SPECTROMETER AND DETECTOR CONSTRUCTION, DESIGN AND FABRICATION

SOME EXAMPLES FROM THE LAST YEARS

21.08.2018, HARALD GLÜCKLER, ZEA-1 @ FZJ

Mitglied der Helmholtz-Gemeinschaft

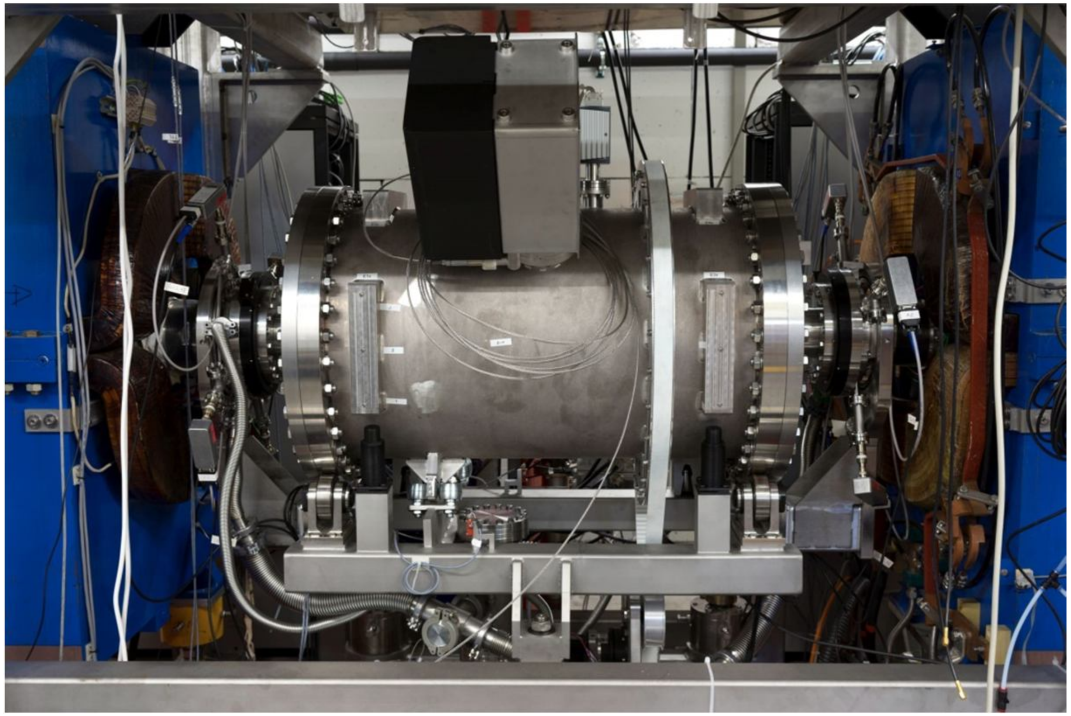
JÜLICH Forschungszentrum

MOTIVATION

- Since the last 40 years ZEA-1 | Engineering and Technology has developed, designed and built
  (a large number) of spectrometers, detector systems and other components for cutting edge science.

- Scientists often have crazy ideas, especially about the demands of a new spectrometer or detector system.

MOTIVATION



RF-Wien filter
@ COSY

„Today it seems impossible,…

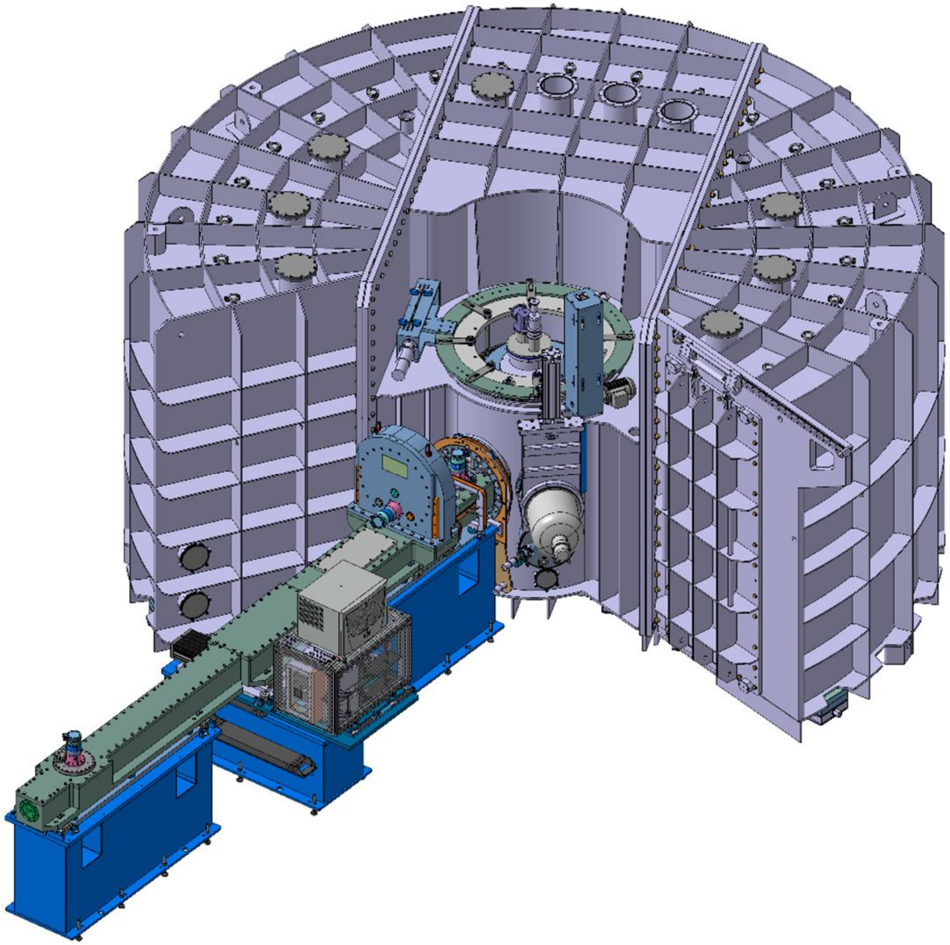
…but tomorrow it will be only difficult!"

OUTLINE

- Focus on two different research fields at Jülich:
  - Spectrometer for condensed matter research using neutrons
  - Device for nuclear fusion research at the stellarator W7X

TOPAS

Time Of Flight Spectrometer with Polarization Analysis



TOPAS is the new thermal time-of-flight spectrometer operated by the JCNS at the nuclear research reactor FRM2 in Garching near Munich.

ZEA-1 was responsible for the construction of this spectrometer, taking into account all the wishes of the scientists.

The design, calculations, production and testing of most components was carried out at ZEA-1.

TOPAS

Some basics about neutrons

Neutrons have no electrical charge

Neutrons have a magnetic moment

Neutrons have a spin (1/2)

Free neutrons decay (mean lifetime: 881,5 sec)

With neutrons one can determine:

- the atomic and/or magnetic structure of a material (elastic scattering)
- the atomic and molecular motion as well as magnetic and crystal field excitations. (inelastic scattering)

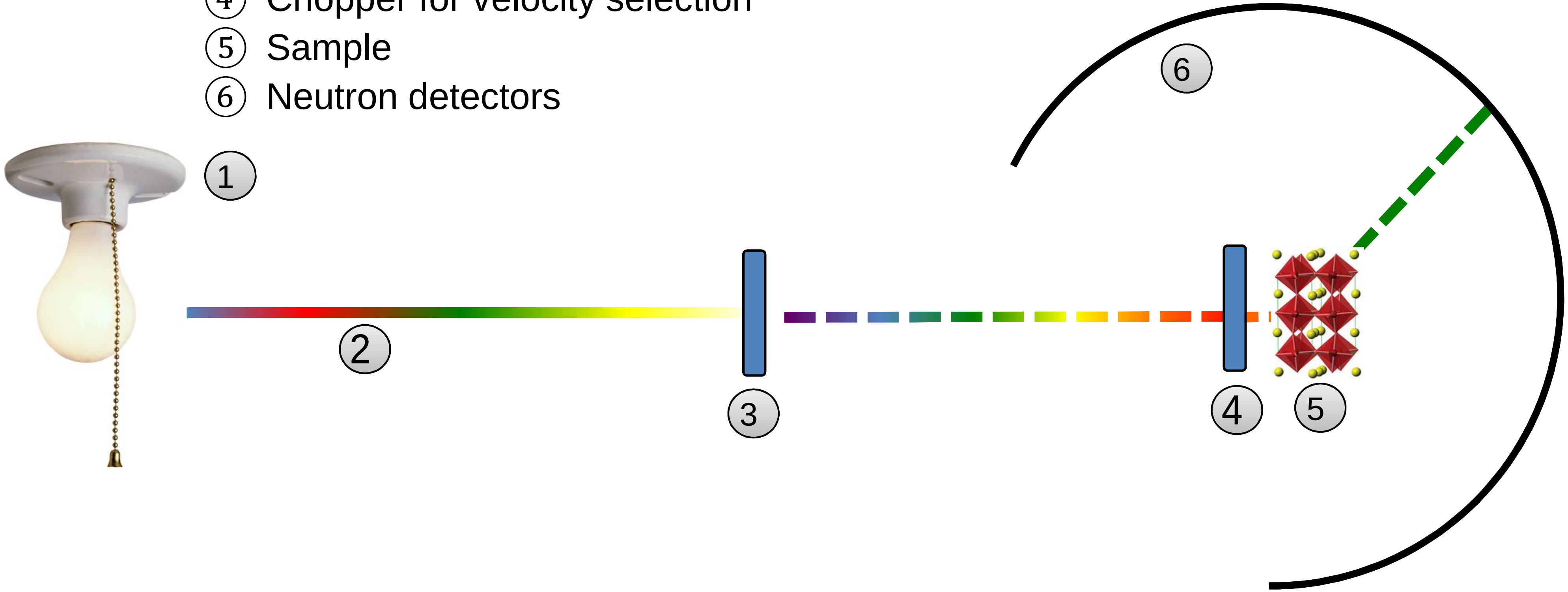
Energy ranges in neutron experiments:

- Energy varies between some µeV up to 500 keV
- Neutron velocity varies between some m/s up to 10000 km/s
- Neutron “temperature” varies between some mK up to some MK

TOPAS

Some basics about neutrons scattering

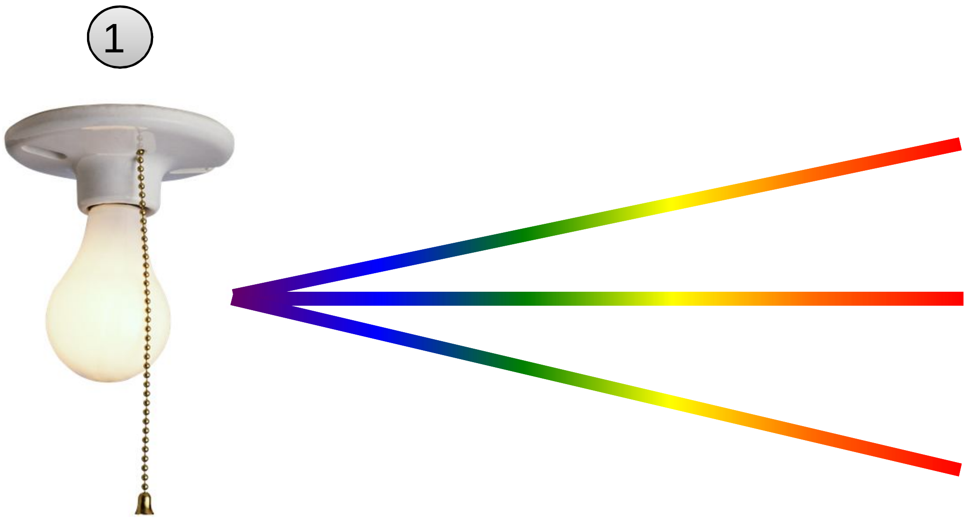
① Neutron source – here neutrons are produced by nuclear fission
② Guidance system to transport the neutrons
③ Pulse chopper to get a time structure
④ Chopper for velocity selection
⑤ Sample
⑥ Neutron detectors



TOPAS

Some basics about neutrons scattering

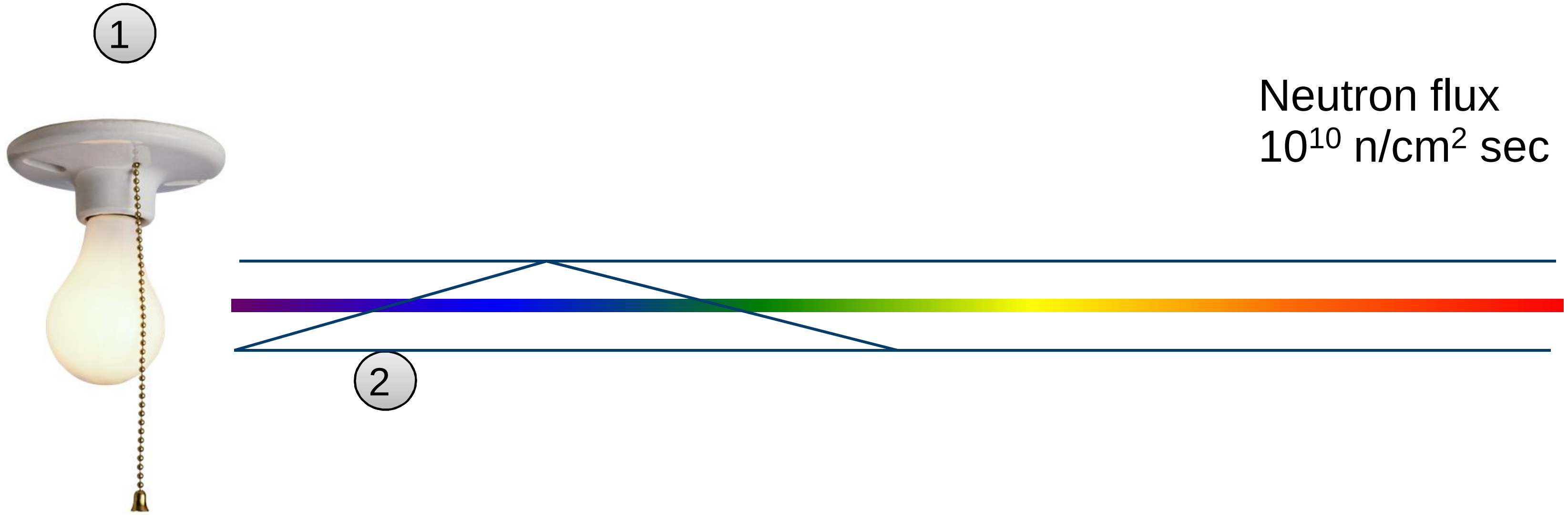
- The neutron source permanently produces a large number of free neutrons (ca. 10^{18} n/sec)
- The neutrons are emitted in all directions
- The neutrons have a broad velocity (or energy) distribution
- Neutrons have to be slowed down by moderators.



TOPAS

Some basics about neutrons scattering

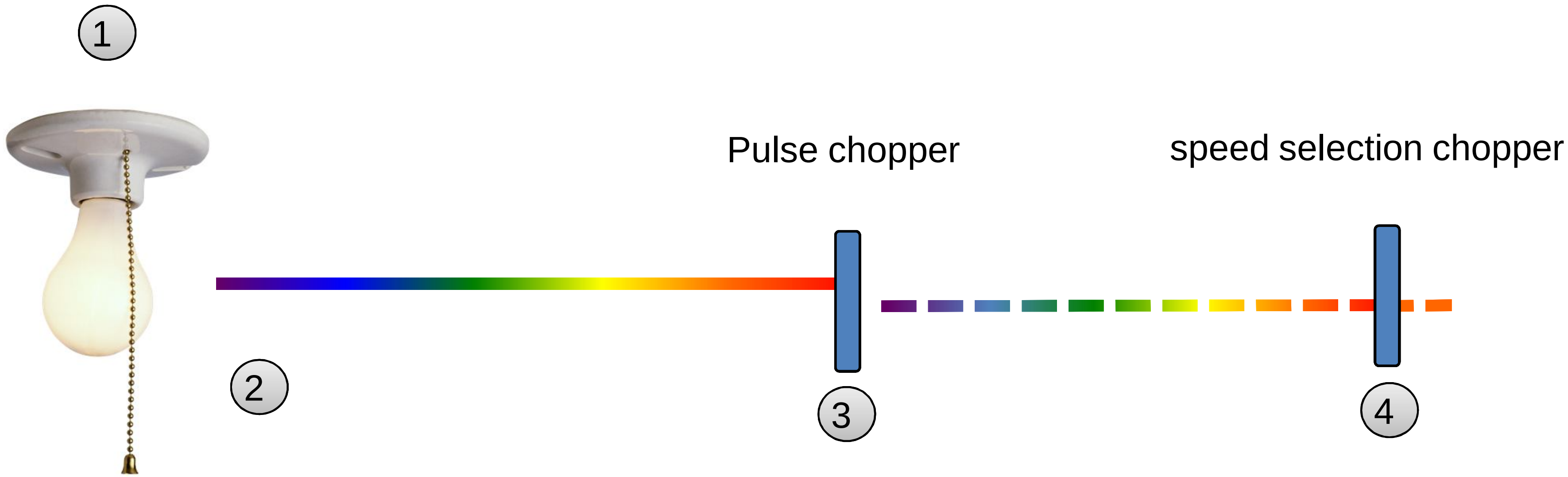
- The neutron guide is a mirror system, so that the incident neutrons are reflected and thus guided to the instrument.



