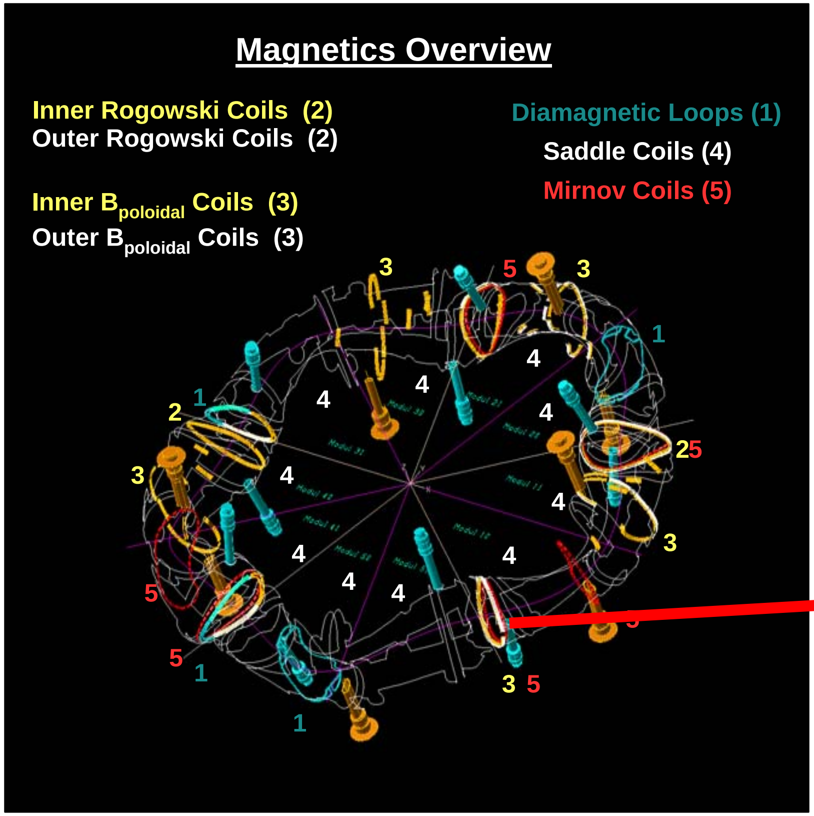
designed in collaboration with FZ-Jülich
constructed by Horiba Jobin-Yvon: **HEXOS**



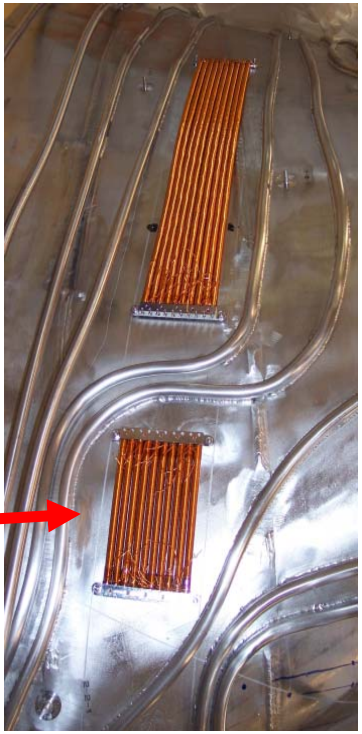


A high efficiency extreme ultraviolet overview spectrometer system (HEXOS) consisting of two double grating spectrometers viewing the same plasma volume while covering the wavelength range 2.5 to 100 nm has already been completed and is being tested at the TEXTOR tokamak at FZJ.

Magnetic diagnostics, integration



first installed
Rogowski coil segments



The first Rogowski coil segments have already been mounted as well as saddle coils at the W7-X vacuum vessel.

Steady state diagnostics

ROBUSTNESS, STABILITY MEASUREMENT: gain, drifts, etc

Challenges

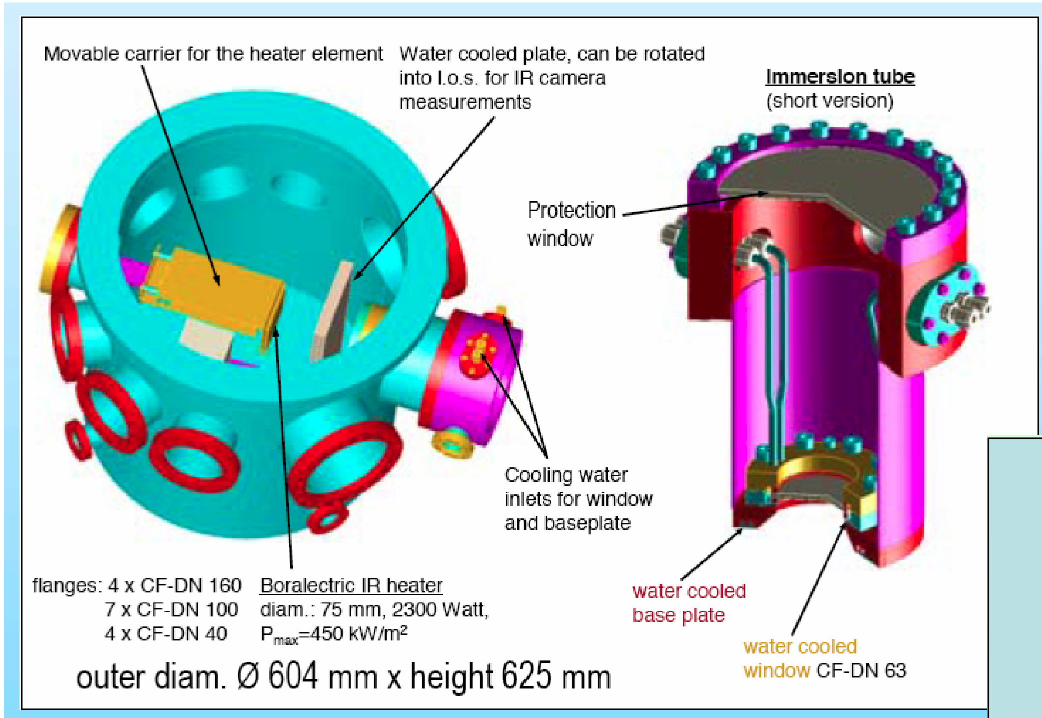
- **Magnetics:** long time integration
- **Interferometry:** fringe jumps
- **Spectroscopy**: coating of windows, mirrors
  cleaning
  in-situ calibration
  all PFOC actively cooled:
  windows, shutters, mirrors

Diagnostics for high power steady state operation have to fulfil several demands. They must first be robust, reliable and stable. The long pulses demand for additional technical challenges: long pulse integrators for the magnetic sensor signals and actively cooled plasma facing components, i.e. windows, mirrors, shutters. The windows suffer in addition coating, demanding for the development of in-situ calibration and/or cleaning methods.

Physics
F. Wagner
(H.-J. Hartfuß)

Diagnostics
H.-J. Hartfuß

Cooled PFOC, thermal load



Programs are being conducted to develop cooled optical windows. In a special test-stand the windows can thermally been loaded with comparable power fluxes as expected in W7-X, up to 50 kW/m2.

Physics
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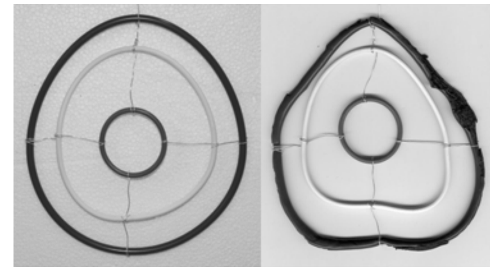
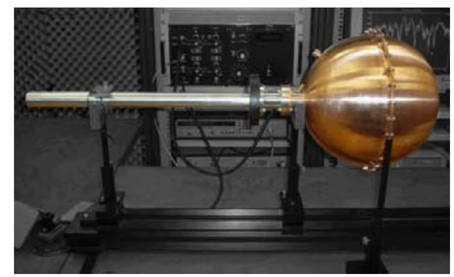
(H.-J. Hartfuß)

Diagnostics
H.-J. Hartfuß

W7-X presentation, 2006

EC stray radiation test chamber



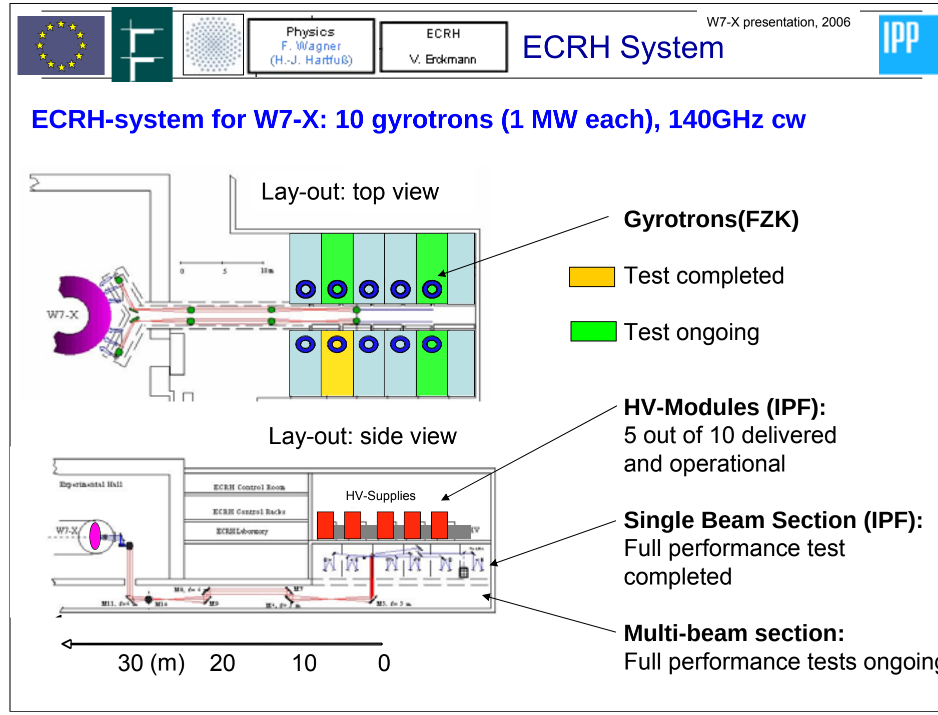


stray radiation chamber: 50 kW/m^2, 140 GHz continuously

- all in-vessel components include. divertor components, windows gate valves etc.