TOPAS

Some basics about neutrons scattering

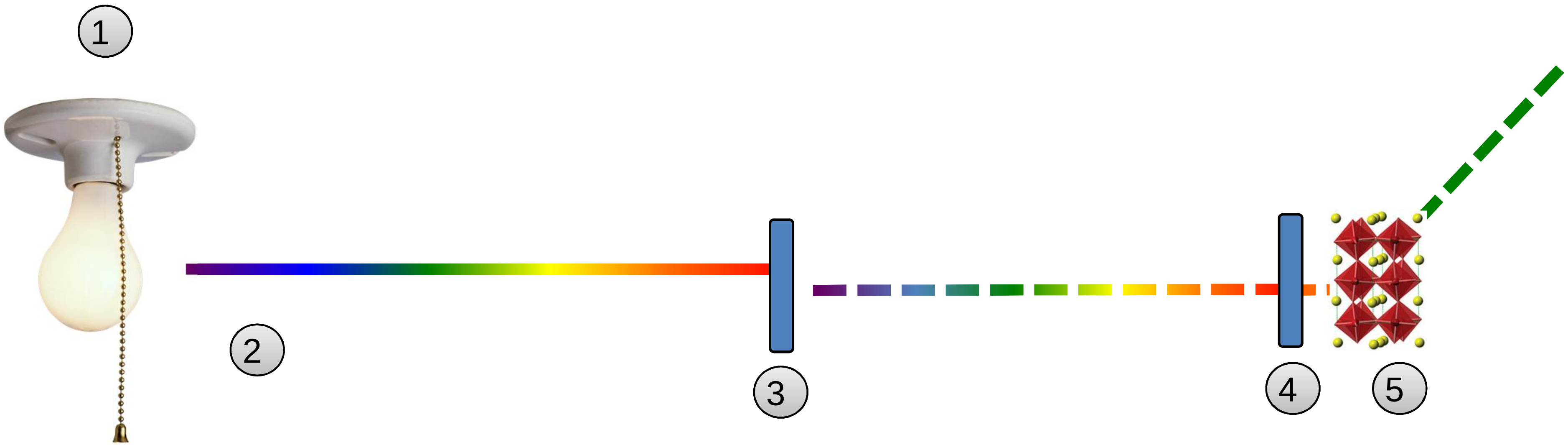
- Scientists need neutrons with a defined energy (velocity) for their investigations.
- Chopper systems are used to cut out the desired energy from the neutron spectrum.
- The pulse chopper divides the beam into packages.
- The speed selection chopper lets all neutrons pass at the right speed and cuts off the others. Only neutrons with the right velocity pass through the chopper system and hit the sample.



TOPAS

Some basics about neutrons scattering

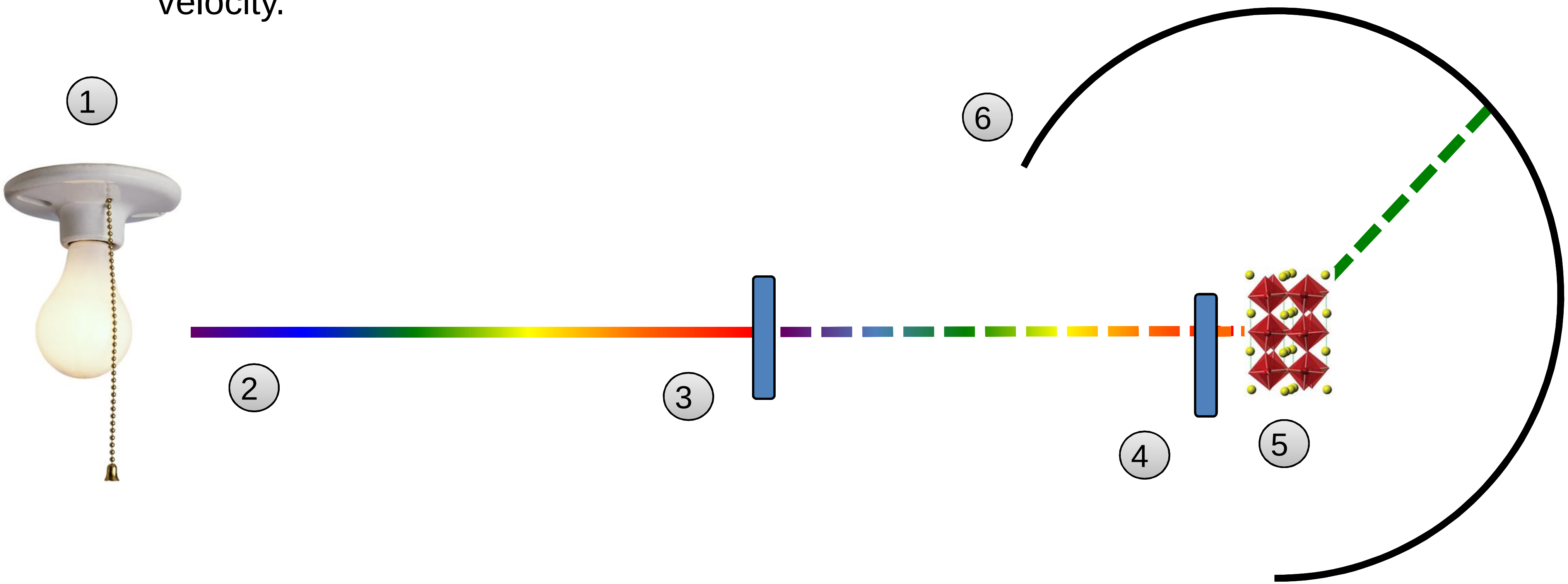
- In the sample, the neutrons collide with the atoms and change their velocity and emergence angle.



TOPAS

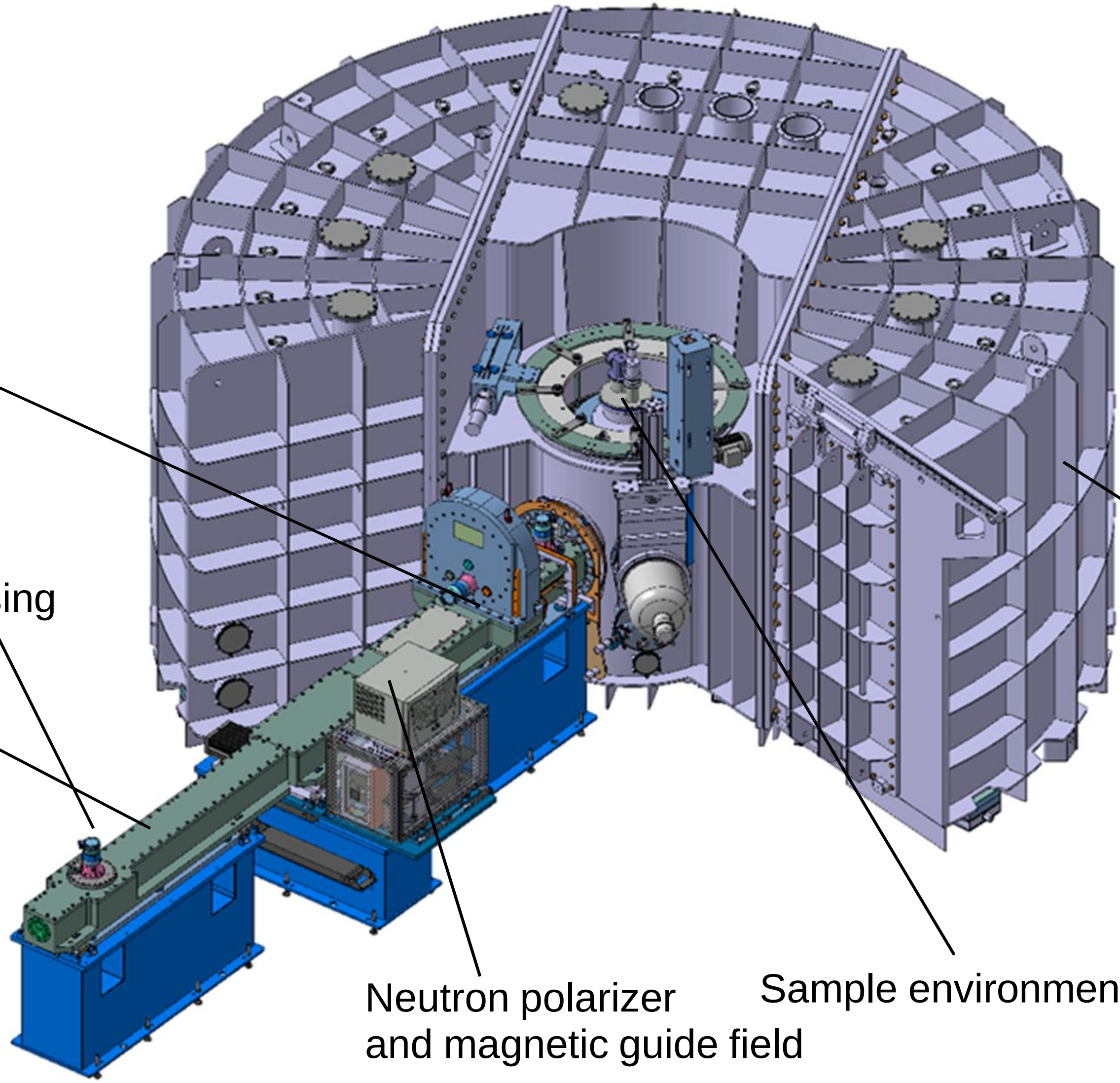
Some basics about neutrons scattering

- The neutron detector (located at a known distance from the sample) detects the scattered neutrons. From this time signature it is possible to to determine how the atoms in the sample have changed the neutron velocity.



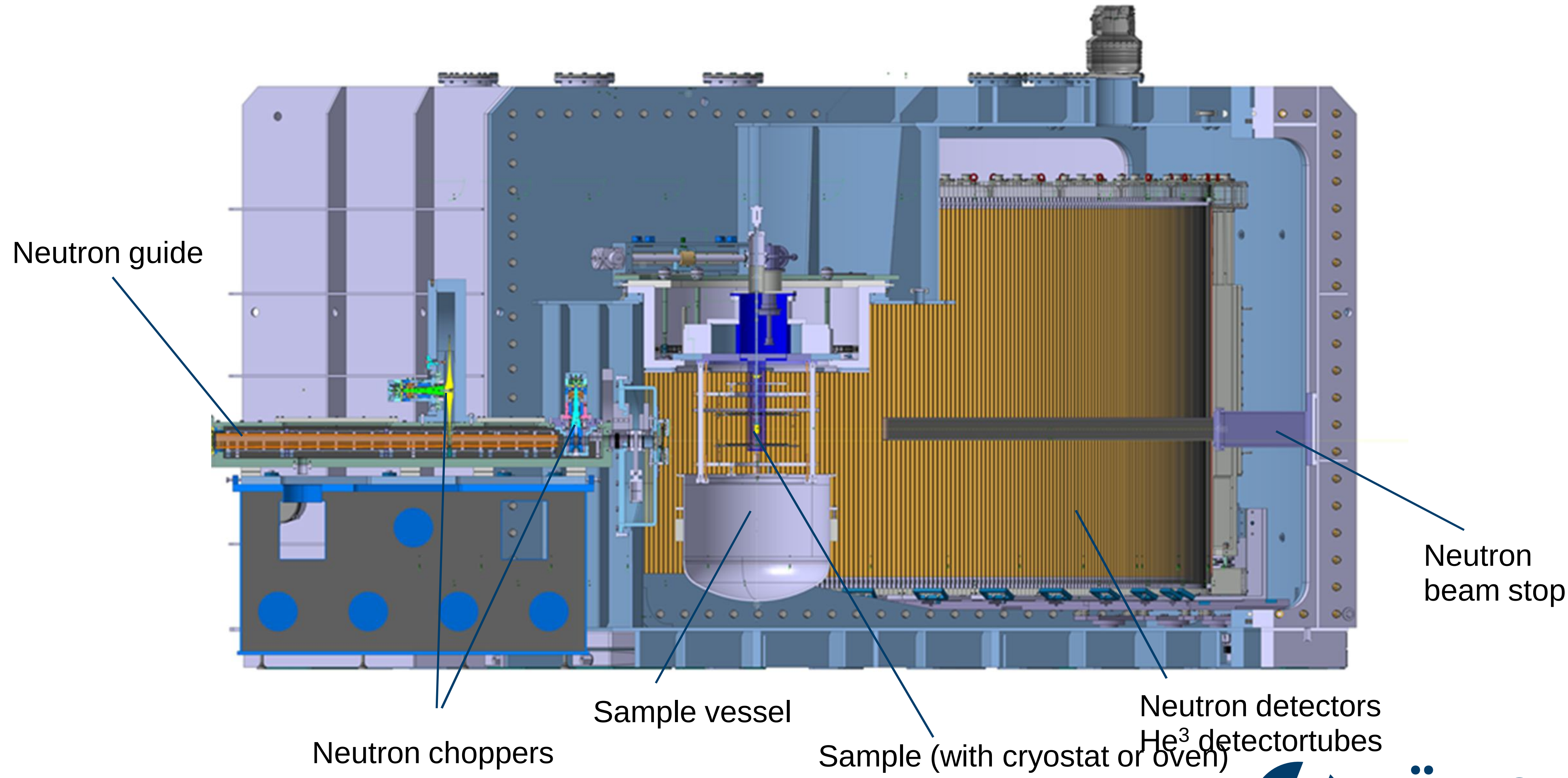
TOPAS

Time Of Flight Spectrometer with Polarization Analysis – main components



TOPAS

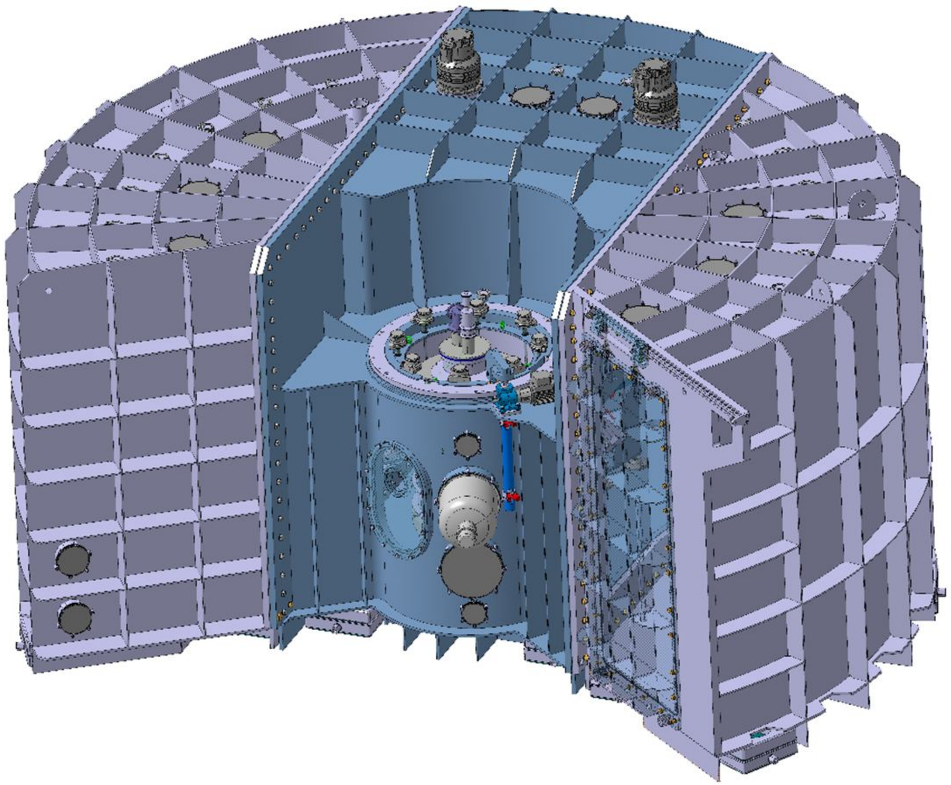
Time Of Flight Spectrometer with Polarization Analysis – inside the vacuum chamber