All in-vessel components as well as windows and valves have to cope with a high level of non-absorbed microwave background stray radiation present under certain heating and current drive scenarios in W7-X. A test stand has been established to develop microwave resistant windows and to test the behaviour of valves and gaskets under conditions of up to about 50 kW/m2 mm-wave radiation. (See also page 99.)

A 10 MW cw ECRH system operating at 140 GHz will provide the fundamental heating of W7-X, especially for its major scientific objective - the demonstration of steady-state operation at reactor relevant plasma parameters. The ECRH system is being developed and build by FZ Karlsruhe (FZK) as a joint project with IPP and IPF Stuttgart. The ‘Project Microwave Heating for W7-X‘ (PMW) coordinates all engineering and scientific activities in the collaborating laboratories and in industry. The modular design of the ECRH system comprises 10 units with 1 MW each. A W7-X prototype gyrotron with 1 MW output power has been developed in collaboration with European research laboratories and industries (TED, France). The ten gyrotrons at Greifswald will be arranged in two subgroups symmetrically to a underground beam duct in the ECRH hall. The RF-beams of each subgroup are combined and transmitted by a purely optical multibeam waveguide (MBWG) transmission line of typical 50-70 m length from the gyrotrons to the torus. The combination of the five gyrotron-beams to two beam lines with a power of 5 MW each reduces the complexity of the system considerably.



For each gyrotron, a matching assembly of five Single-Beam Waveguide mirrors (SBWG) is mounted on a common base frame. Two phase correcting mirrors match the gyrotron output beam to the stigmatic Gaussian beam with the correct beam parameters, two others are used to set the appropriate polarisation needed for optimum absorption of the radiation in the plasma. A fifth mirror directs the beam to a plane mirror array (beam combining optics unit), which is situated at the input plane of the MBWG. A newly designed short-pulse calorimeter (< 0.5 s) is installed on each SBWG-frame for absolute calibration of the gyrotron output power. The MBWG is designed to transmit up to seven beams from the gyrotron area (input plane) to the Stellarator hall (output plane). It consists of 4 focusing mirrors in a confocal arrangement plus additional plane mirrors to fit the transmission lines into the building. The configuration of the mirrors is such that mode conversion, which is a general feature of curved surfaces, cancels at the end of the MBWG. Additionally, distances and focal lengths for each beam path are designed to achieve a geometric-optical imaging from the gyrotron output to the torus windows, which makes the system insensitive to misalignment.
At the output plane of the MBWG, a mirror array separates the beams again and directs them through diamond vacuum barrier windows to the in-vessel front steering launcher. The entire transmission-system was tested on the low-power test facility at the IPF and shows an efficiency of 90±2 % in good agreement with the calculations of the transmission properties (92%).The installation of all SBWG-mirror modules as well as the MBWG-mirrors is completed in the beam duct. The beam lines are presently under high power, cw test. The MBWG system could easily handle more than twice the rf-power due to the low power density on the mirror surfaces, which is compatible with the ITER demand.

Physics
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(H.-J. Hartfuß)

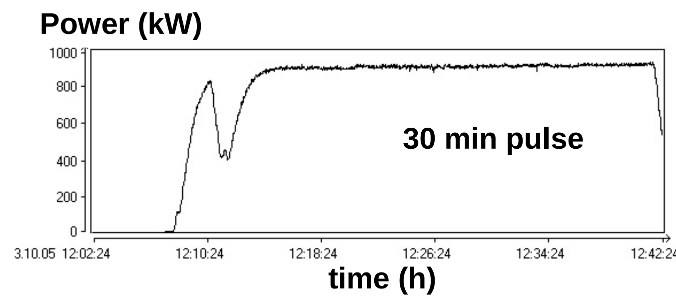
ECRH
V. Erckmann

W7-X presentation, 2006

ECRH System

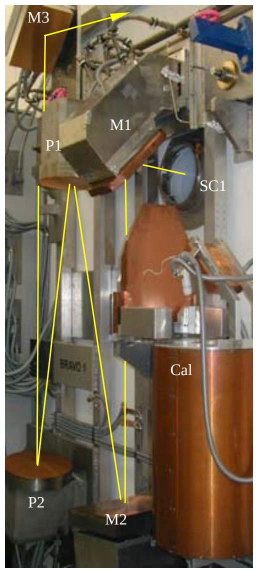
Gyrotrons and Magnets: Status

TED Maquette
operational at IPP
TED Prototype 1
installed; operational
TED S. No.1
oper. at IPP at full performance
(0.9 MW, 30 min)
TED S.No.2
under test at FZK
CPI-Prototype
oper. at IPP at full performance
8 SC-magnets,
6 delivered and operational

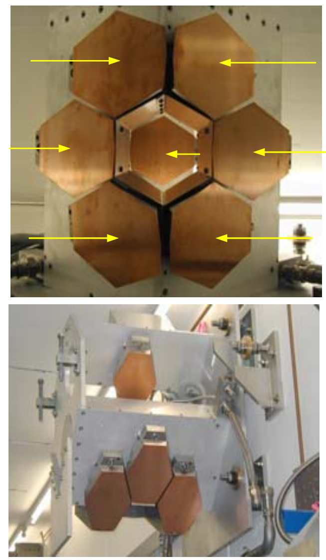


The development of the W7-X Gyrotrons started in 1998 in Europe with Thales Electron Devices (TED) and in USA with CPI as industrial partners. Both programs were terminated successfully and the ECRH-project has now entered the phase of series production and commissioning, two TED series Gyrotrons are delivered. The diagram shows a 30 min pulse at 140 GHz and at a power level of about 800 kW at the load.

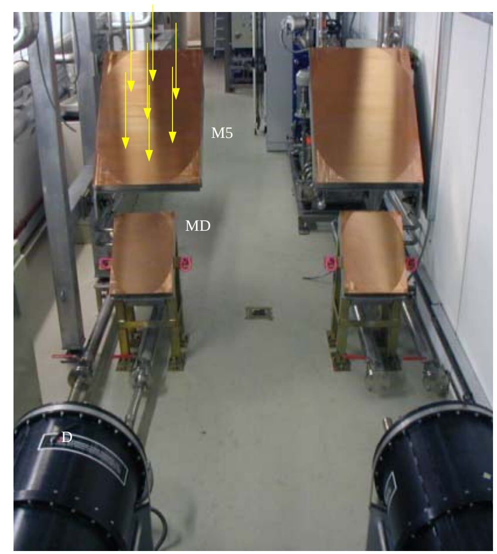
Optical transfer-line and its components



Single Beam Module



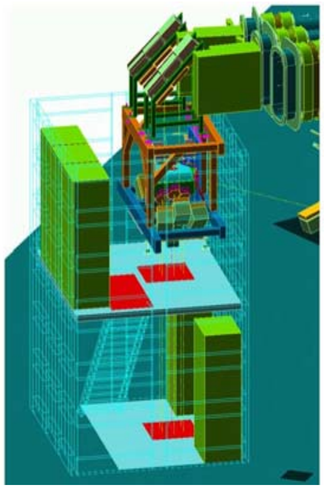
Beam Combining Optics

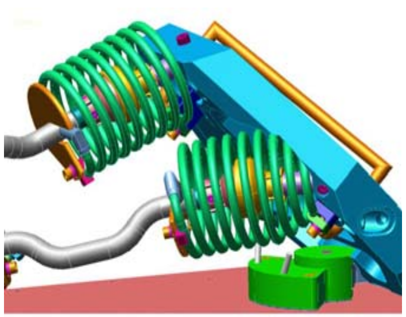


MBWG and CW-load

The installation of all mirrors for the transmission system in the underground beam duct is completed. The most loaded sections of the transmission lines consisting of 7 mirrors was tested successfully with 900 kW for 30-minutes. No major problems were identified.

Transmission System near Torus: Tower, In-vessel Components





ECRH-Towers:
houses all optical elements to feed the launcher, outline design completed, detailed design started

First wall, In-vessel reflectors and ECA diagnostics
outline design and integration started

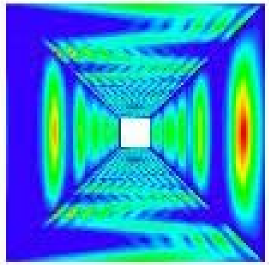
Launcher
Mock-up completed, one (of two alternative) concepts (in-vessel driving rods and mirror cooling) qualified, survived 10 000 load cycles.

Rebuilt of **Launcher Mock-up** ongoing.
Tests in the ‘µ-wave Stray-Radiation-Loading’ test facility (IPP-Garching) scheduled.

The R&D of the in-vessel components is underway, all parts inside the port are actively cooled to cope with the microwave and plasma radiation loading. A motor driven ECRH antenna mock-up was fabricated and the mechanical stability was successfully tested in a long-term programme with 10000 load cycles.

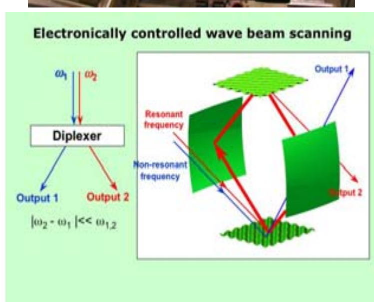
ECRH System

ITER related ECRH activities



High power tests of the **Remote Steering Launcher** Mock-up at IPP completed (EFDA-contract, FOM/IPF/IPP)

High power tests of **ITER CW-Calorimeter** (EFDA contract, IFP Milano/IPF/IPP)



Fast Directional Switch (FADIS) for High-power μ-wave beams (no loss, no mechanical drive), IAP-Nizhnji Novgorod/IPF/CNR/IPP (ITER task-proposal submitted)

The ECRH Installation at IPP-Greifswald serves as a test bed for ITER-ECRH components, as frequency and RF-Power per Gyrotron are very similar to the ITER ECRH-System. The optical transmission system provides an easy and flexible access for test-components. Basic R&D to improve present day high-power microwave systems is an ongoing activity. In particular, a new component for fast microwave switching/beam combining is under investigation (Fast Directional Switch, FADIS-project).

1) Zig-Zag propagation of a wave beam pattern in an rectangular remote steering launcher wave guide. A tuning range of +- 12° was experimentally achieved (in agreement with calculations).

2) Shown is the cw-calorimeter (1 MW, Milano).

3) Left: Schematic of the fast switch; the diplexer discriminates the two beams in their frequency ($\Delta f/f=10^{-4}$) and sends it in either direction. Right: Principle of the high-Q resonator to realise the switch.

Device Control

Main tasks of the W7-X control system:

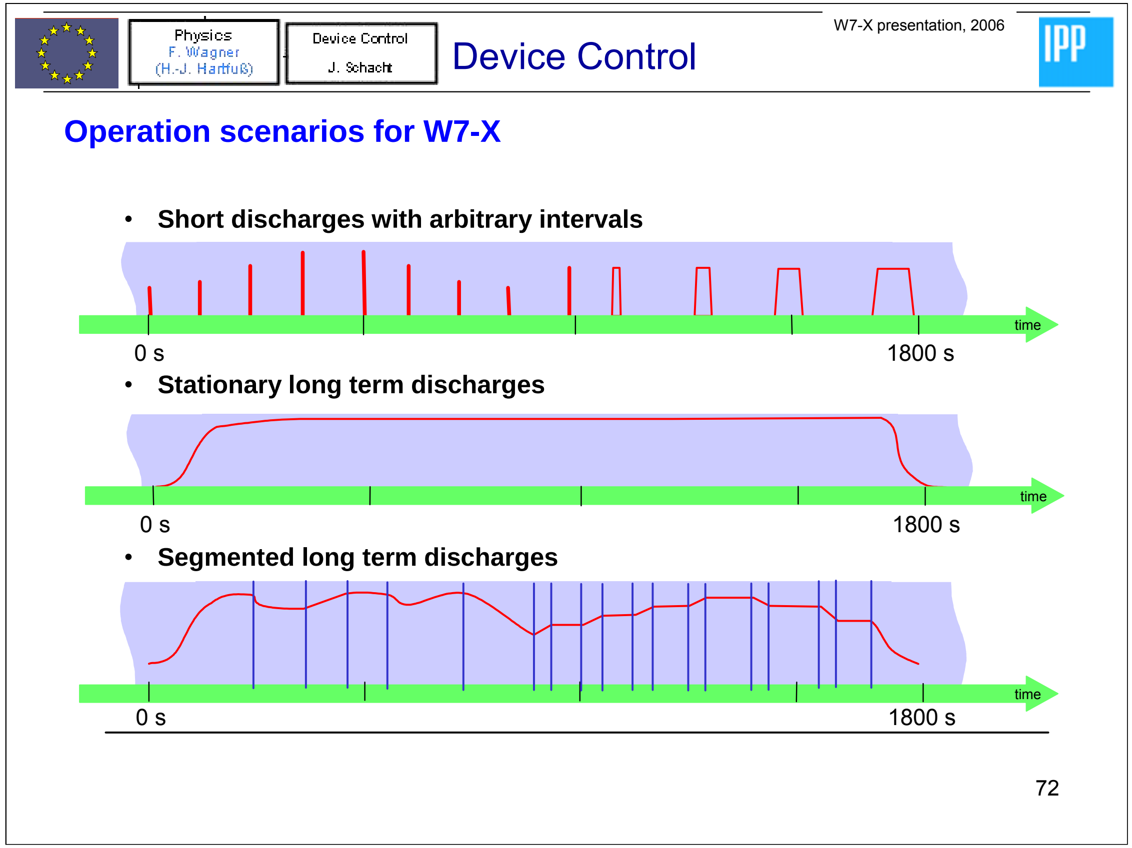
Stand-alone control of components
No basic difference between technical components and diagnostics
Necessary for commissioning and tests

Safety of isolated components and environment
Interactions between different components and with people are handled by the central safety system

Preparation of the components and of the whole system
Operational management is the responsible unit for preparation of the components
Slow sequence control starts and controls tasks like baking and conditioning of the vessel

Segment control
Generating objects from database information and processing them
Segment control is used in the slave mode of operation during experiments but it can also be used in the stand-alone mode for testing.

The superconducting stellarator W7-X is an experimental device with steady state capability. It will run pulses of up to 30 minutes duration with full heating power. Conventional operation based on short pulses with arbitrary intervals will be employed as well as steady state long-pulse discharges consisting of a string of arbitrary sequences of short phases with different settings and plasma parameters in a single discharge are planned. The control system will allow these different modes of operation.



In the phase of commissioning and for exploration of new operating scenarios and parameters conventional short pulse („shots") operation with arbitrary intervals will be used (upper trace)..

For the demonstration of the steady state operation capability and for the investigation of effects with long time constants high power discharges up to 30 min duration with full heating power are technically possible (middle trace).

The most common mode of operation will be series of experiments in one discharge - so called segmented long term discharges. In a single discharge experiments with a wide spectrum of parameters are carried out (lower trace).

•W7-X will start operation at the beginning of the next decade and will probably work for two decades.

•Available technology will dramatically change during this time.

•In order to minimize costs and manpower for planning, maintaining and upgrading the system during its lifetime one has to minimize the number of different components. In this situation it is mandatory to standardize components and share experience in order to reduce development and training costs and avoid frustrating learning phases. Developments of ones own product may only be justified if the necessary specifications are not available on the market. Product lines from market leaders promise the longest lifetime.

Wendelstein 7-X has the typical risks of a experimental fusion device. It will be operated, however, without tritium. Danger is minimized in the first step by a safe component design including properly designed passive protection systems.

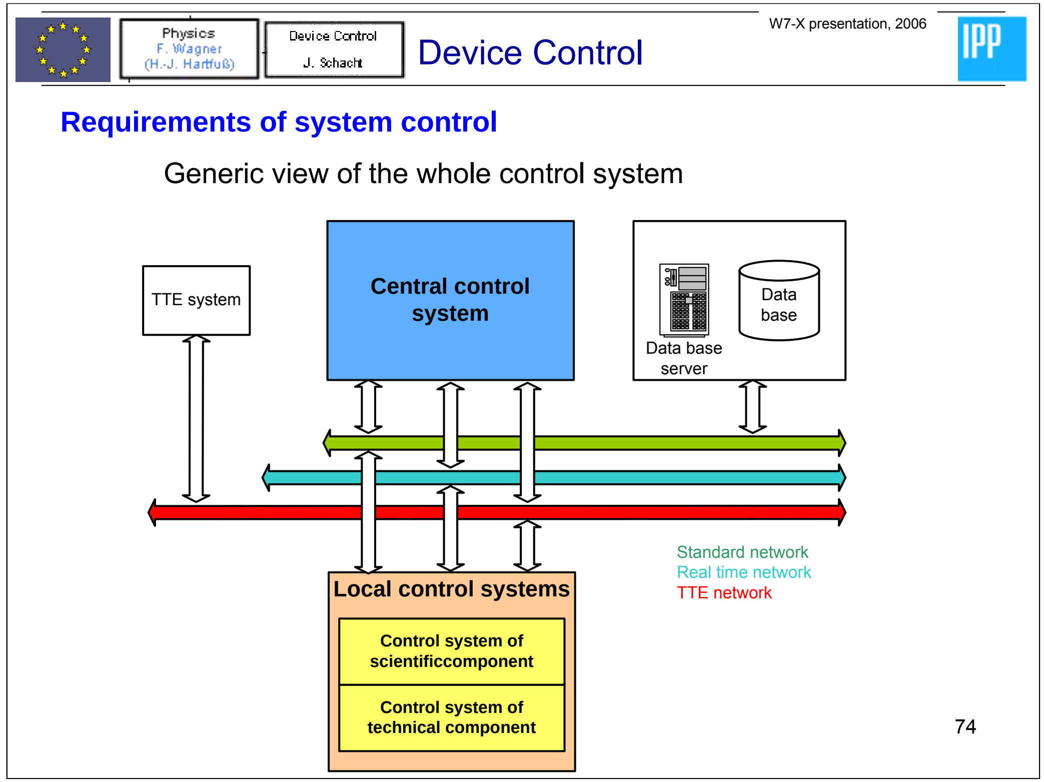
Device Control

Requirements of system control

- Flexibility
  - In magnetic configurations and plasma operation
- Scalability
  - In the final stage there will be about 30 local control systems and about 100 diagnostics
- Maintainability
- Reliability
- Continuous control
  - Discharges up to 30 minutes with full or possibly longer with reduced heating power
- Machine control
- Safety of all components and of the whole system
  - Slow control:
    - Control of states and slow processes
    - Visualization of states and parameters
    - **→ PLC technique (cycle time: 50-150 ms)**
  - Real Time control:
    - Experiment scheduler → segment control system (segment grid: 1ms)
    - Plasma heating, feedback systems, plasma diagnostic systems
    - **Computers with a real time operating system (VxWorks)**

Remaining hazards have to be averted by a safety control system which provides interlocks and controls the human access to the device.
Legal regulations and technical standards related to safety are strictly obeyed. Some parts of the device will have to be approved by authorities according to legal regulations.
Safety requirements are defined by a detailed safety analysis.