JÜLICH
Forschungszentrum

TOPAS

Time Of Flight Spectrometer with Polarization Analysis – vacuum chamber



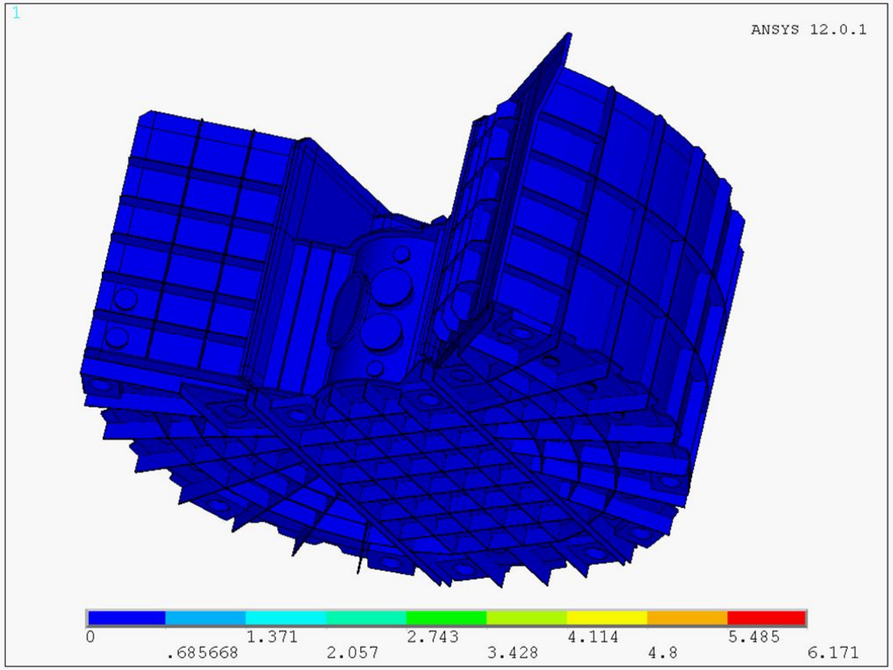
- Materials: 1.4571 stainless steel
  magnetic permeability $\mu_{rel} < 1,3$
  1.4429 stainless steel
  in the sample surrounding
  magnetic permeability $\mu_{rel} < 1,005$

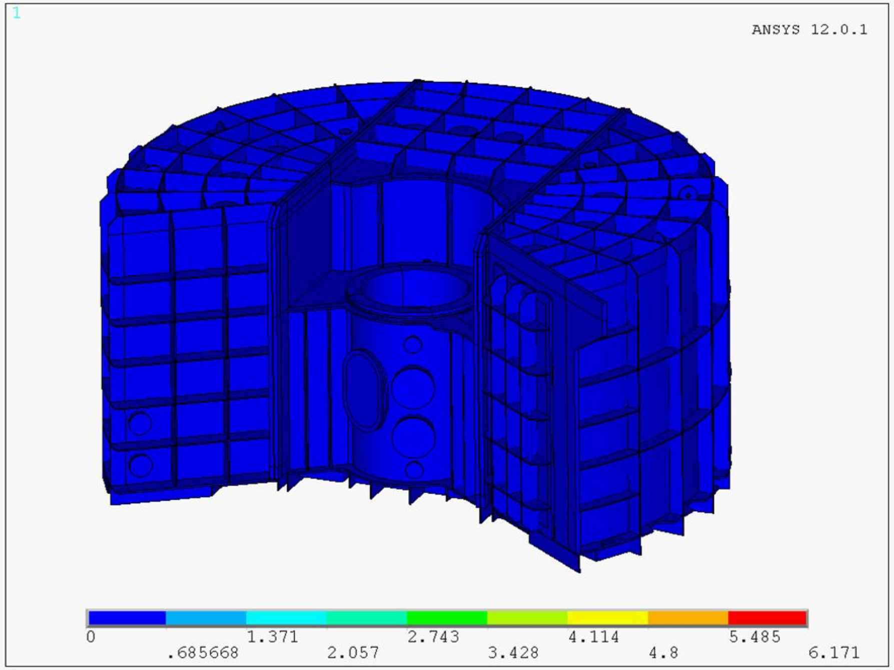
- Diameter: 6500 mm
- Height: 3200 mm
- Total mass: 30,5 t
- Volume: 75 m^3
- achievable residual pressure < 10^{-5} mbar

TOPAS

Time Of Flight Spectrometer with Polarization Analysis – vacuum chamber

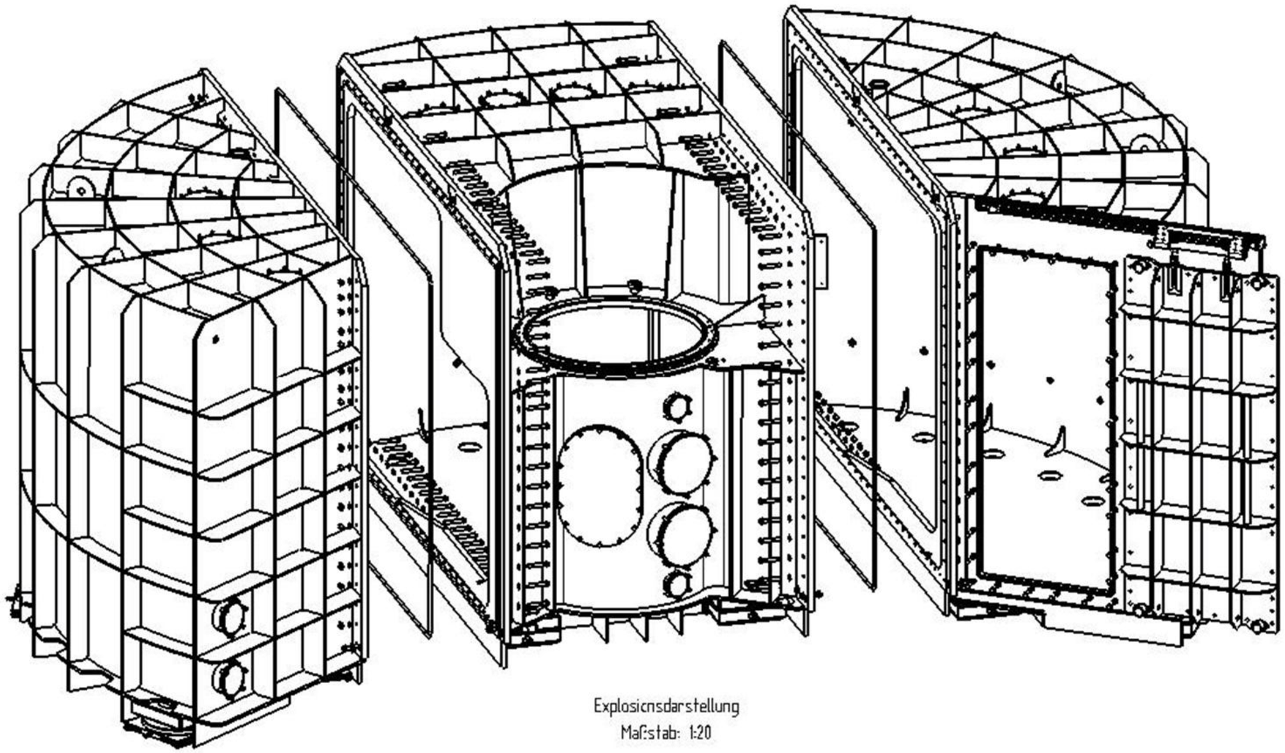
- the vacuum chamber had to be reinforced by a welded-on rib structure to prevent deformations due to the vacuum.
- welding seams with a total length of 2 km





TOPAS

Time Of Flight Spectrometer with Polarization Analysis – vacuum chamber

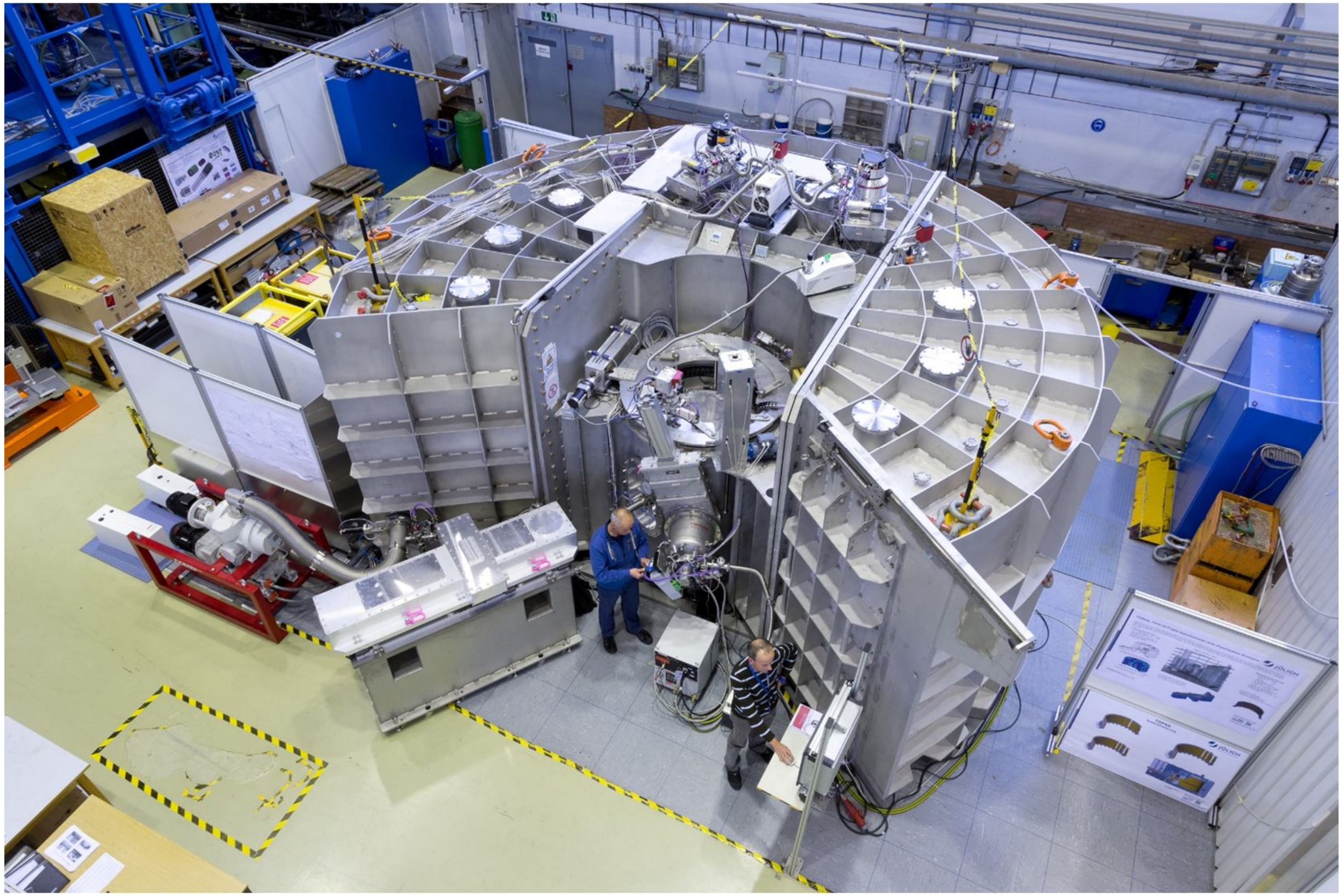


Construction details

- Chamber is segmented in three segments. (also better for handling)
- To connect the segments, the segments have to be screwed together vacuum-tight.
- 98 bolts per flange
  M 24, silver plated
  tightening torque 400 Nm
- For the sealing perbunan –O-rings were used (length 13 m, 20 mm diameter

TOPAS

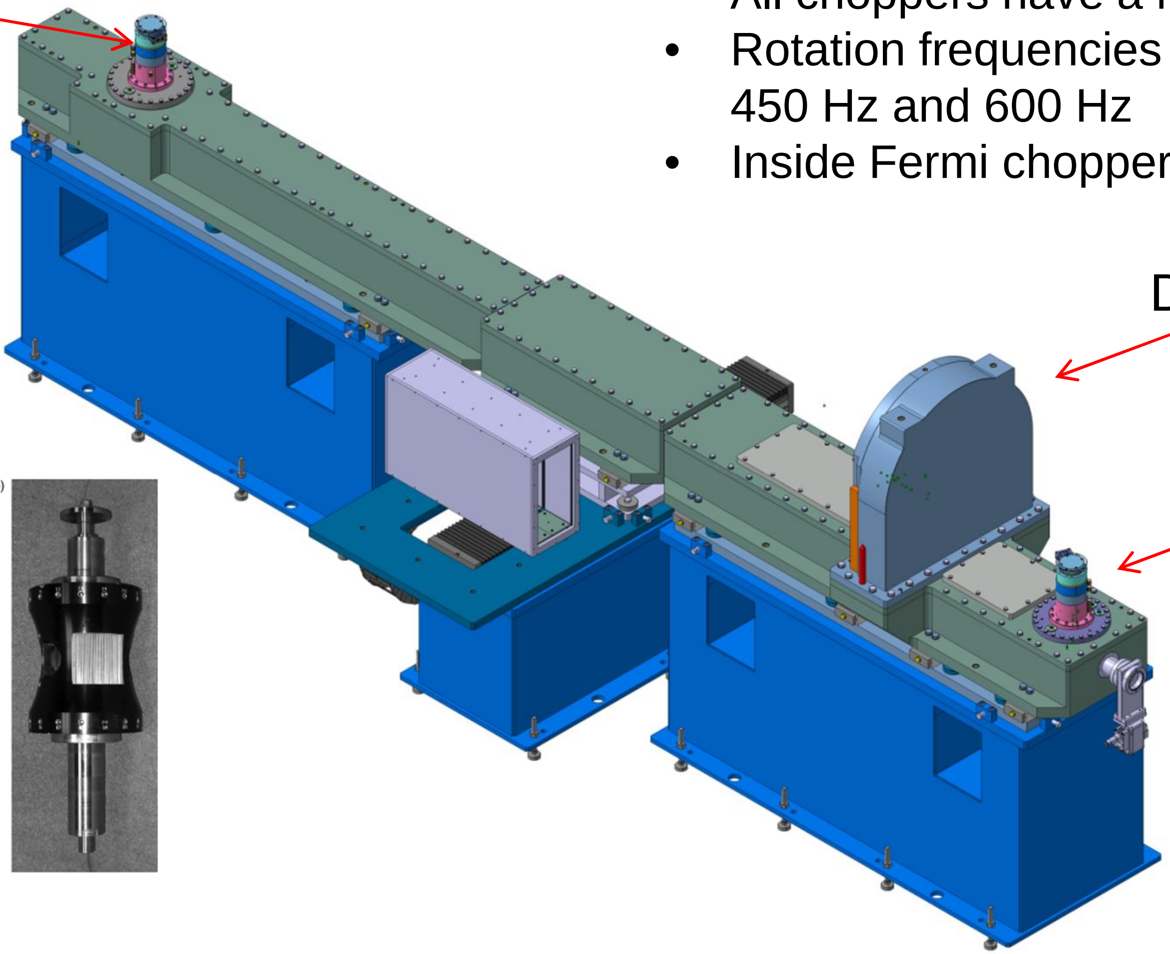
Time Of Flight Spectrometer with Polarization Analysis

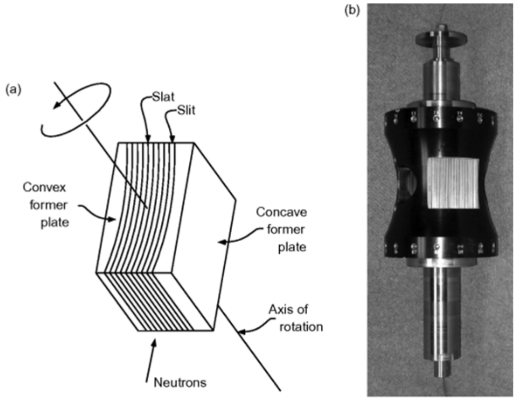


TOPAS

Time Of Flight Spectrometer with Polarization Analysis – chopper system

- One disk chopper (pulse chopper)
- Two Fermi chopper (speed selection)
- All choppers have a magnetic bearing
- Rotation frequencies for speed selection: 450 Hz and 600 Hz
- Inside Fermi chopper $^{10}B_4C$-coated Si-wavers