The Controller of the subsystems in the experiment are based an two types of Controller. The first group uses PLC techniques; the second group are computers equipped with a Real Time Operating System and special hardware cards.
The requirements to the response time and precision of time stamps of the local systems are very different. Short response time with data processing in real time and a time resolution in a range of 20 ns are essential for data acquisition systems, segment processing and fast feed back control.
Most control systems of the technical components and diagnostic systems, based on PLC, are less demanding. Because the cycle time of a PLC often exceeds 10-50 ms, time resolution and time accuracy can be much lower as for real time computer systems.



•The device control system consists of a central control system, a large number of local control systems, a data base system and a Trigger Time Event system (TTE system).

•The local control systems at the bottom of the figure are individually designed for each technical component like coils, heating systems, cooling system etc. or scientific component like diagnostics.

•<u>Three networks</u> fulfill all demands of the system concerning network communication on different levels.

•Standard network means the installed standard LAN running TCP/IP protocol. It is used for transmission of all information with no or minor real time requirements.

•<u>The real time network</u> is technologically similar but physically separated from the standard network. It is a simply structured switched Ethernet. Data packets are transmitted with the UDP protocol or with a very simple layer 2 protocol. Layer 2 switching, simple protocols, short data packets and low loading permit applications with real time requirements in the order of 100 µs. This network will be used for the distribution of event messages and of measured values. Multicast is commonly used.

•<u>The TTE network</u> is a unidirectional optical fiber network with a simple proprietary protocol. It is used for the distribution of the precise system time and for broadcasting event messages with real time requirements in the order of 10 µs. Segment switching messages will be distributed via this network and via the Real time network for those units, which are not connected to the TTE system.

Physics
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(H.-J. Hartfuß)

Device Control
J. Schacht

Device Control

W7-X presentation, 2006

Tasks of the system control

- Safety of isolated component and environment
  - 2 principles:
    - inherent safety of each component
      → **design & construction, local safety system**
    - overall safety (for staff and machine) controlled by enabling/disabling of components depending on the operational states
      → **task of the central safety system**
- Stand-alone control of component
  - No basic difference between technical components and diagnostics
  - Necessary for commissioning and tests
- Segment control
  - Loading prepared segment programs from a central data base and simultaneous execution in all components' segment computers
- Automatic control of component as a slave of the central control system
  - Standard for experimental operation of W7-X

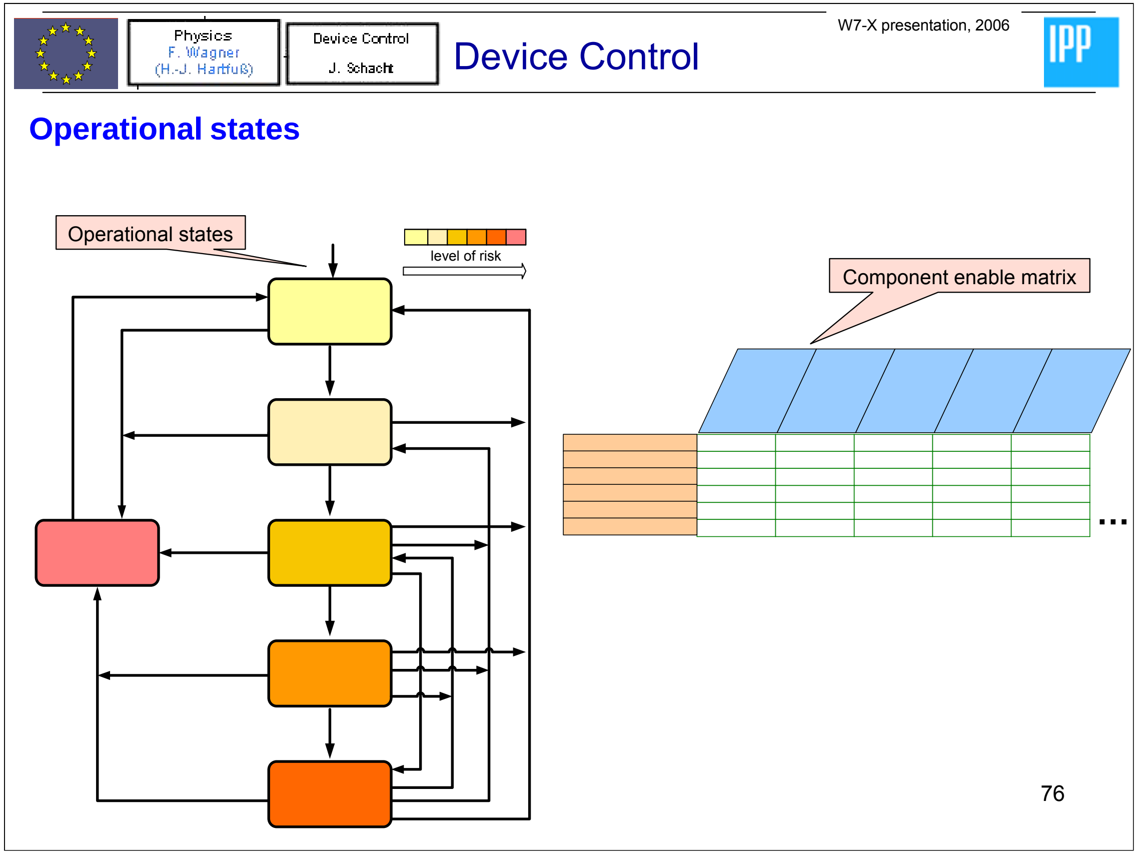
75

There is no basic difference between the control systems of technical and scientific components. The implementation will be strongly different because of different requirements to the different components. All control systems of components are able to run the component in stand-alone mode for commissioning and tests. They provide the safety of each component and of the environment as far as this is possible for the isolated control system. Interactions with other components and with the environment, staff working at the experiment, are handled by the central safety system. Control of each component by means of segment descriptions is also a task of the component control systems. If there are high real time requirements to a component this means that its control system has to include a real time computer. Segment control is used in the slave mode of operation during experiments but it can also be used in the standalone mode for testing. Enabling slave mode of operation is generally a task of each component control system. This does not only mean segment control but any signal exchange with the central control system. The mechanism for switching between stand-alone and slave mode must also be implemented in the component control system.

A set of six basic system states has been defined:

- Emergency stop,
- Switched off,
- Standby,
- Experiment pause,
- Experiment operation, and
- Partially protected operation.

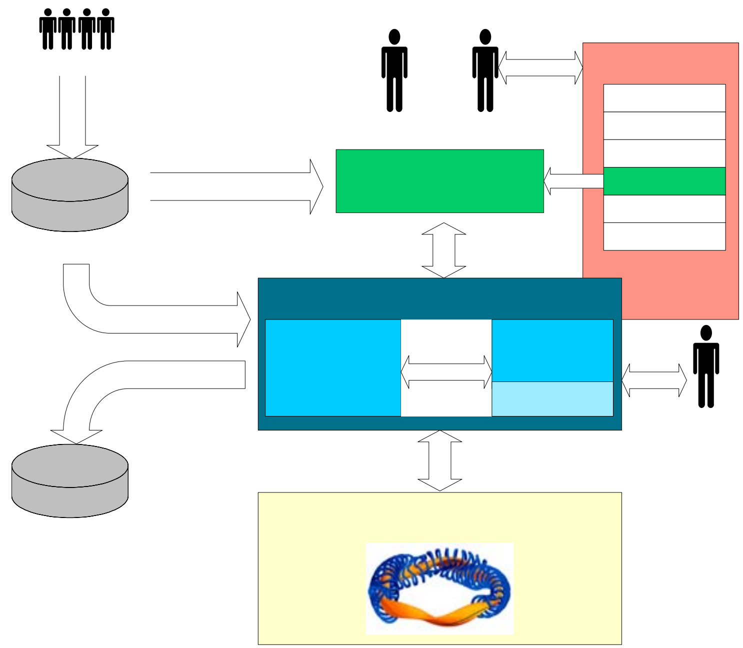
Each system state defines hazard potentials of the whole device. These system states provide a basis for design and definition of safety systems reactions. For example, the access to the torus hall and to the plasma vessel will be defined on the basis of the actual system state. The state **Emergency stop** is a special state. The transition into this state can be enforced from all others states at any time by pressing one of many emergency stop buttons. At a transition to this state the emergency stop of all components of the whole system is invoked.



The components are responsible for handling safety related problems as far as possible on the component level. The central control system ensures safety of interactions between the components of the whole experiment and safety of persons in the experiment hall. A set of standard safety signals has been defined for the communications between the safety systems of the components and the central safety system. The central system sends emergency stop and enable signals to the local control components. The components confirm that they are in the state **emergency stop** or in a safe state, respectively. If the central safety system does not enable a component, then any activities with a hazard potential inside the torus hall are prevented. Deactivation of the enable signal by the central safety system during operation enforces a transition of the component into a safe state. The local components confirm their safe state and prevent any hazardous activities in order to protect personnel, other components and the environment.

Device Control

Segment processing



•The Experiment operation is the standard state for running physics experiments and technical tests.

•All necessary components of the control and data acquisition systems are normally switched on and can be activated.