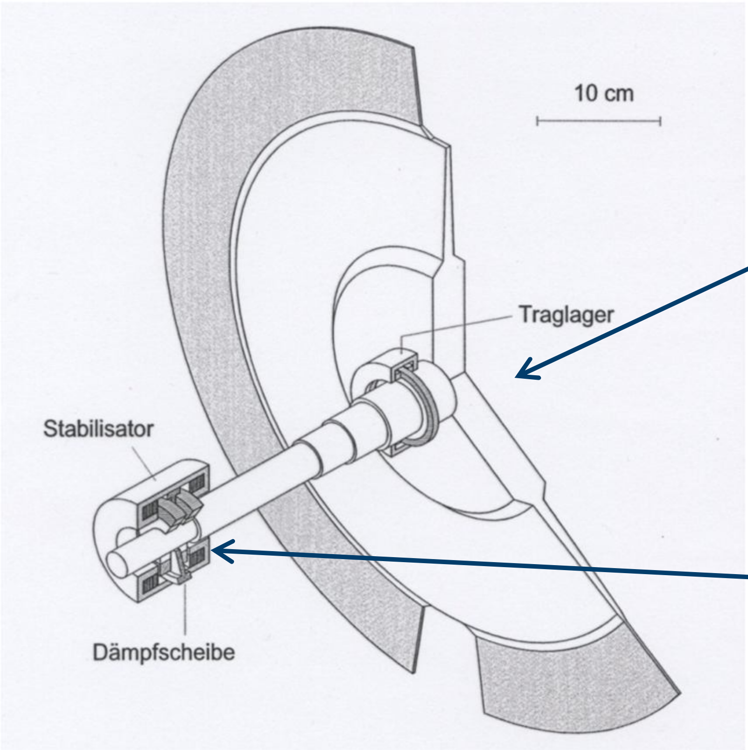




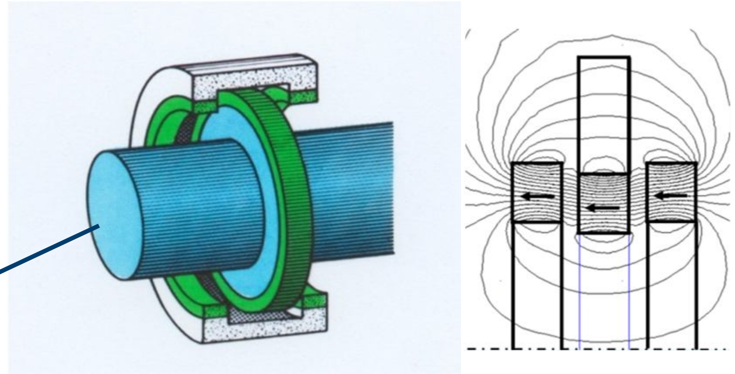
TOPAS

Time Of Flight Spectrometer with Polarization Analysis – chopper system

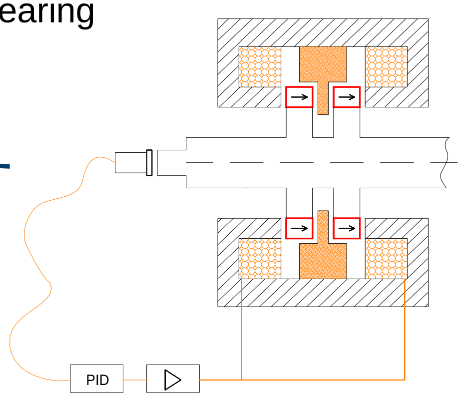
- Magnetic bearing choppers “System Juelich” (passive magnetic bearing)



Typical disk chopper bearing arrangement



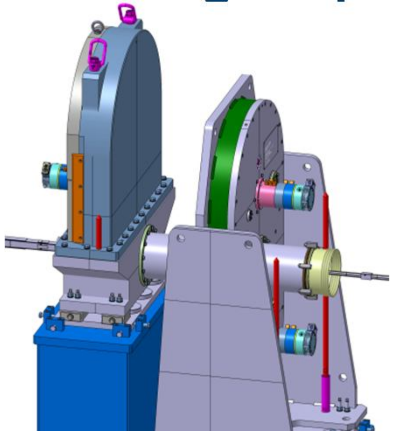
Passive radial load bearing



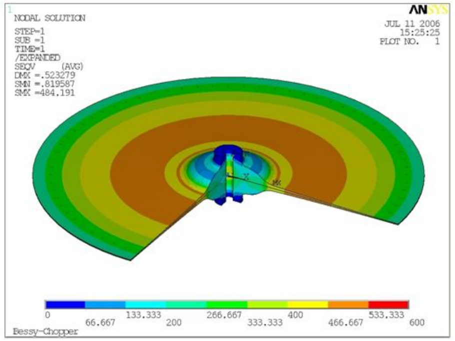
Active axial stabilisation

TOPAS

Time Of Flight Spectrometer with Polarization Analysis – chopper system



Full 3D CAD design

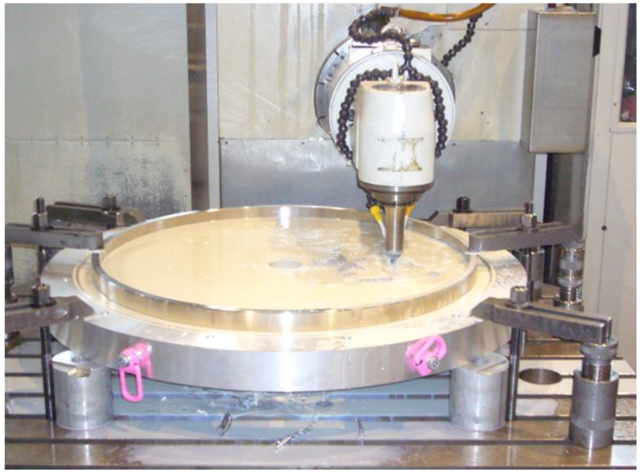


Rotor FEM calculation

Housing crash simulation

Assembling

Magnetic bearing parts



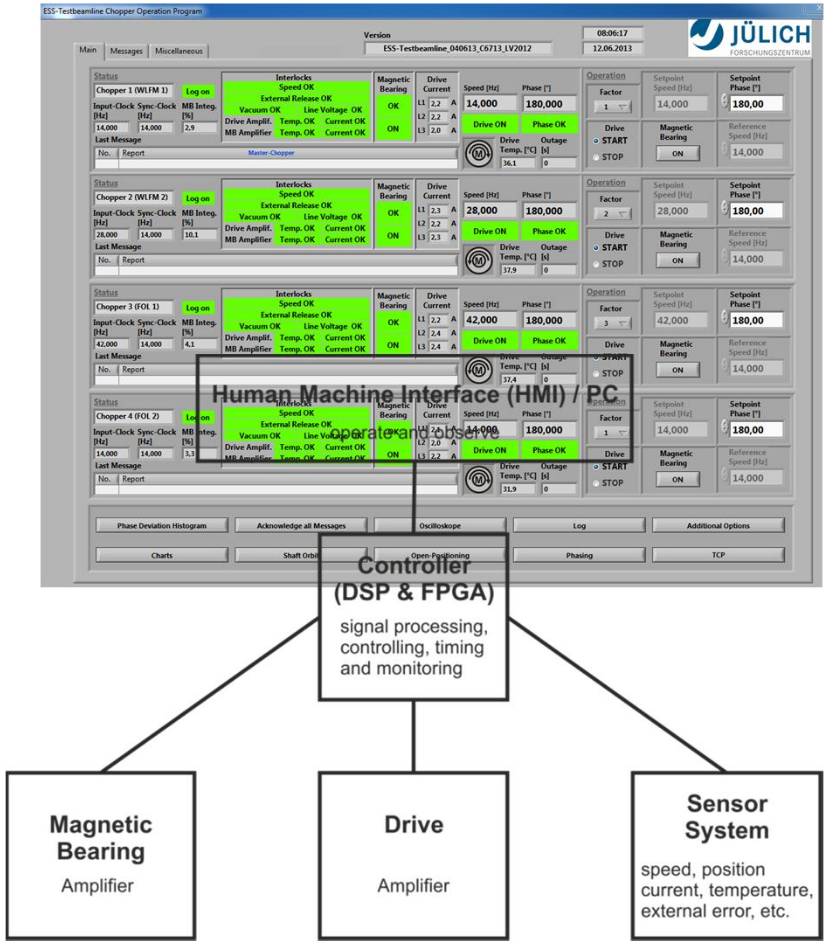
Housing and Rotors

Balancing

TOPAS

Time Of Flight Spectrometer with Polarization Analysis – chopper system control electronics

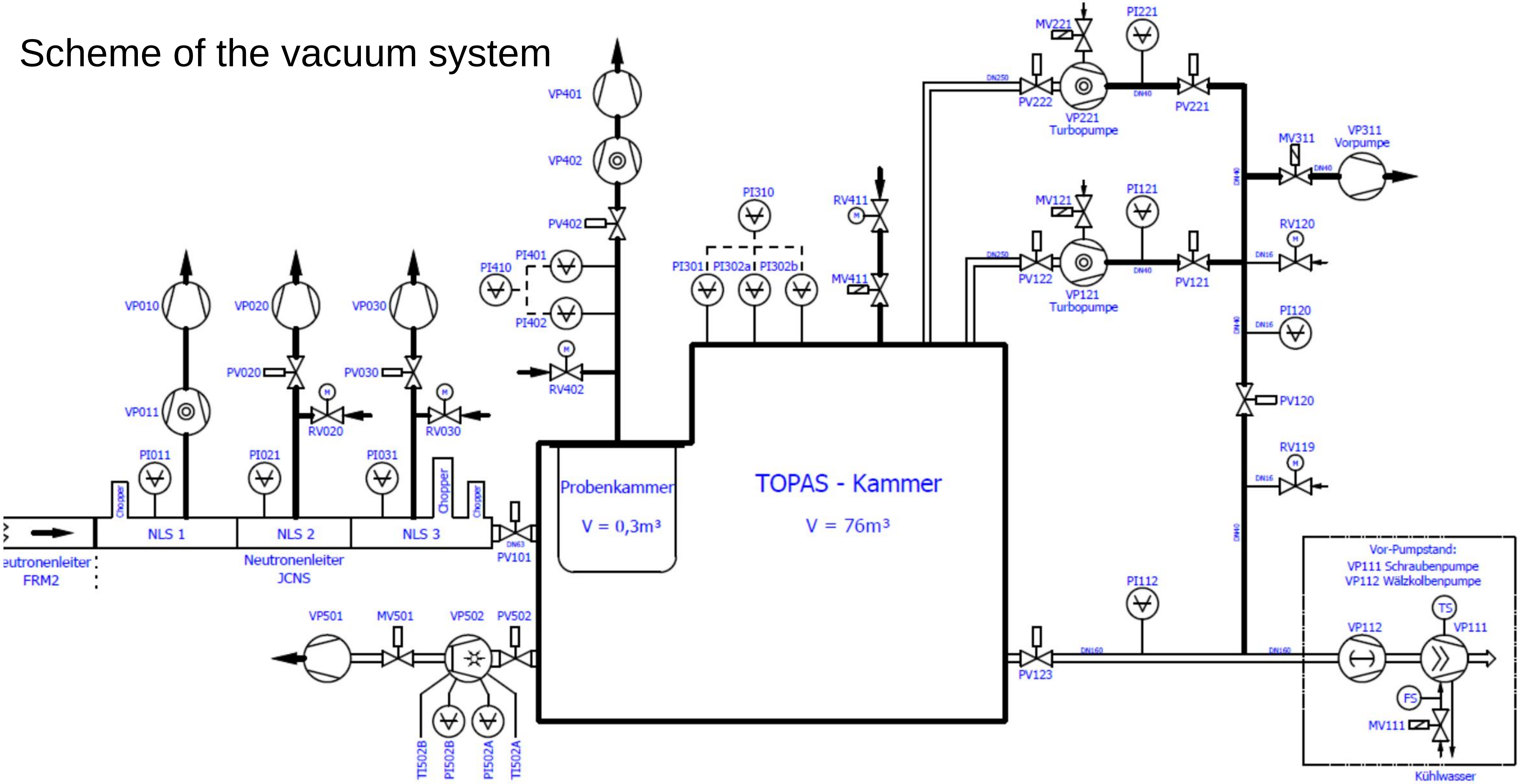
- State of the art (floating point DSP)
- Digital control of magnetic bearing
- Software-Controller (parameterization by software)
- Error diagnosis and equipment condition monitoring
- Remote maintenance
- Resolution of time signals 10ns



TOPAS

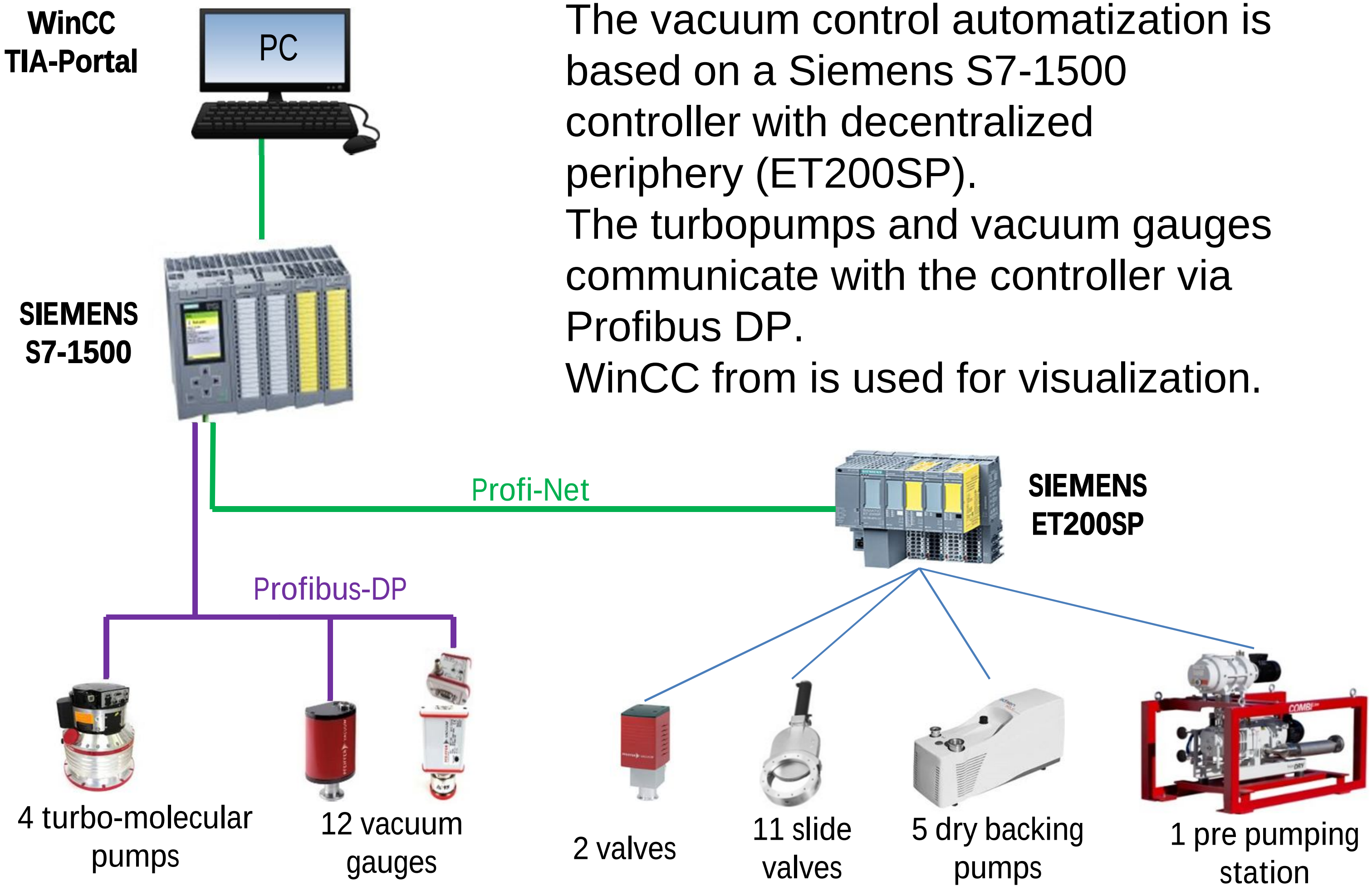
Time Of Flight Spectrometer with Polarization Analysis – vacuum system