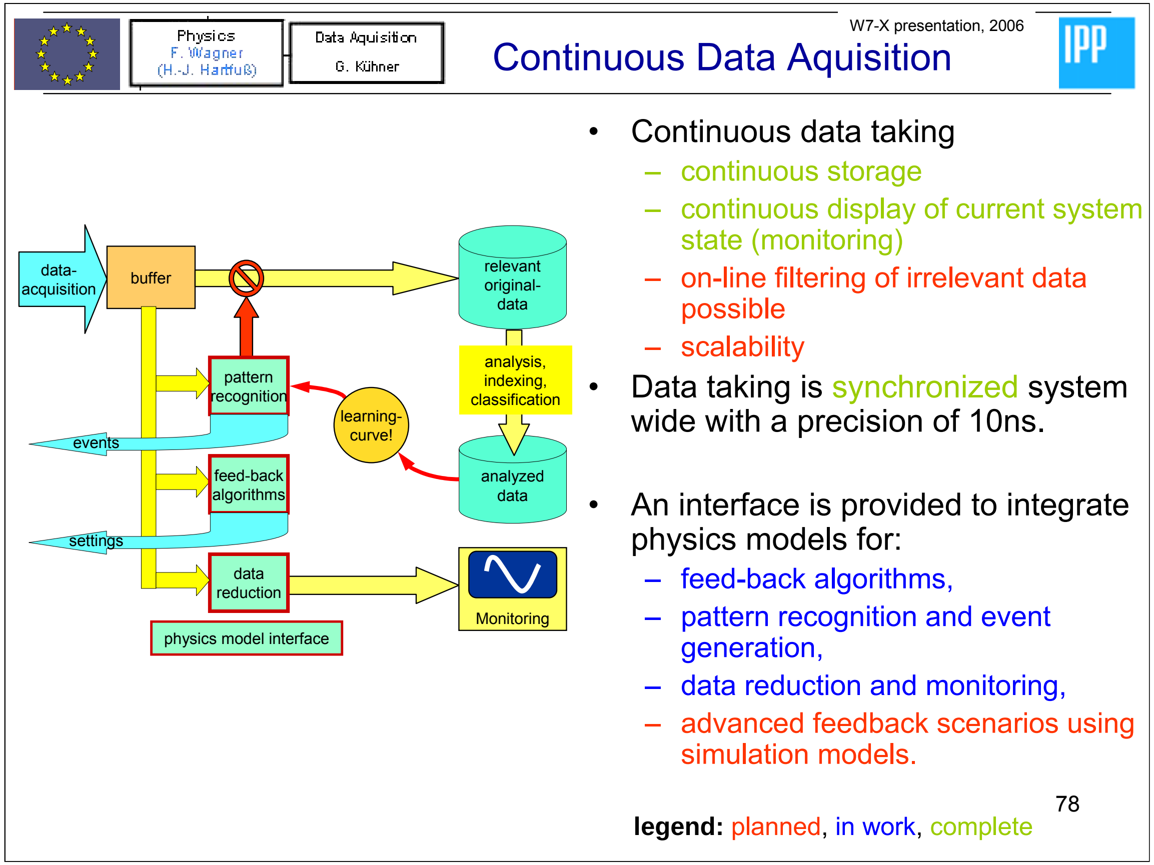
•Experiments can be controlled by the segment control system in a more or less automatic manner.

•A session leader selects the predefined segment programs for the experimental phase and starts and supervises the processing of these segments.

•The torus hall during the operational state **Experiment operation** is not accessible.

The plasma-diagnostics set up of W7-X as well as the supporting computer hardware are large and complex and will evolve permanently over the intended lifetime of 20 years and in a way which is difficult to predict in the long term. Phases of experimental operation and phases of (diagnostics) evolution will take frequent turns. The software environment necessary to operate and maintain such a system requires flexibility to a very large extent as well as adequate management of complexity. Furthermore the experiment aims at continuous operation (~30 min.) which introduces a new quality for data acquisition (and control) tasks.

Under this conditions it is advantageous to have an integrated abstract model view of the system describing its properties and functions in a technology independent manner thus providing a reference for its complete lifetime. This model should reflect the view of the system users (scientists, engineers, technicians) in an intuitive manner and provide the structural basis for the design of the interfaces for user interaction. A fundamental and comprehensive systems analysis has been performed during the last years to obtain a model view of the planned software system which is sufficiently modular to account for any changes in the employed hardware technology and which is sufficiently intuitive to support the work of several generations of operators and scientists.



Based on this model a graphical editor is being developed to provide support for system configuration and planning of experiment programs.

Technological overview:

hardware technologies: acquired datatypes are analogue, counts, images; sample frequencies 1Hz..10MHz; storage rates are up to 1TB/day; storage employs scalable object base and RAID systems.

software technologies: graphics, scientific graphics, numerics, distributed and high performance computing, unicast and multicast networking protocols;

Data Models and Databases

- **data model and database for:**
  - system structure
    - logical, physical
    - geometry
  - control structure
    - static
    - communication
  - experiment behaviour
    - segment definitions
    - physics scenarios
    - experiment programs
  - data analysis and physics modeling
- **archive system:**
  - measured data
    - complete log of experiment configuration
    - archive of measured data
      - » reduced data sets for faster access during browsing in large datasets
      - » classification schemes to utilize indexing during access/browsing
  - analyzed data
    - with versioning and data source tracing

legend: planned, in work, complete

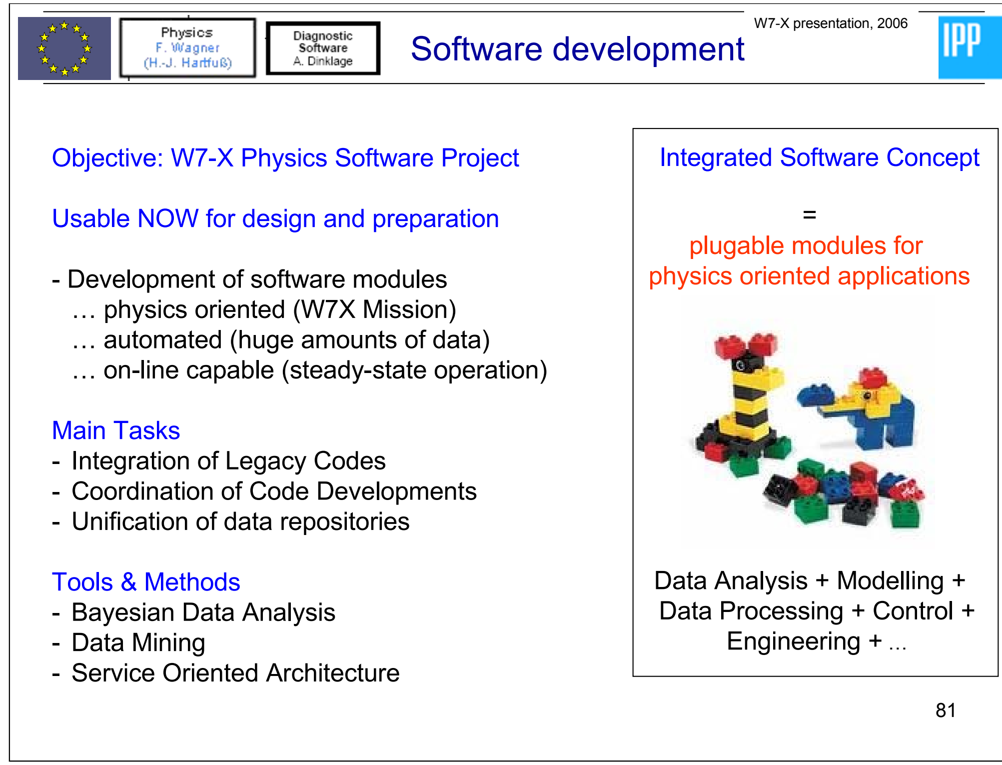
Self-explanatory.

Application Development

- **standardized graphical user interfaces**
  - preparation of experiment- and lab-setups
    - browsing and editing the system structure (experiment setups)
    - physics scenarios planning
    - resource based planning and optimization (availability of diagnostics...)
    - success conditions (signal patterns) and quality criteria (e.g. statistical significance)
  - operation of experiment- and lab-setups
  - browsing of acquired data
    - browsing measured and analyzed data
    - selecting, tagging and commenting datasets and parameter sets for analysis
  - user context and security
    - user/context views
    - access control
- **standard API for database access**
    - model data
    - measured data
    - analysis chain automation
- **standard APIs for data exchange with**
    - rt-applications
    - model applications or external tools
- **standard presentation and reporting for**
    - data from database
    - network data
- **remote participation**
    - preparation of experiment programs
    - monitoring of measured data

legend: planned, in work, complete

Self-explanatory.



Diagnostic software development has to happen parallel to the development of the machine hardware. There are several reasons to make use of theses codes as early as possible:
First, engineering decisions require physics input. An example is the expected radiation load from the plasma on surface materials during steady-state operation.
Second, data analysis codes can used as virtual diagnostics. This gives powerful tools for the design and optimization of diagnostics.
Third, physics modelling is required for the preparation of the W7X device operation – examples are the heating scenarios of the plasma.

The requirements on physics software are derived from the physics goals of W7X – they comprise issues like demonstration of stellarator optimization, measurement of plasma profiles for transport studies or the indirect measurements to determine key quantities in stellarator physics, such as the radial electric field. All these issues will finally help to answer the question, whether an optimised stellarator is a viable reactor concept.
Therefore, we also have to face new technical challenges for our software developments:

Since we are aiming at steady-state operation we need to provide highly automated procedures.

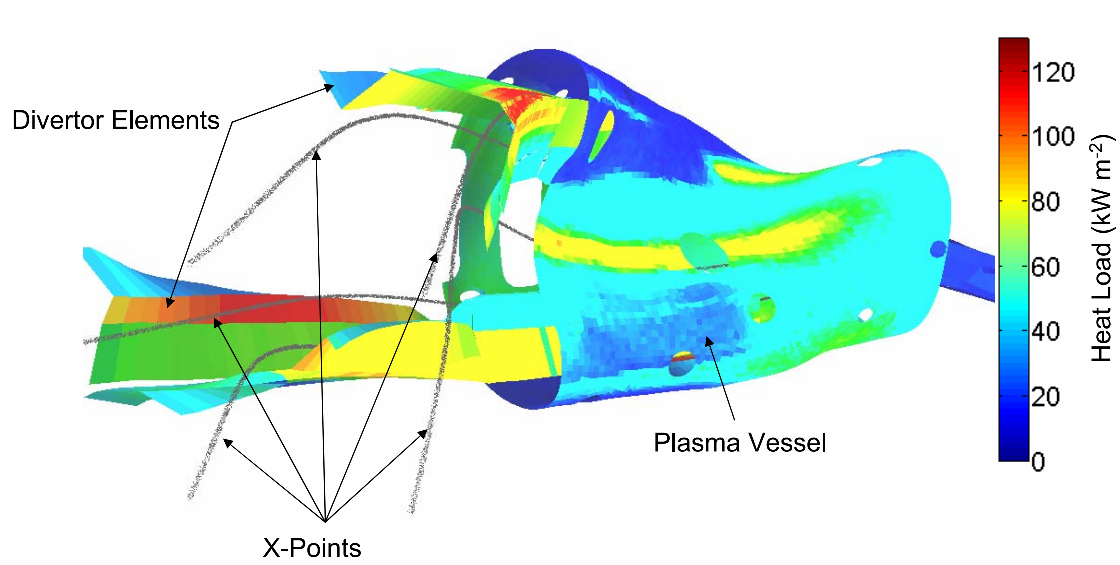
It is also necessary to provide analyzed data on-line, because the W7X capabilities must allow interventions during the operation and advanced control scheme, which are based on analyzed data [e.g. feed-forward control schemes].

Facing the amount of work and the available material it is clear to build on existing codes and software modules. The strategy we are following is a consequent integration of software and a unified infrastructure, such as data bases

The tools we are planning to use are Bayesian data analysis techniques, which can be regarded as standardized data processing instructions. We need to employ data mining procedures to process the expected huge amounts of data. An aspect which reflects the basic idea of our software project is to use service oriented architecture. The benefit of this approach is visualized in the cartoon on the right. *Similar to building bricks, it is our goal to prepare a set of software modules that can be used for building more complex applications. We call this an Integrated Software Concept because we plan to involve all parties necessary on the complex way to resolve the physics issues of W7-X.)

An example for which the necessity to link different efforts becomes obvious is the calculation of heat loads due to plasma radiation as shown in the next slide.

Simulation of W7-X Radiation Heat Load



Shown are the results of Monte-Carlo simulations of the plasma radiation. The radiation emerges from the X-Points of magnetic field which are tailored for the power and particle exhaust in W7-X. These X-Points are twisted lines in 3-d geometry. The five grey scattered stripes represent the radiation sources.

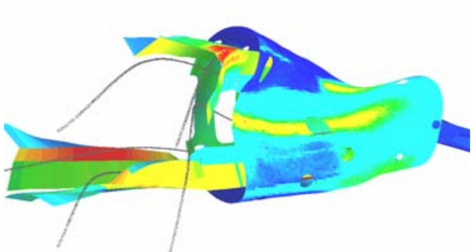
A cut through the components shows the divertor elements and the plasma vessel which are coloured according to the results of the heat flux calculations.

The results of the simulations show quantitatively the regions of highly loaded materials. They allow to validate the choice of materials which can stand the expected high heat flux. On the other hand, parts of the plasma vessel are expected to have a low load. Hence, they need much less armed plasma facing shields. The simulations also to study the effect of the shape of the magnetic field or a variation in applied heating.

The next slide explains what pieces of software and data do we need to arrive at such simulation results?

Software development

Pieces of software must interact to resolve physics/engineering issues.



Magnetic Field Calculations

Geometry DataBase

Magnetic Field DataBase

Modelling of Radiation Loads

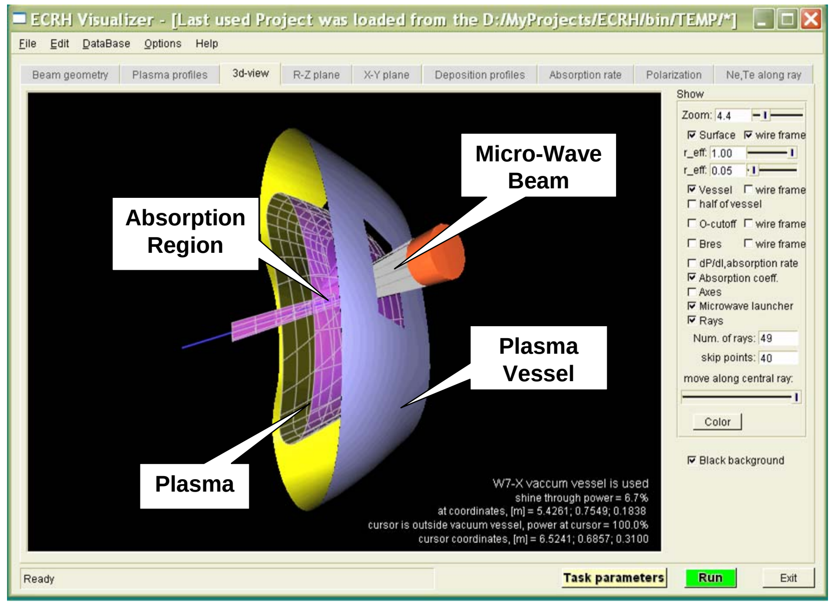
Detection & Interpretation

Engineering

A detailed look on the necessary components shows that physical modelling is required. This example also show, that not only software-modules but also data repositories are important in our concept. These data bases are to be designed to be re-used for different purposes. Consequently, the data bases must be unified in order to be able to refer to a „basic“ data base. This example emphasizes the benefit of software components, which can be plugged to each other. This example also shows the necessities to contribute to engineering issues in W7-X: more or less general key-elements are to be combined for a specific solution.

Software development

Physical modelling and engineering: Simulation of absorption of electron-cyclotron heating



A second software example is the preparation of the device operation of W7-X. In this viewgraph, two magnetic surfaces are shown as purple wire-frames. The central axis of the magnetic field is the blue line. The plasma vessel is coloured blue-grey on the outside and yellow in the inside. This simulation shows results of the irradiation of microwaves. The beam is shown in grey. The source is represented by the launcher coloured in red.

Movie (Ray tracing): When we start to rotate the section of the W7-X plasma vessel the deflection of the beam can be comprehended. The deposition of the heating is indicated in red and the shine-through on the back-side of the vessel is determined in this simulation as well.

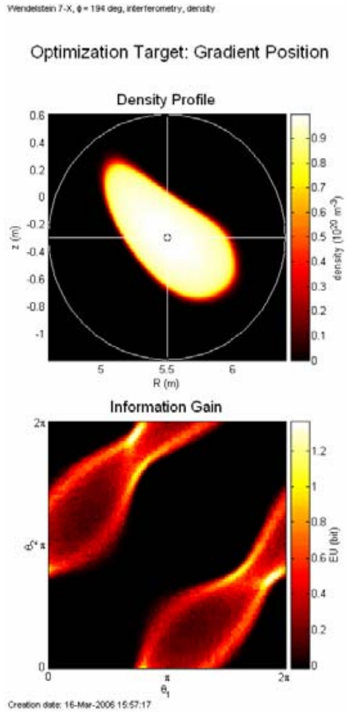
The importance of this tool is due to the huge heating power for electron cyclotron micro-wave heating. For plasma performance and physics understanding, it is highly relevant to understand where the heating is applied. For engineering, it is important to determine the fraction of non-absorbed heating power. For example, at the envisaged heating of 10 MW the shine-through with the settings applied here is as high as 670 kW.

Physics
F. Wagner
(H.-J. Hartfuß)

Diagnostic Software
A. Dinklage

Software development

W7-X presentation, 2006



Diagnostics Design: Optimization of Sightlines

Objective:
- Optimization of design parameters *(here: laser beam chords)*

Approach
- Employ information theory
- Optimization of cost functions *(here: information gain)*

Benefit
- Virtual Diagnostics
- Study Robustness
- Include Physical Aspects *(here: reconstruction of gradient positions)*

85

This slide addresses another task of software development, viz. the optimisation of diagnostics at the given plasma and device geometry. The figure shows in the upper panel an expected density profile in the W7-X interferometer plane. The issue studied here is the choice of appropriate interferometer chord positions. In this example we incorporate a physical design target – that is the reproduction of the gradient position.

Movie (Interferometry): The lower panel shows the result – which is the expected information gain (for a given range of data). The result is parameterized in figures of a starting angle and an ending angle. Each point in the plane corresponds to a line of sight (chord outside the plasma in upper panel – no information gain in lower panel (black)). Sensing the gradient region best means to transverse the plasma in the gradient region as long as possible. The approach is based on a virtual instrument, which allows us to study the effect of all design parameters quantitatively. Beyond obvious outcomes the robustness of the choice of design parameters can be studied. Additional insight was found if error-statistics and signal-to-noise considerations were added and carried out simultaneously.

Major emphasis at present is preparation of unified data sources and software infrastructure, general software infrastructure (documentation), general stellarator specific libraries, data analysis applications.

Technological innovations via W7-X

Structural analysis

- Stress and deformation calculations of complex formed compound structures subject to mechanical and electromechanical forces (with Efremov, TU-Warshow, CEA, ENEA…)
- Eddy-current calculations of complex components

Production technology

- Plasma vessel: welding construction of a complex formed container at minimal welding distortions
- Precision water-jet cutting of openings in 3-d shaped structures
- Air-pressure technique to produce freely shaped water-cooled panels for wall-protection

Process engineering

- Calculations of heat transmission at thermal loads up to 20 MW/m² for the target plates

Control/Electronic

- Development of a trigger time event system for fast synchronisation of control processes

The following slides summarise some of the technical innovations achieved in the frame of the W7-X project jointly with industry.

Technological innovations via W7-X

Material technology

- Development of an Al-alloy as jacket for the SC conductor which hardens at elevated temperatures and is suitable for low temperatures.
- Development of bonding techniques (with CEA) of
  - CuCrZr with CFC
  - Cu with steel
  - CuCrZr with steel
  - B_4C coatings of steel surfaces

Cryo-technology

- Development of a novel radiation shield from fibre-glass re-enforced epoxy material with integrated copper mesh

Electrical engineering

- Manufacturing of large superconducting non-planar coils
- Casting technology of coil casings under stringent accuracy conditions
- LINAC radiation testing of massive steal structures
- Continuous wall-thickness measurement during SC cable production

Self-explanatory.