Scheme of the vacuum system



TOPAS

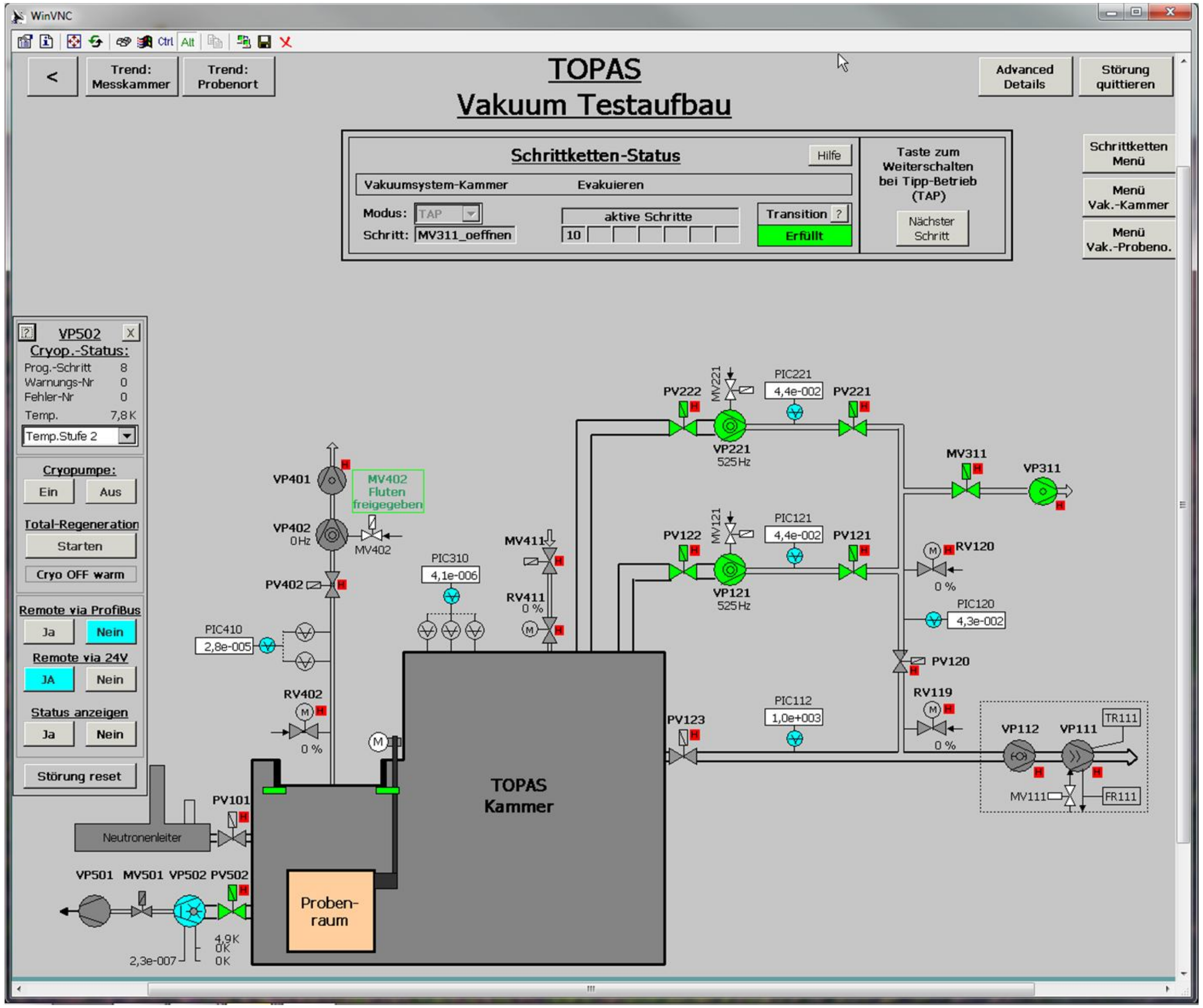
Time Of Flight Spectrometer with Polarization Analysis – vacuum control automatization



The vacuum control automatization is based on a Siemens S7-1500 controller with decentralized periphery (ET200SP).
The turbopumps and vacuum gauges communicate with the controller via Profibus DP.
WinCC from is used for visualization.

TOPAS

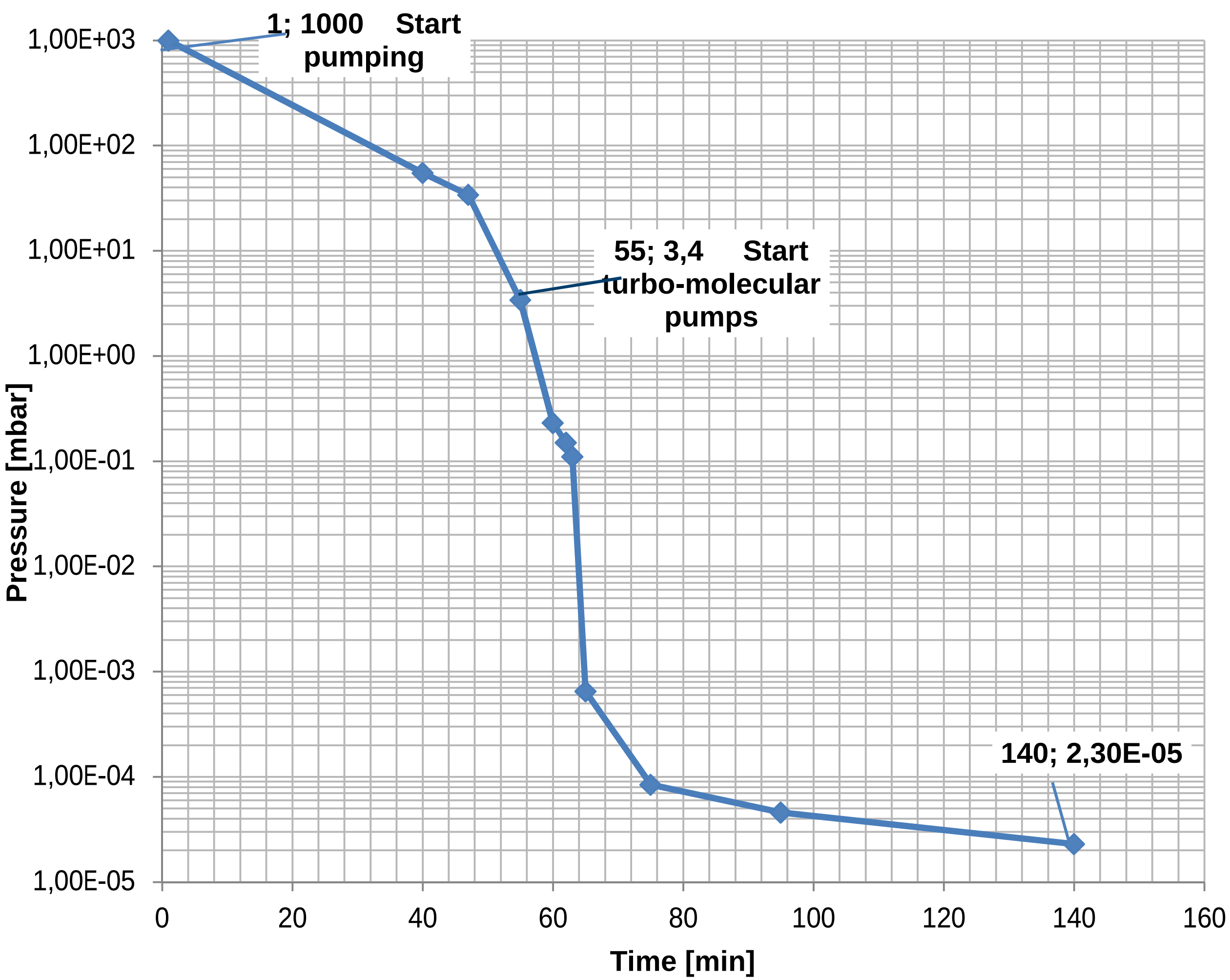
Time Of Flight Spectrometer with Polarization Analysis – vacuum control automatization



TOPAS

Time Of Flight Spectrometer with Polarization Analysis - evacuating the chamber

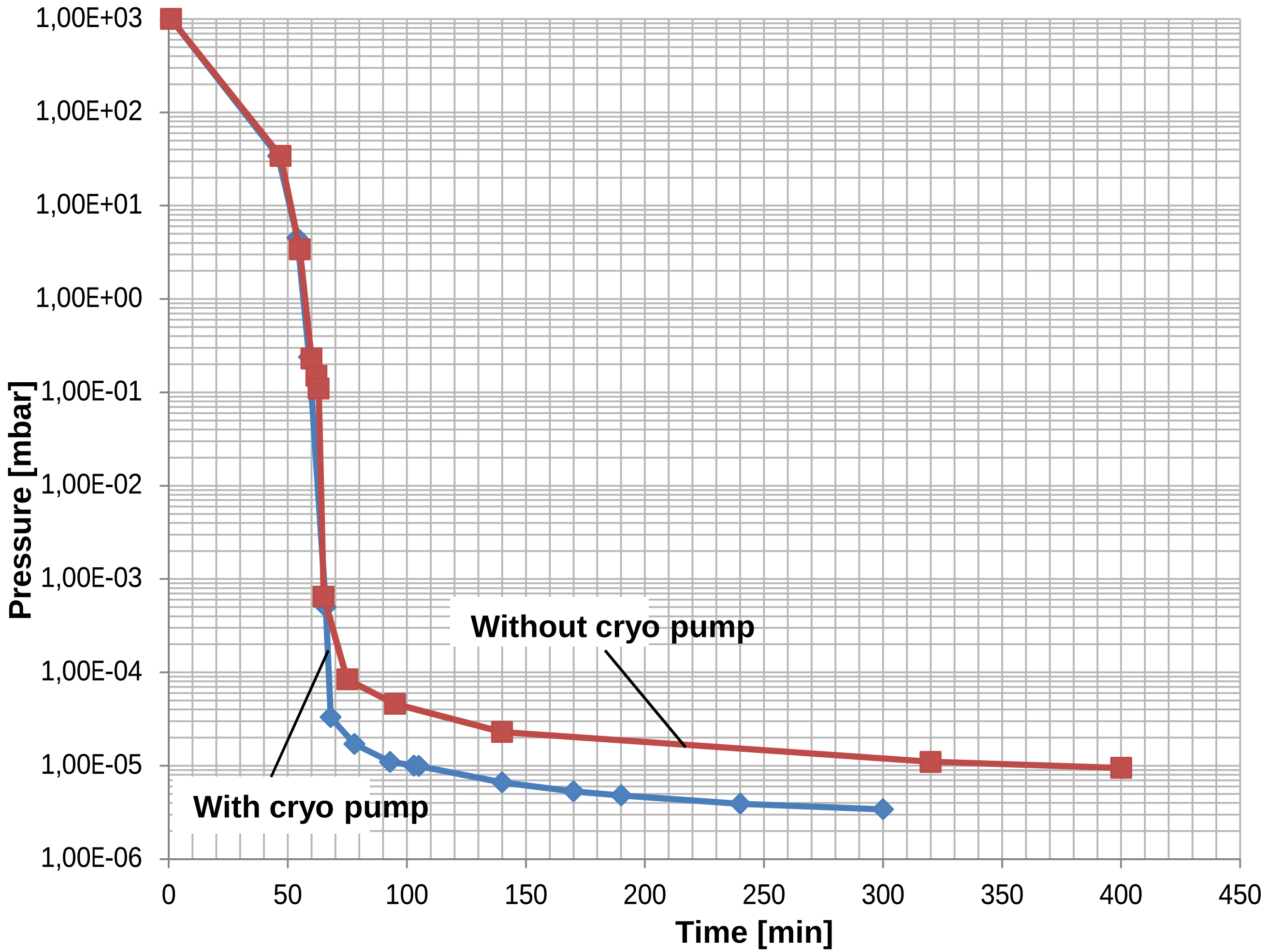
Time	Pressure
min	mbar
1	**1000**
40	55
47	34
55	**3,4**
60	2,30E-01
62	1,50E-01
63	1,10E-01
65	6,50E-04
75	8,40E-05
95	4,60E-05
140	**2,30E-05**
300	8,90E-06
500	6,20E-06
1070	4,90E-06
1265	4,60E-06
1405	4,40E-06
1580	4,20E-06
2645	3,30E-06
5390	2,70E-06
5760	2,60E-06



TOPAS

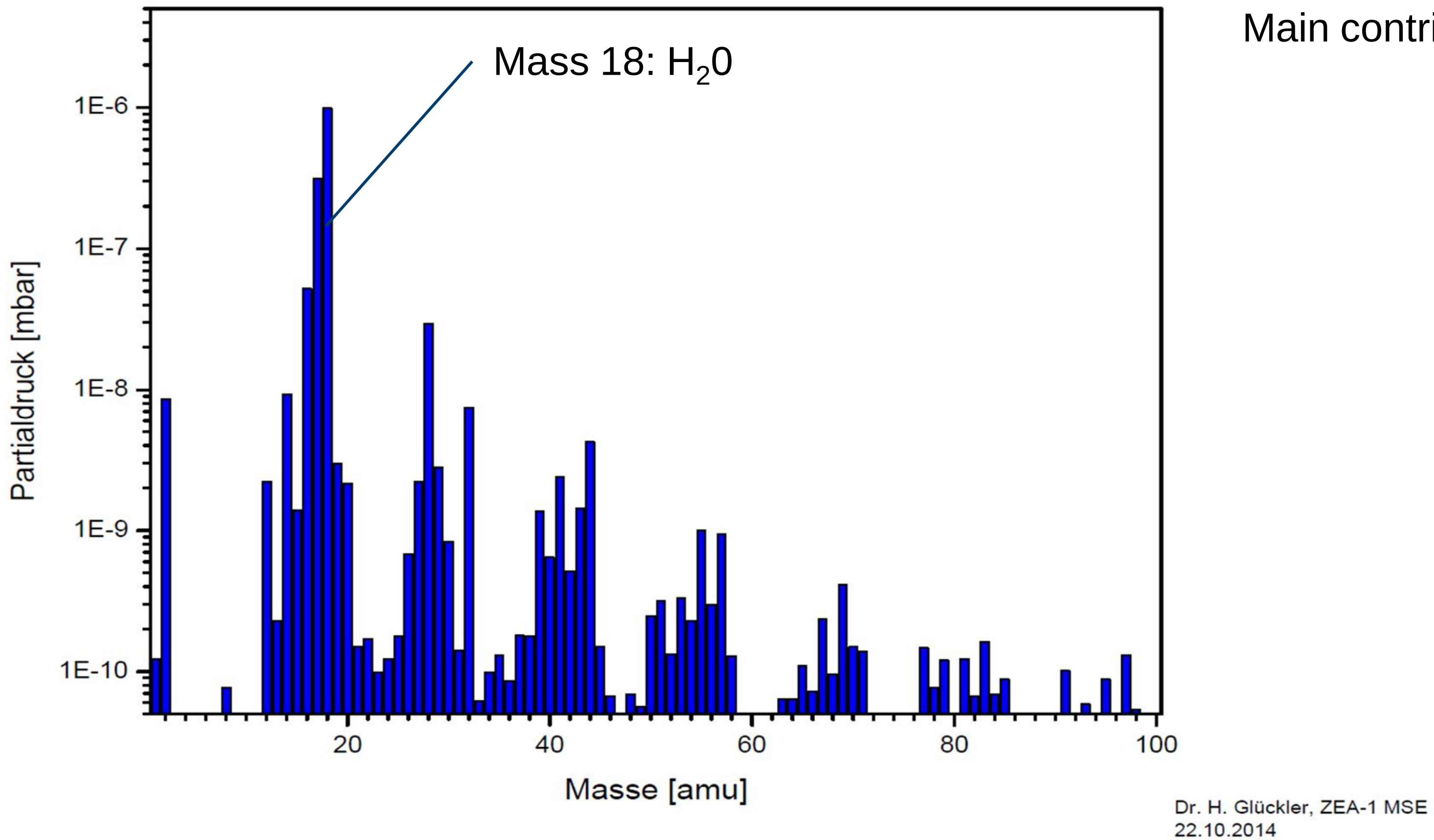
Time Of Flight Spectrometer with Polarization Analysis – evacuating the chamber – we can do it even better or faster

Time min	Pressure mbar
1	**1000**
46	**34**
54	4,5
55	
59	2,40E-01
65	**Cryo pump on**
66	5,00E-04
68	3,30E-05
75	
78	1,70E-05
93	1,10E-05
95	
103	1,00E-05
105	9,90E-06
140	**6,60E-06**
170	5,30E-06
190	4,80E-06
240	3,90E-06
300	3,40E-06



TOPAS

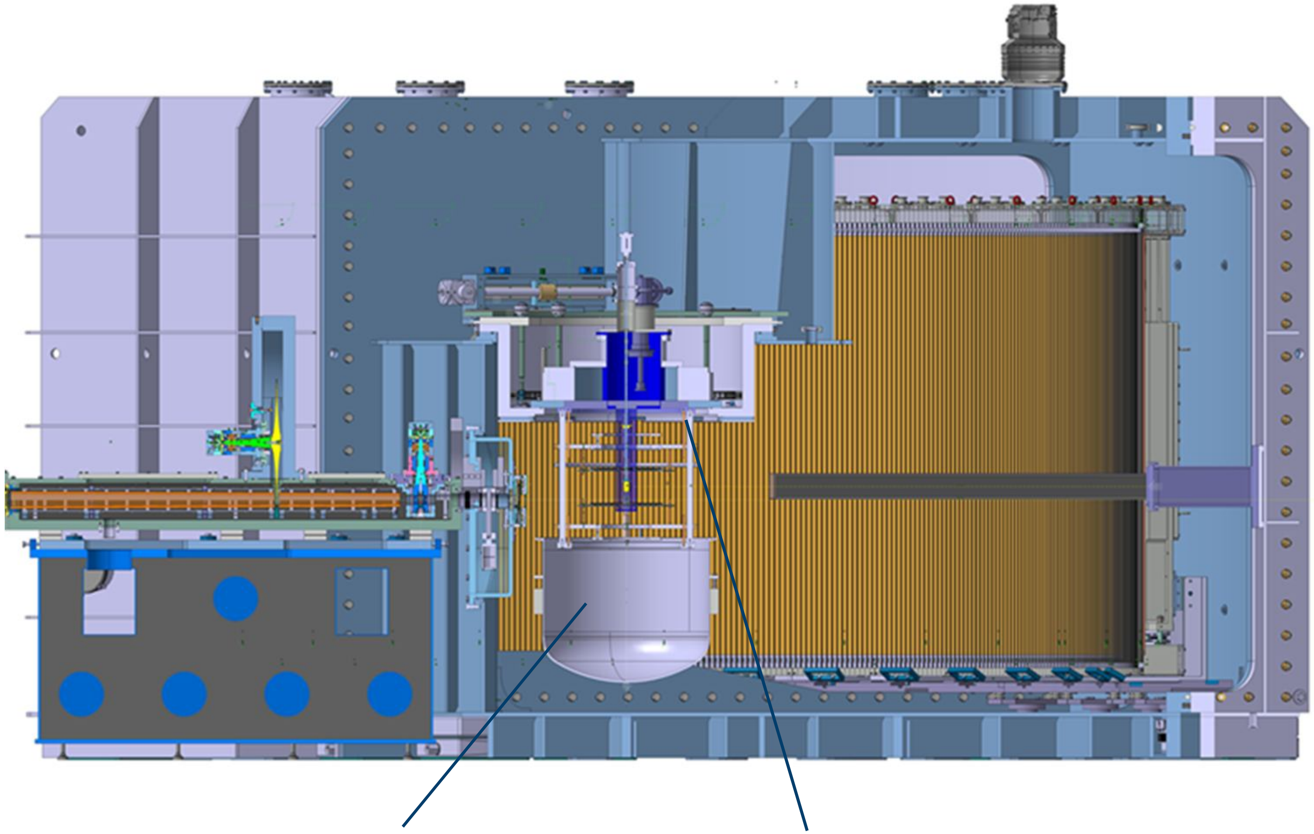
Time Of Flight Spectrometer with Polarization Analysis – residual gas analysis



Main contribution comes from water

TOPAS

Time Of Flight Spectrometer with Polarization Analysis – sample manipulation



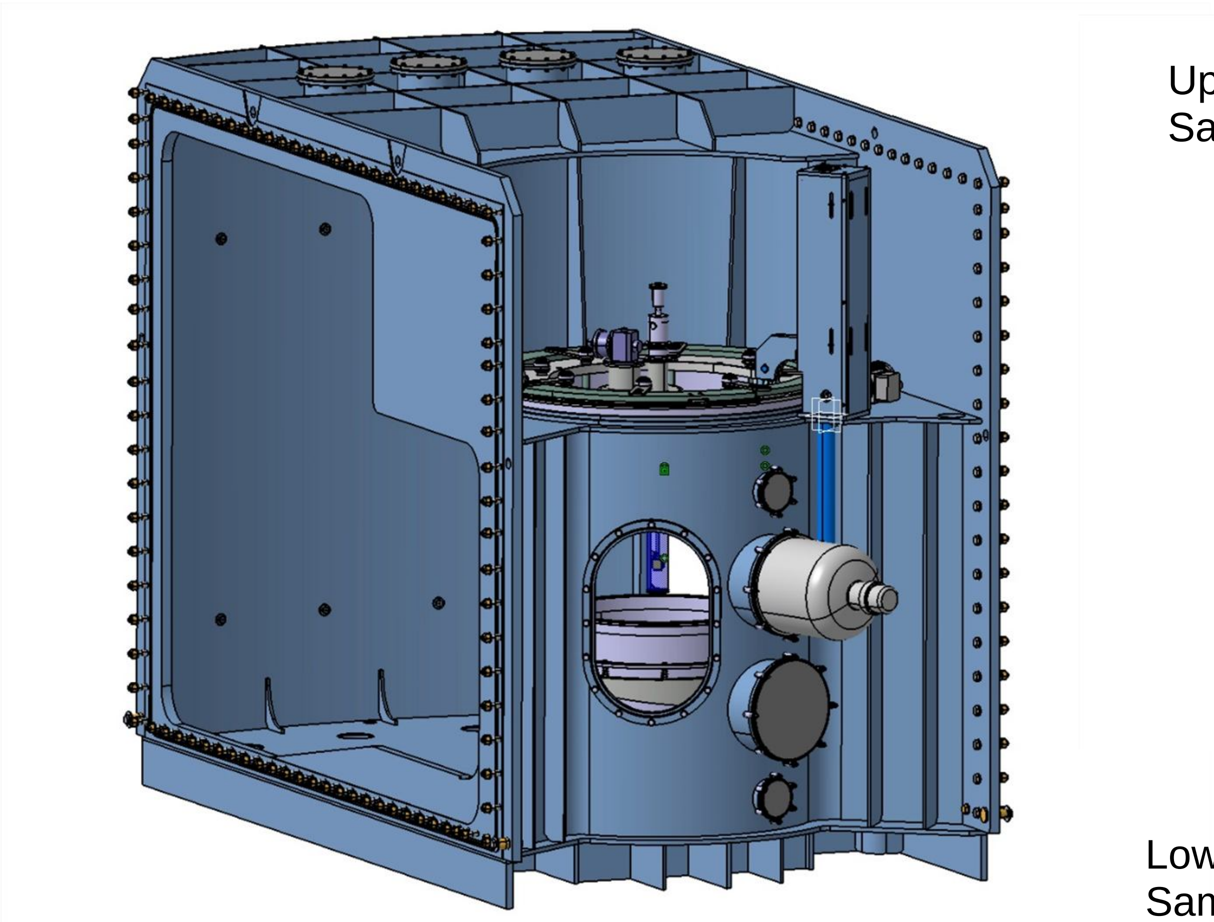
Movable sample vessel
volume: 0,4 m^3

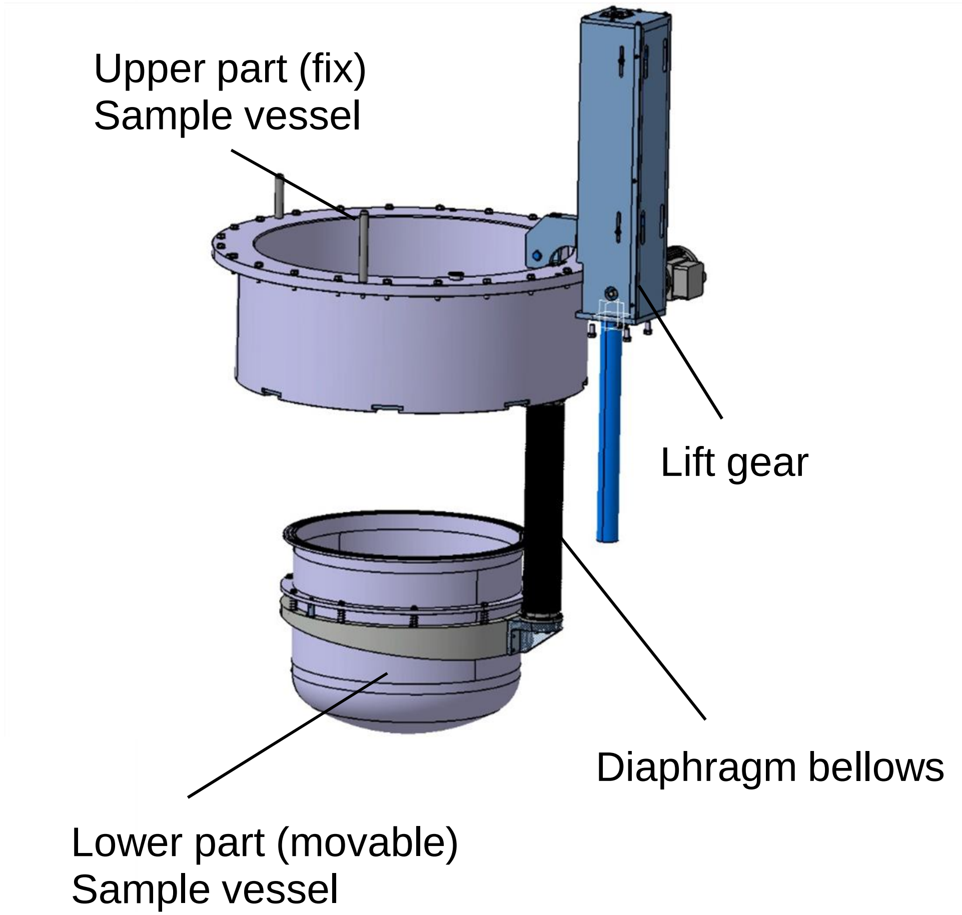
Sample vessel upper part

- To change a sample it is not a good idea to vent the complete vacuum chamber
- For changing a sample, the movable sample container is moved against the lower surface of the upper part of the sample vessel insert container by means of a lifting gear and a guide rail.
- The flange of the movable sample container contains an O-ring which seals the complete sample vessel
- Materials: AlMg4,5Mn
  Volume: ca. 0,4 m^3
- Time needed to change a sample: some minutes

TOPAS

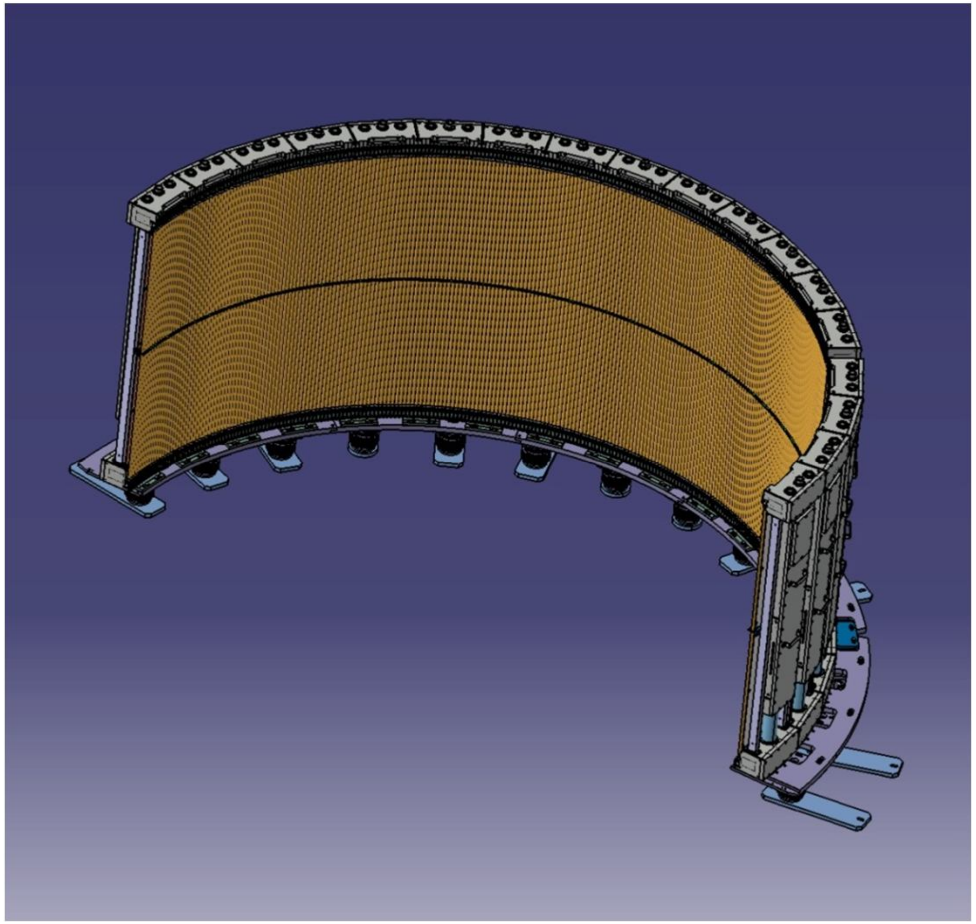
Time Of Flight Spectrometer with Polarization Analysis – sample vessel





TOPAS

Time Of Flight Spectrometer with Polarization Analysis – neutron detectors

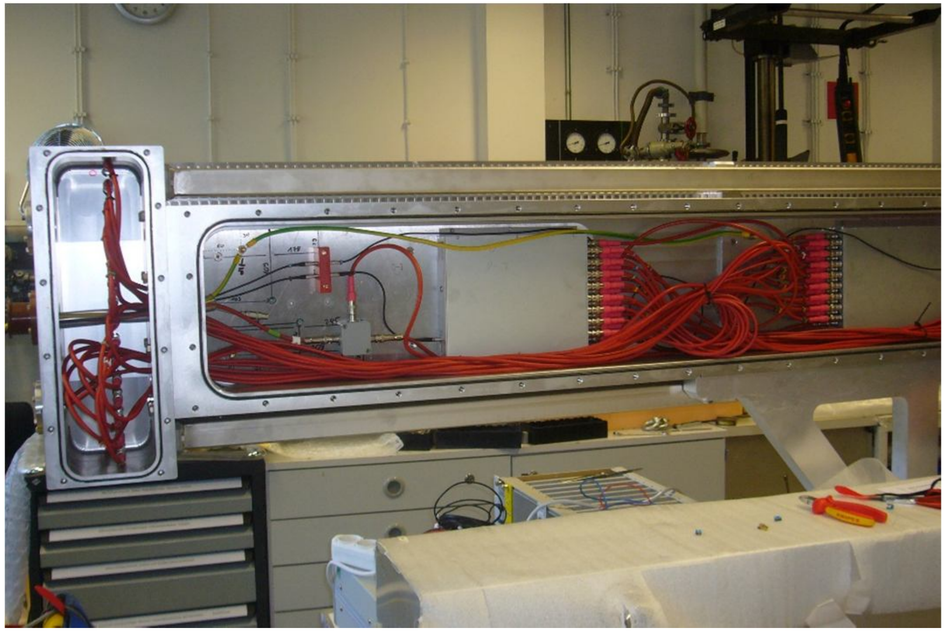


- 288 neutron detectors
  (tubes filled with ^{3}He gas – very expensive)
- n + ^{3}He → ^{3}H + p , Q = 0,764 MeV
- 16 tubes are combined to a detector box
  (18 boxes which carry also the amplifiers and HV)
- 3 detector boxes are mounted on a „detector bank“
- Distance sample – detector: 2,5 m (+/- 1 mm)
- Covered angle range: 180°
- All detectors are inside the vacuum chamber
  (but not the amplifiers and HV)

TOPAS

Time Of Flight Spectrometer with Polarization Analysis – neutron detectors

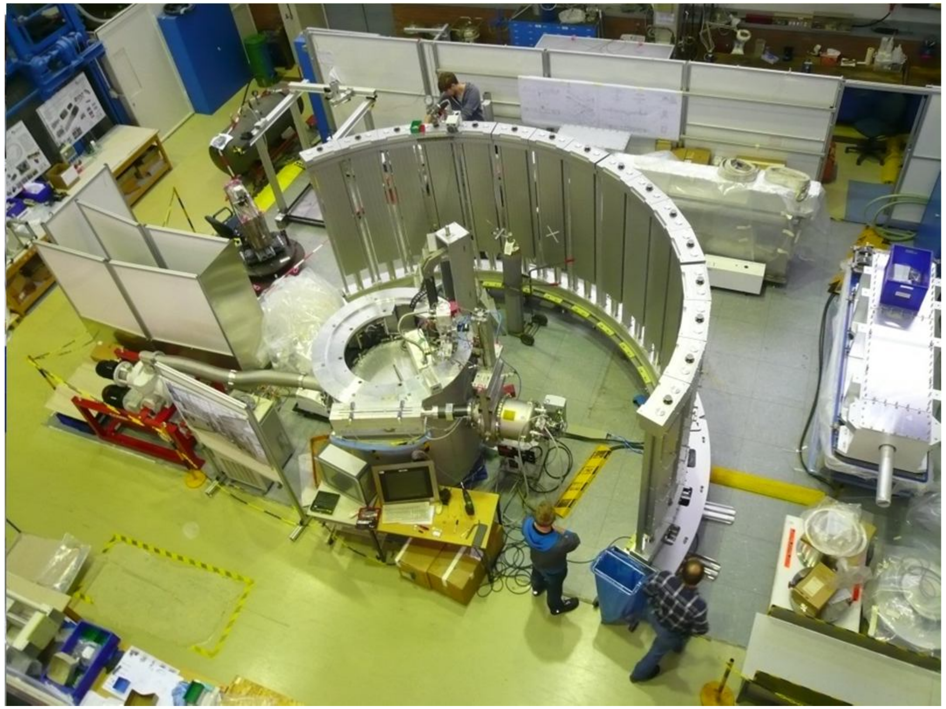
- detector box (front view)
- detector box (back view, without cover plate)