Technological innovations via W7-X

Electrical engineering /SC technology

- Development of a high-current power supply (20 kA/30 V) with low ripple
- Development of a Ni-resistor as safety system for energy absorption at a rapid discharge of the coil system
- Development of a fast and reliable quench detection system based on 500 signals at mV voltage level in a noisy environment (with FZK)
- Development of current leads for 20 kA to minimise refrigeration power under stand-by conditions
- Development of a low-resistance electrical joints for high currents (1nΩ/18 kA) (with FZJ)

Assembly technology

- Development of a system for precise assembly of heavy components
- Development of combined systems for rapid and precise measurement of complex 3-d shaped components

Vacuum technology

- Tests of turbo-molecular pumps suitable for operation in magnetic fields.
- Development of leak tests on the basis of SF_6 (with FZK)
- Development of leak testing techniques for complex shaped test bodies

Self-explanatory.

Technological innovations: Network-building

FZ-Karlsruhe	Gyrotrons, quench-detection system, current feed-throughs
FZ-Jülich	Busbar-system, diagnostics,
CEA Cadarache	high-heatflux components; structural calculations
CEA Saclay	Test of SC coils
CIEMAT	industry monitoring of support structure
Atominstitut Vienna	superconductor, industry monitoring of coils
UKAEA	metrology of planar coils
PSI	Test, SC coil connections
ENEA	engineering support in coil structure
TU Warsaw	structure mechanical calculations
TU Lublijana	structure mechanical calculations
Efremov Inst.	FE calculations, test of SC joints
IfP, UNI Stuttgart	ECRH components
Budger-Inst. Russia FZ-Jülich KFKI, Budapest IPP Warshow Univ. Opole	diagnostics

Self-explanatory.

Procurement issues

Chances for industries
Technical challenging tasks
Growth of internal know-how
Growth of prestige: competent and capable firms are known within the associations
Safety of a reliable contract partner

Procurement action
Follow the common rules in Europe
Information source for orders is the EU supplement of the official document (www.ted.publications.eu.int/official/)
Additionally, the associations are asked for potential bidders (here: ATI Wien)
Firms with special technical potential can be accepted in the list of the 17 technologies

Tender action
Rigid forms are established which have to be obeyed; deviations from these prescriptions may lead to removal
The information on short notice is desired if the participation in an tender action is planned. This is not committal.
Regular contacts are desired to remove on time all technical uncertainties
All technical requirements must be followed; improvements are welcome but they have to be clearly highlighted as deviations for the technical specification
The requirements of quality assurance have to be carefully considered

Contract phase
Reference are the definitions and requirements of the technical specification
Technical clarifications have to be done as early as possible
Pre-tests and qualification of processes should be done well on time
On both sides should be a clear project structure
Both sides have to define a precise communication structure which must be obeyed

Self-explanatory.

W7X is the last large superconducting device built in the EU before ITER and is, therefore, expected to help maintaining and developing industrial manufacturing and quality assurance capability in a number of technologies required for ITER construction.

Although the W7X coils are much smaller than the ITER coils and use exclusively NbTi conductors, the W7X and ITER coils share the same basic design and manufacturing concept: the winding pack uses a cable-in-conduit conductor with internal forced flow helium cooling, the winding pack is vacuum impregnated with epoxy resin and embedded in a steel casing. The W7X coil manufacturing contracts are, therefore, helping industry to qualify and demonstrate their readiness for ITER coil construction. The Quality Assurance, inspection and testing procedures of the W7X and ITER coils share many common features and the knowledge acquired by industry with W7X is directly applicable to ITER. In the area of coil instrumentation, the W7X development and experience, including in particular quench detection, are relevant to ITER.

Relevance of W7-X for ITER

- W7-X is a pilot project for ITER

- Direct technical solutions which can be applied to ITER

- It can provide early hands-on training for future use at ITER

- W7-X has accumulated experience in the collaboration with industry

-Training of industry staff, ITER staff, staff in the associations and related institutions

- Network building
    - between technologically oriented institutions
    - between SC devices under construction

In-vessel components, such as protection tiles and actively cooled first wall components have been developed for Tore-Supra and also in the framework of the ITER R&D programme. The production of these components for W7X will add to the body of industrial manufacturing and Quality Assurance know-how in preparation for ITER construction.
In the area of assembly, the W7X requirements on dimensional accuracy are a challenge and require the use of modern sophisticated optical metrology techniques. The experience gained for the large and complex W7X components will be of direct interest to ITER.
For more conventional technologies, such as power supplies, cryogenic and vacuum systems, ITER is expected to benefit from the industrial interest and manufacturing capability generated by the W7X activities.
Whereas the physics basis for ITER is well developed there is a need on steady-state operational experience, plasma control and diagnostics, and on long-pulse technology, specifically heating and exhaust. In Europe, W7-X will continue the work done with Tore-Supra and it will be operated together with the other long-pulse superconducting devices LHD, KSTAR, EAST and SST-1.
Of immediate ITER relevance is the development of the ECRH system and of high-load plasma facing components.

CFI-14.7 Annex1

W7-X presentation, 2006

The 17 technologies specific to fusion and essential for the Next Step

Plasma engineering

	Contribution from W7-X
High power, high frequency sources (in the range 5-8 and 120-180 GHz)	major
Neutral Beam Power Supplies and High Voltage Components (of the order of 1MV)	partially (HV)
Plasma Facing Components	
Tiles and Coatings	major
Plasma Facing Component Models	input
Vessel, Shield and Blanket	
Vacuum Vessel, segments of Neutron Shields and of Tritium Breeding Blankets	partly / no
Superconducting Magnets	
Strands	partly
Conductors	partly
Model Coil Windings	partly
High Power Electrical Amplifiers	partly
Remote Handling Equipment	
Qualification of Standards and Tools	partly
Remote handling devices (transporters and ectuators)	
Fuel Cycle	
Tritium Compatible Vacuum Cryopumps and Mechanical Pumps	no
Tritium Compatible Vacuum Valves	no
Components for Tritium Handling and Atmosphere Detritiation	no
Materials for fusion specific applications	
Low activation structural materials for in-vessel components of a fusion reactor	no
Material for tritium breeding blankets icluding ceramic breeder and beryllium pebbles and permeation barriers	no

This table is taken form report CFI-14.7 Annex 1

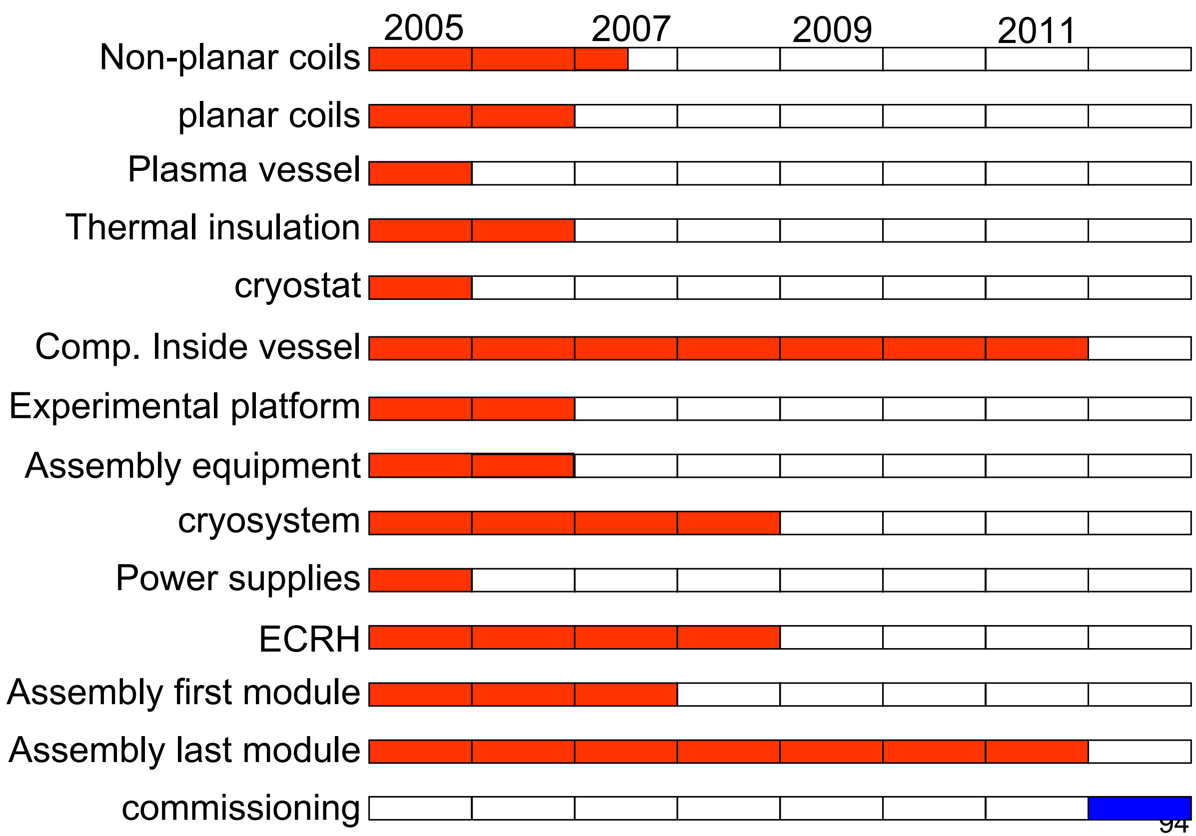
Max-Planck-Institute for Plasmaphysics branch Greifswald

Experimental hall

Pre-assembly hall

Self-explanatory.

To work in IPP: Time schedule of W7-X



Completion dates of the various components.