TOPAS

Time Of Flight Spectrometer with Polarization Analysis – neutron detectors

Mounting and adjusting the detector boxes

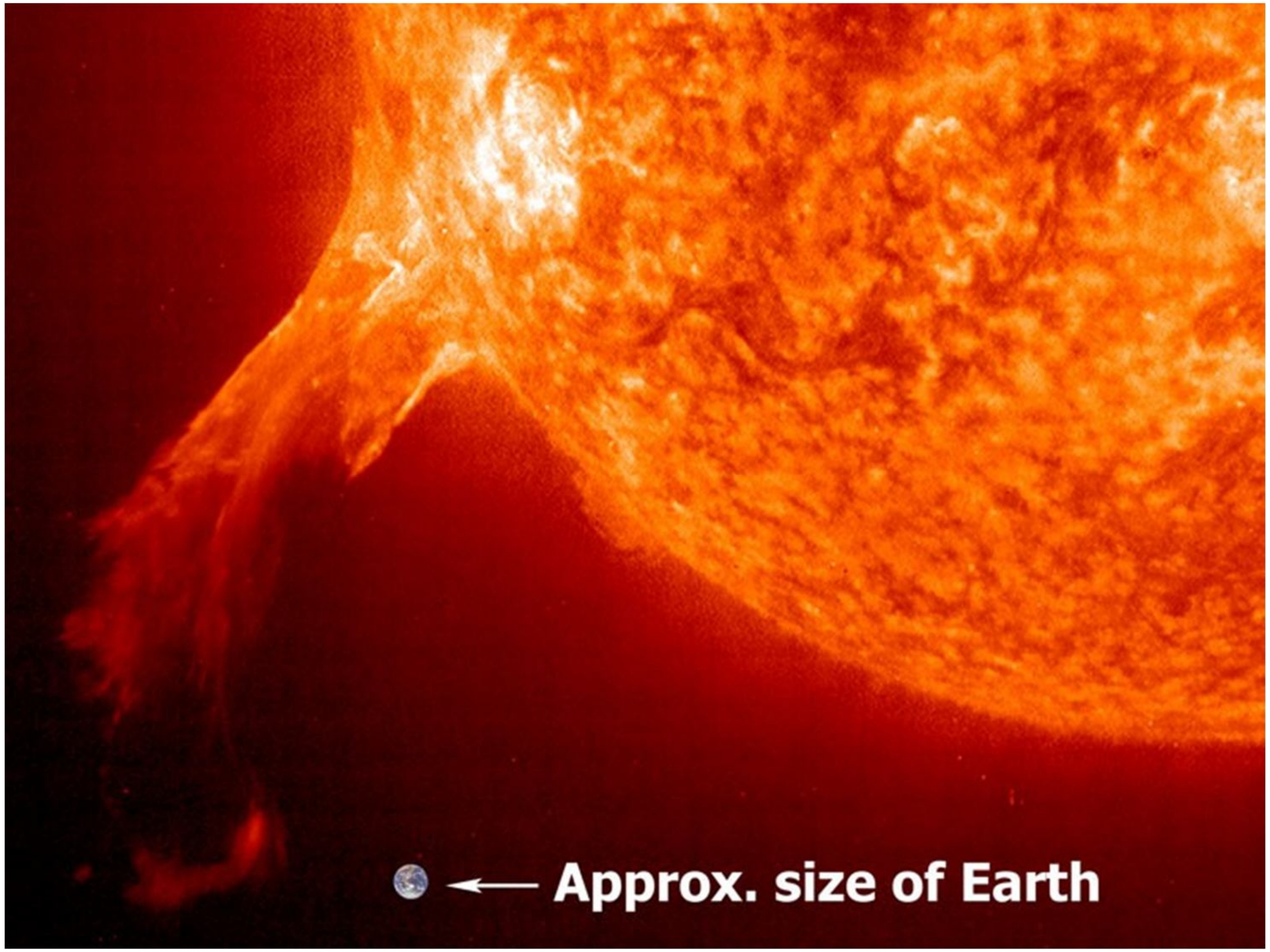


TOPAS

Time Of Flight Spectrometer with Polarization Analysis – neutron detectors

Mounting and adjusting the detectors inside the vacuum chamber –
Development of a rail system

PLASMA HEATING FOR NUCLEAR FUSION



Inside the sun

- Temperature approx. 15 MK
- Hydrogen is converted to Helium – nuclear fusion
- Conversion rate (per second): 564 million tons Hydrogen → 560 million tons Helium
- 4 million tons are missing

- Produced energy $E = \Delta m\, c^2$

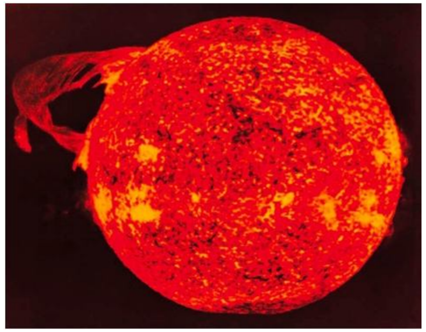
PLASMA HEATING FOR NUCLEAR FUSION

what is plasma?

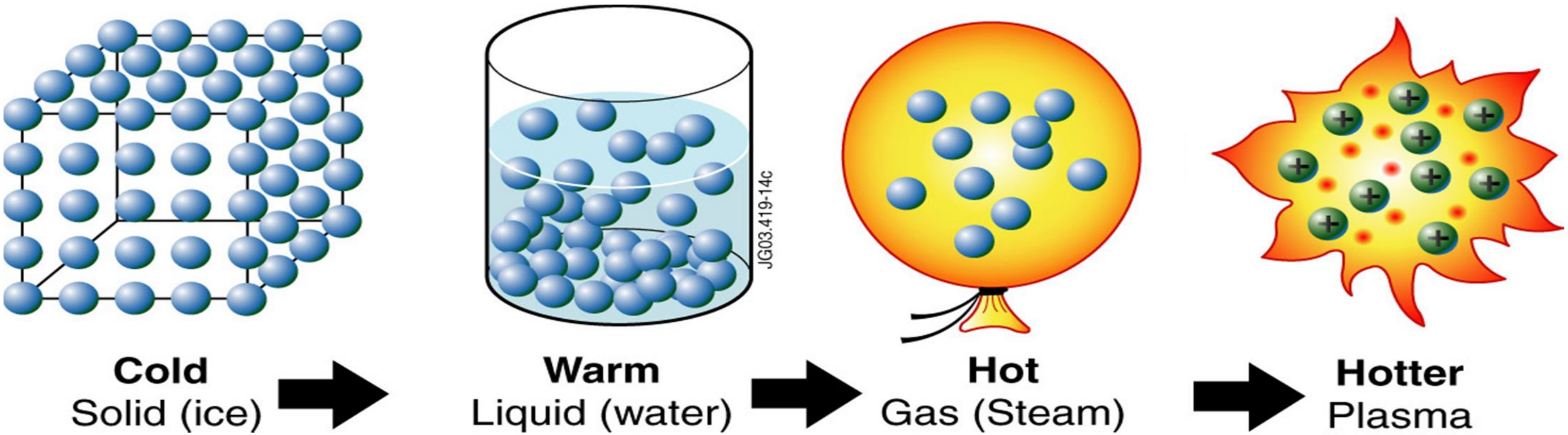
0°C

100°C

100.000°C



15.000.000°C

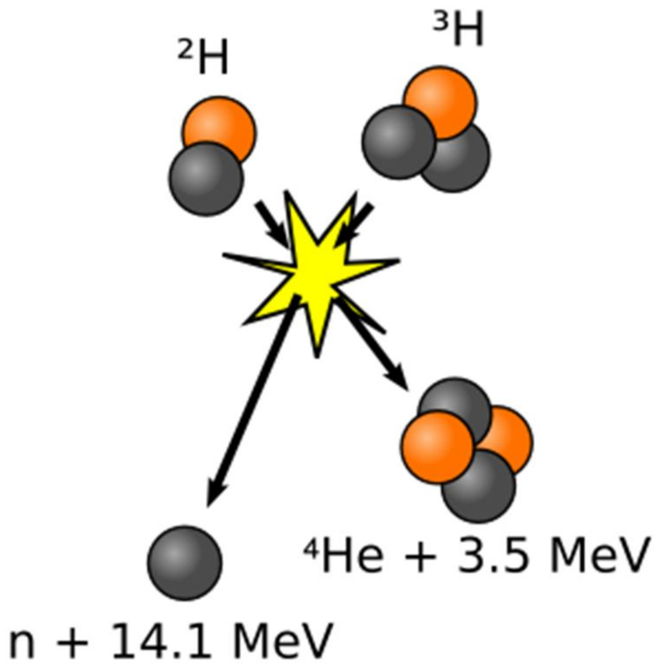


PLASMA HEATING FOR NUCLEAR FUSION

nuclear fusion reaction

Tritium ^3H
Deuterium ^2H

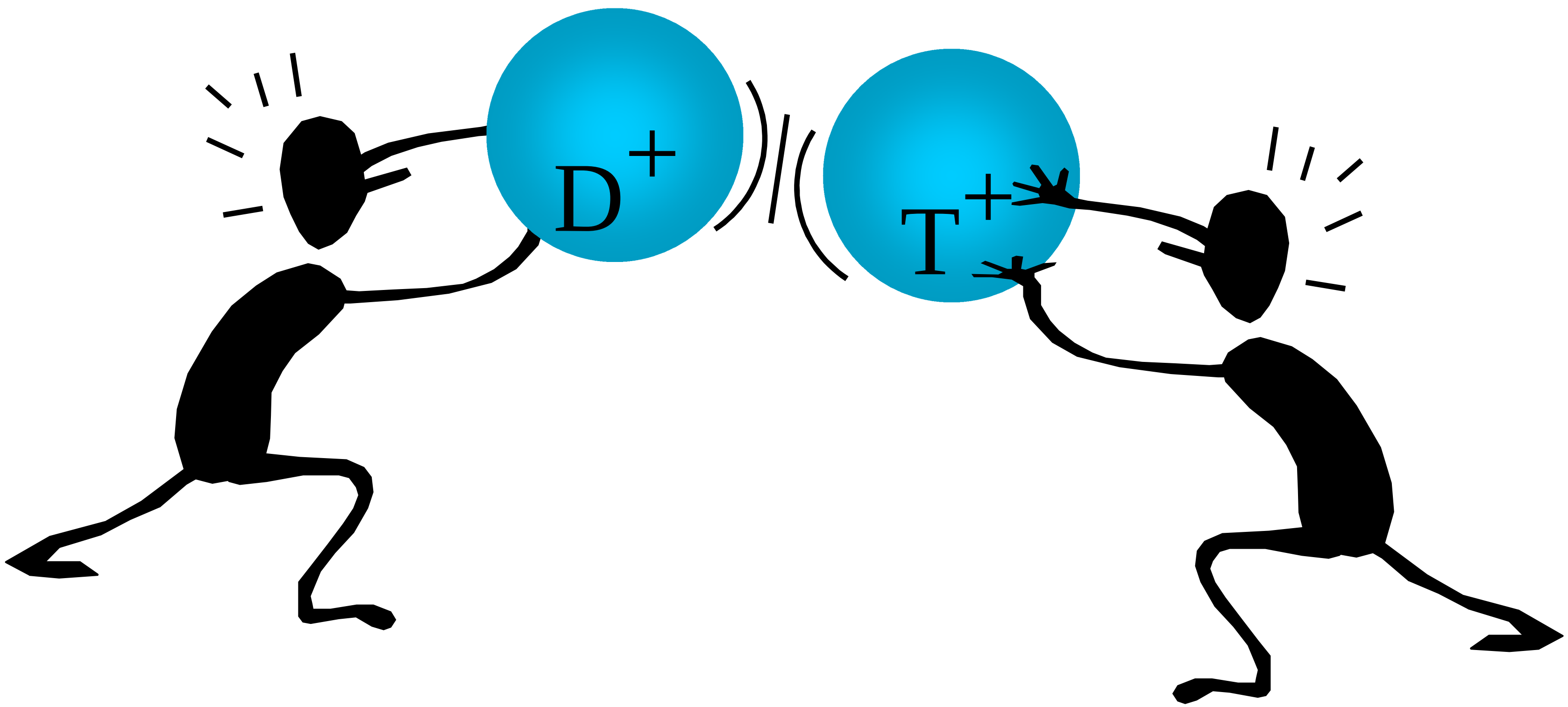
$^3H + ^2H \rightarrow ^4He + n + \text{energy}$