To work in IPP: Staff training

Technologies, technical solutions

- Superconductivity, cable-in-conduit technology, quench-detection, coil testing, instrumentation)
- FE calculations
- cryo-technology and thermal insulation
- design of 3-d elements
- leak detection, lubrication at low temperature
- metrology tools (laser tracker and scanner, photogrammetry, back office)

Management:

-preparation of technical specifications for non-standard components
-contract management of large and complex contracts
-exercise management tools like handling of non-conformities, change-notes
-Experience in quality management
-experience in project documentation systems
-qualification of materials and processes
(e.g. low temperature properties, compound structures, joining of dissimilar materials)
-experience in working with interlinked work breakdown structures (WBS) to follow the schedule of tasks within the departments and the project globally
-contacts to several institutions which can support the design and construction of the machine (metrology, material science, test labs)
- back office (measurement of as built configuration, comparison with design geometry)

In summary: All pitfalls of a real project

Self-explanatory.

To work in IPP: Internationality of the staff

Foreigners,
working in IPP Geifswald

Russia	11
Italy	3
China	4
Ukraine	7
India	4
France	4
Poland	3
Netherlands	2
Kazakhstan	1
GB	1
Sweden	1
Georgia	1
Spain	1
Australia	1
Austria	1
In total	**45**

Foreigners in leading
positions of the project

Technical Director	EURATOM
head of magnet department	EURATOM
head of cryostat department	EURATOM
head of assembly technology	EURATOM
head of system integration	ENEA
head of design engineering	Efremov/ITER
Head of backoffice	CEA
Technical advisor	France

Self-explanatory.

To work in IPP: Available technical infrastructure

IPP High heat flux test facility

for testing divertor components

1. Acceptance tests of full size W7-X divertor elements and modules (2004 - 2007)
2. Acceptance tests of full size ITER divertor units during ITER construction phase (>2008) possible

GLADIS facility (Garching)

source: 1 NB Injector (1 MW/ 15 s)
intensity: 5 - 65 MW/m²
cycle rate: ~ 60 /h

Self-explanatory.

To work in IPP: Available technical infrastructure

Vacuum chamber

for testing large equipment
Paschentest of coils

Volume: 55 m^3
Diameter: 4.900 mm
Height : 3.150 mm
Vacuum: < 10^{-7} mbar

Incoming tests of large equipment and final tests immediately before mounting of main components are essential to guarantee the quality against electrical and vacuum failure. A vacuum chamber that might host a planar or non-planar coil, single parts of the bus-bar system or of the central support structure was therefore installed directly at IPP Greifswald. It is equipped with about 20 CF-ports of different size for gas or electrical feedthroughs. The main flange is sealed with a double Viton O-ring (in the upper part of the tank) and a groove (in the lower part of the tank) for intermediate vacuum pumping. Helium leak tests of the cooling tubes and superconducting cables as well as electrical insulation tests under Paschen conditions (stepwise change of pressure from 10-5 mbar to atmosphere) are routinely carried out at room temperature on all coils of the magnet system.

To work in IPP: Available technical infrastructure

microwave stray radiation test chamber (140 GHz, 30 kW/m^2 cw)

The purpose of this test facility is to subject each component, which will be mounted into the plasma vessel to ECRH radiation at a level which might appear during operation in phases of low absorption.

The city of Greifswald

Old hanseatic city

University: Founded 1456

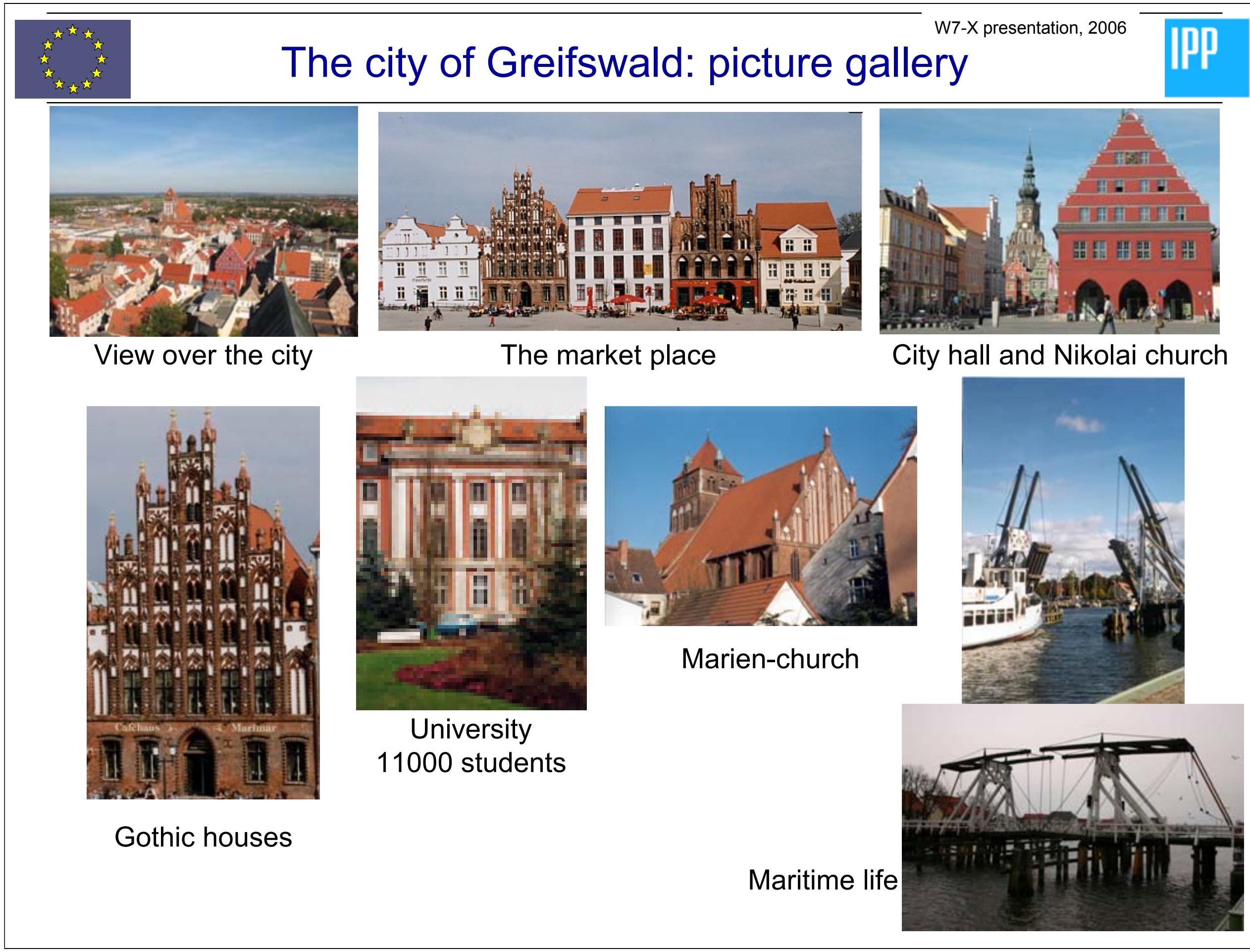
Birth place of the painter Caspar David Friedrich

Basic dates

State:	Mecklenburg-Vorpommern
Area:	50,33 km^2
Inhabitants	52.869
Postcode:	17489-17493
Dialling code:	03834 (from abroad +49 (3834)….)
Geographic Position:	54° 05' n. Br. 13° 23' ö. L.
Car registration number:	HGW
Address municipal authorities:	Markt 17489 Greifswald
Web site:	www.greifswald.de
E-Mail:	info@greifswald.de

Northern Germany at the Baltic Sea

The hanseatic city of Greifswald is located between the two large German islands of Rügen and Usedom. It was founded in 1250 and became soon after its foundation a member of the Hanseatic League. About 200 years later Greifswald's university was founded in 1456 being the second oldest in the Baltic Sea area. Despite its more than 750 years, Greifswald is a youthful city. Everywhere you will find the characteristic vibrancy of a university town.



The three big churches - Dom Sankt Nikolai, Sankt Marien and the Jacobi Church – dominate the skyline of Greifswald. St. Nikolai is the biggest of the three gothic clinker churches in the historic centre and was built by the inhabitants of Greifswald in 1250 to 1410, dedicated to Sankt Nikolaus, the patron saint of seamen and traders.

Greifswald's red-brick Gothic churches and gabled houses are an enduring witness to the commercial and artistic energy of the Hanseatic period. The fishing village of Wieck with the wooden bascule bridge - one of Greifswald's best-known landmarks, the Danish Wiek and Eldena with its ruined Cistercian monastery located in the outskirts of Greifswald, having inspired a number of paintings by Caspar David Friedrich, recall Greifswald's early history.”

Final comments

Fusion research requires large and heavy components, which have to be produced and placed with extreme mechanical accuracy though they are

loaded with large electromagnetic forces,
are subject to eddy currents and
high thermal loads if placed inside the vessel.

Materials are critical from the activation point of view (Co, Ag content),
material properties (metals, epoxy, others) at low temperature are an issue,
thermal insulation at high mechanical strength is of importance.

During the tender phase, intensive analysis of the technical complexity of the offered component is mandatory

All development processes have to be tested in detail with relevant prototypes

Complete evidence and documentation is necessary during project development at a level and quality of space research projects

Summary

Final comments: Relevance of W7-X for ITER

- W7-X is a pilot project for ITER

- Direct technical solutions, which can be applied to ITER

- It can provide early hands-on training for future employment at ITER

- W7-X has accumulated experience in the collaboration with industry

-Training of industry staff, ITER staff, staff in the associations and related institutions (if so desired)

- Network building
    between technologically oriented institutions
    between SC devices under construction

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Head of Assembly: Dr. L. Wegener (lutz.wegener@ipp.mpg.de)

Head of Physics: Prof. Dr. F. Wagner (fritz.wagner@ipp.mpg.de)

Staff issues: Dr. K.-T. Scholz (karl.thilo.scholz@ipp.mpg.de)

Vacancies: www.jobs-in-fusion.de

Procurement issues: Mr. J. Bergmann (joachim.bergmann@ipp.mpg.de)

* Supply and divertor **magnets and cryostat