PLASMA HEATING FOR NUCLEAR FUSION

nuclear fusion reaction

Both nuclei (^3H,^2H) have a positive charge, they repel each other…

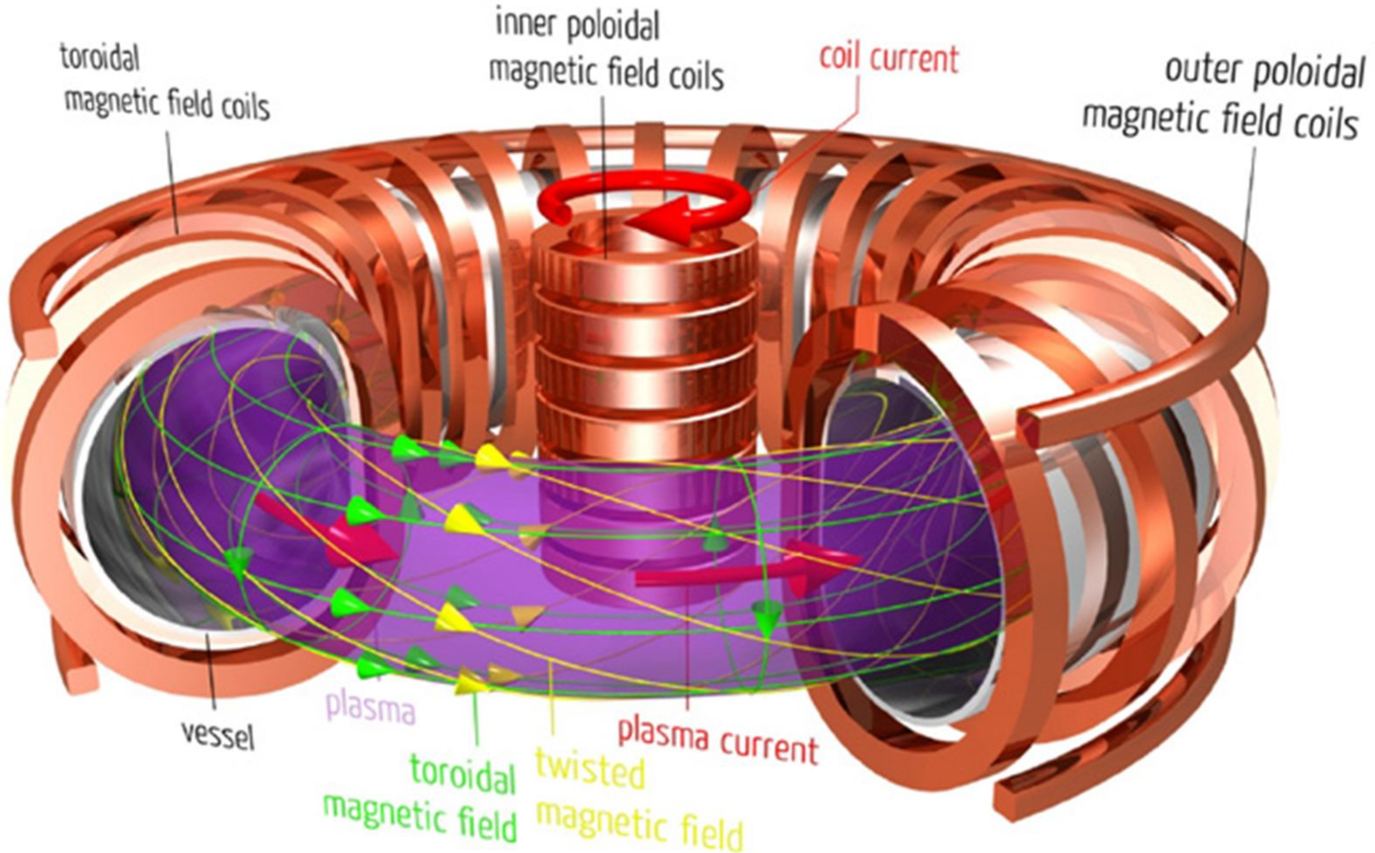


Therefore a lot of energy is needed to enable nuclear fusion on earth

PLASMA HEATING FOR NUCLEAR FUSION

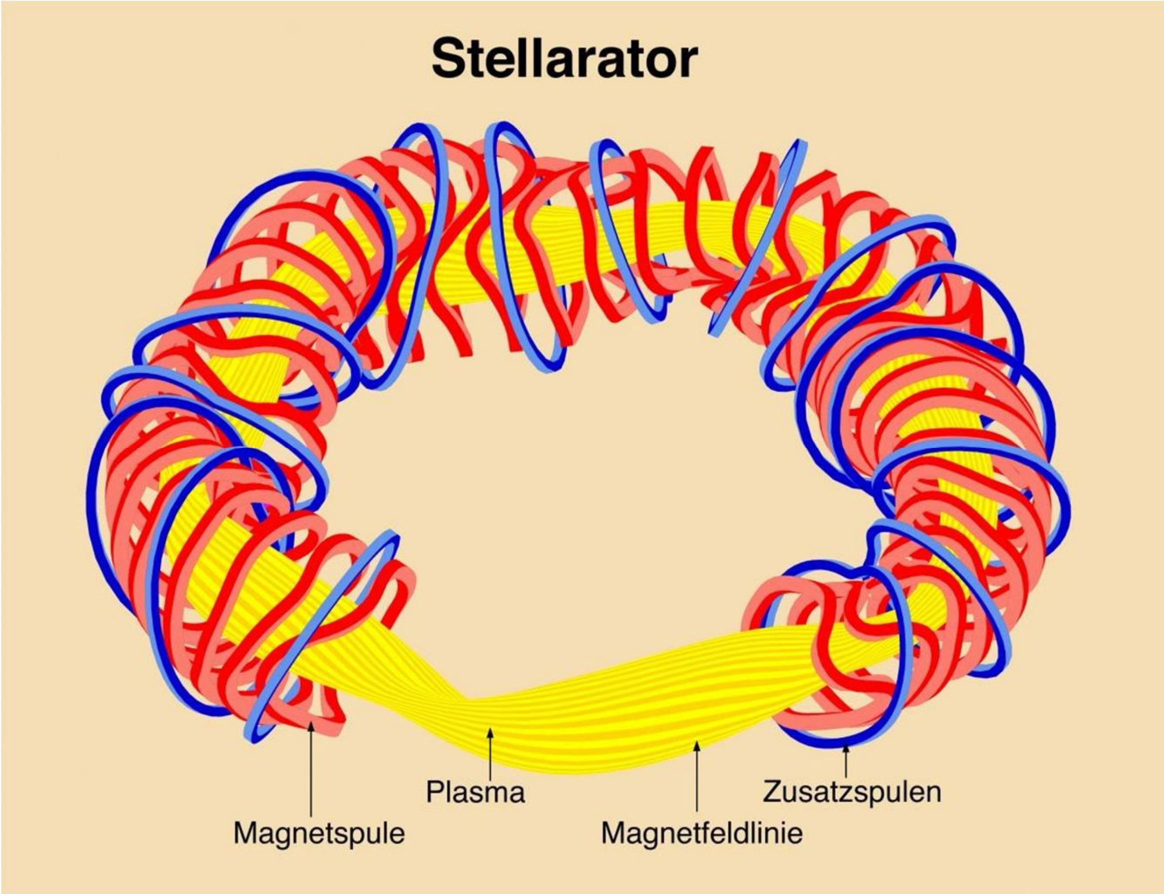
trap for the plasma – magnetic cage

Tokamak



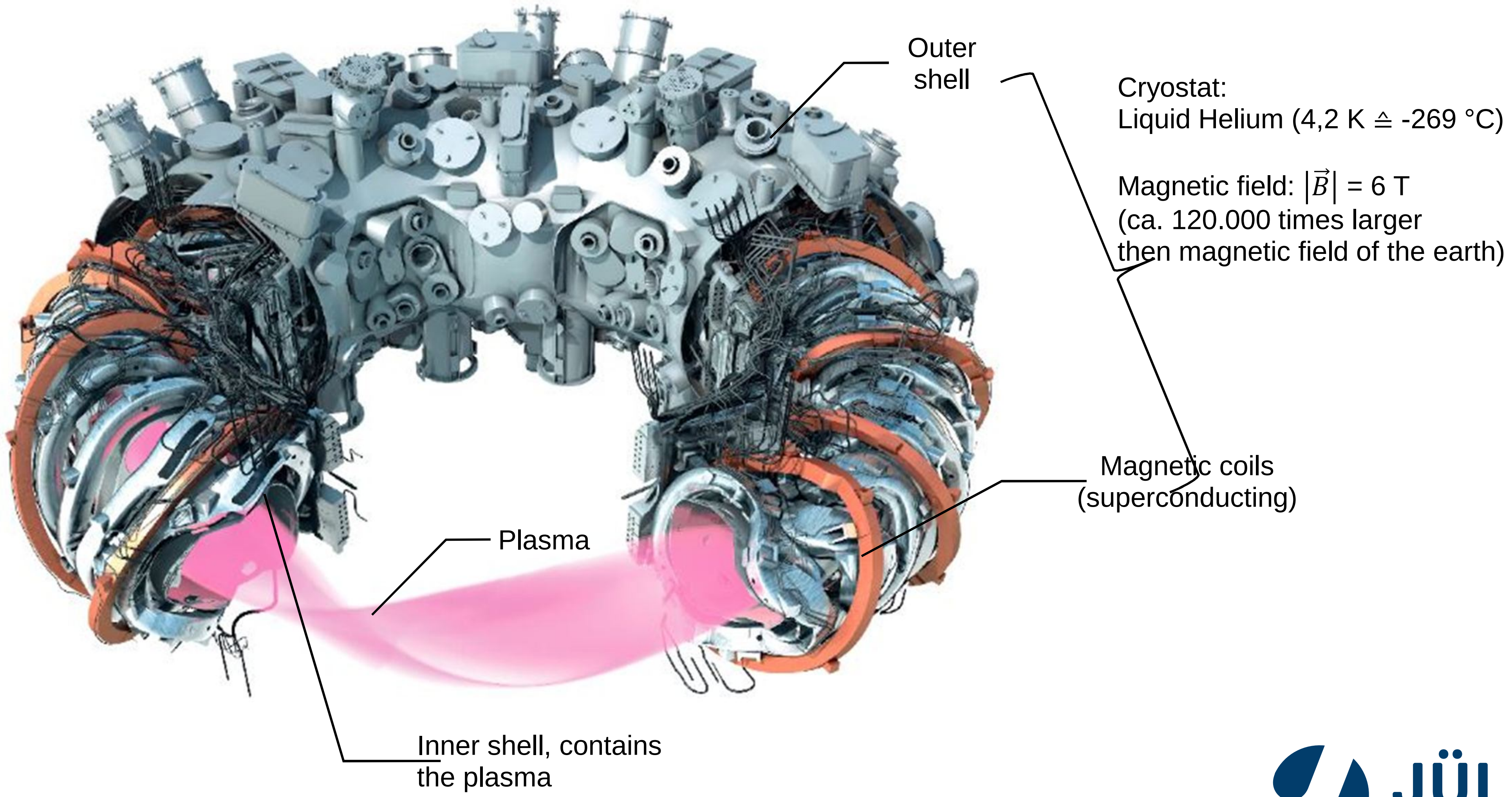
PLASMA HEATING FOR NUCLEAR FUSION

trap for the plasma – magnetic cage



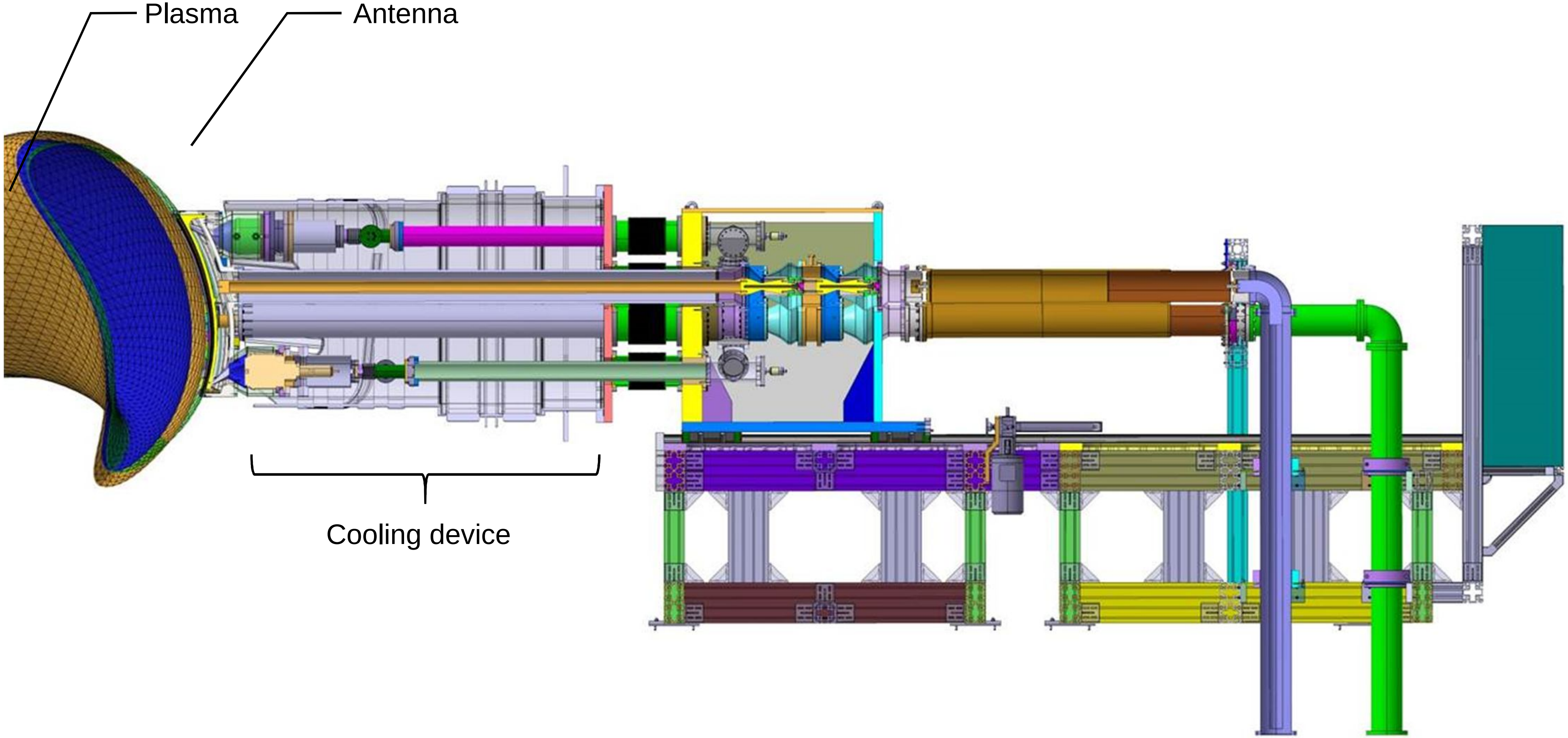
PLASMA HEATING FOR NUCLEAR FUSION

Stellerator Wendelstein 7-X (W7X @ Greifswald/Germany)



PLASMA HEATING FOR NUCLEAR FUSION

ion cyclotron resonance heater – ICRH antenna

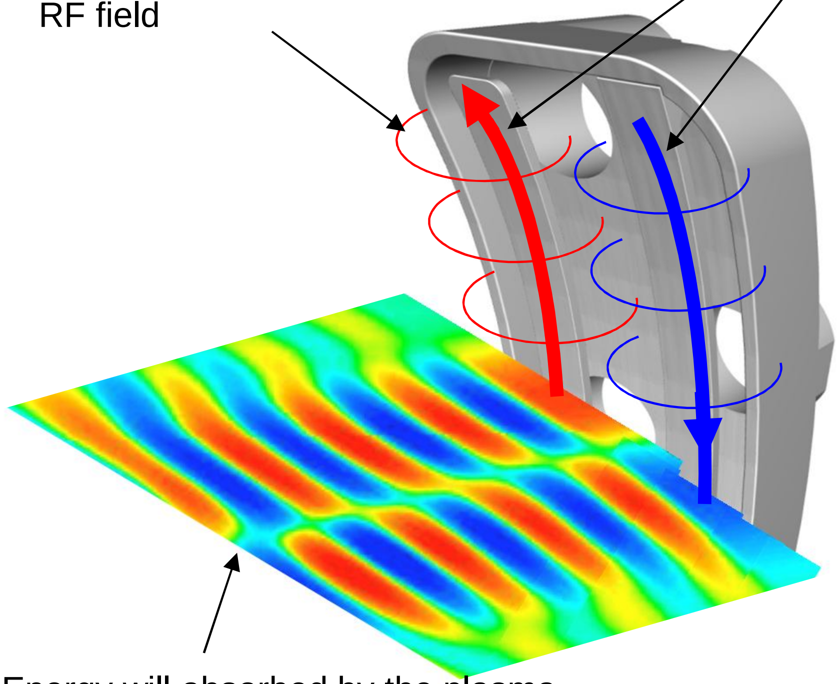


Total length: 10 m

PLASMA HEATING FOR NUCLEAR FUSION

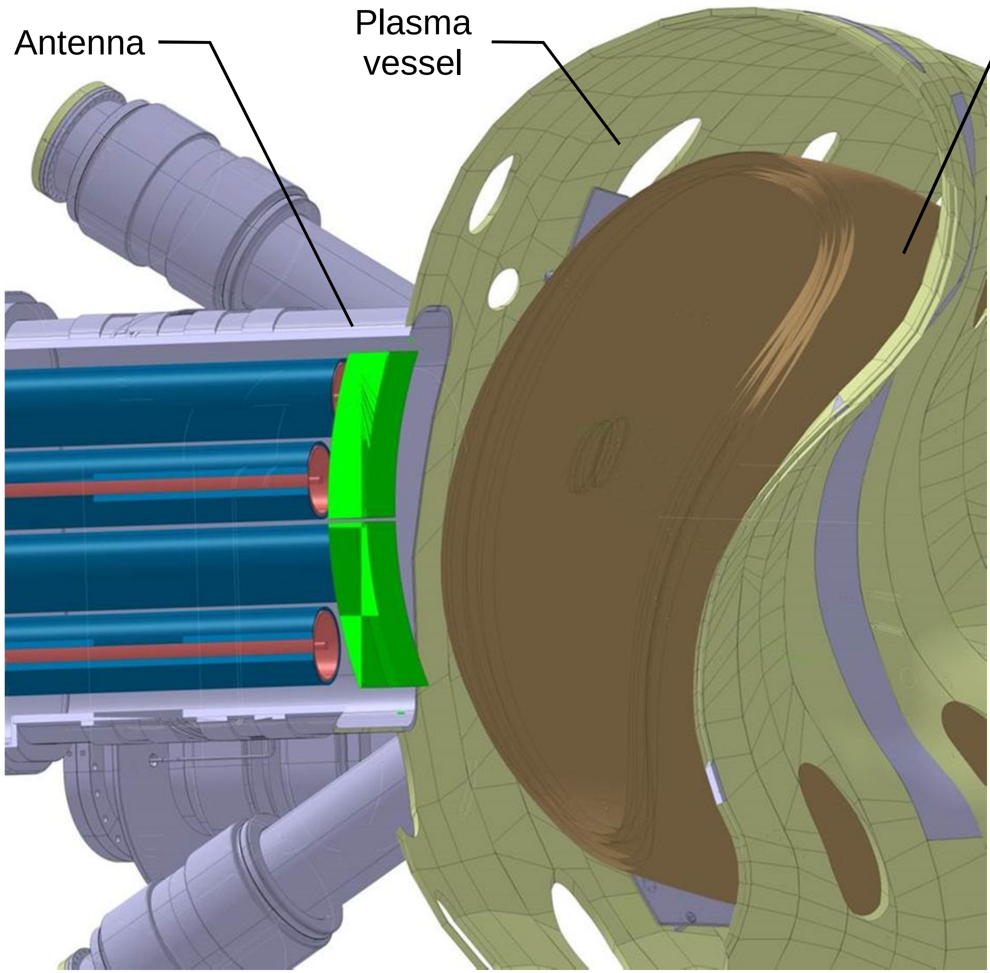
ion cyclotron resonance heater - ICRH

Use electromagnetic waves to heat the plasma to higher temperatures
RF device, emitted power up to 1,5 MW



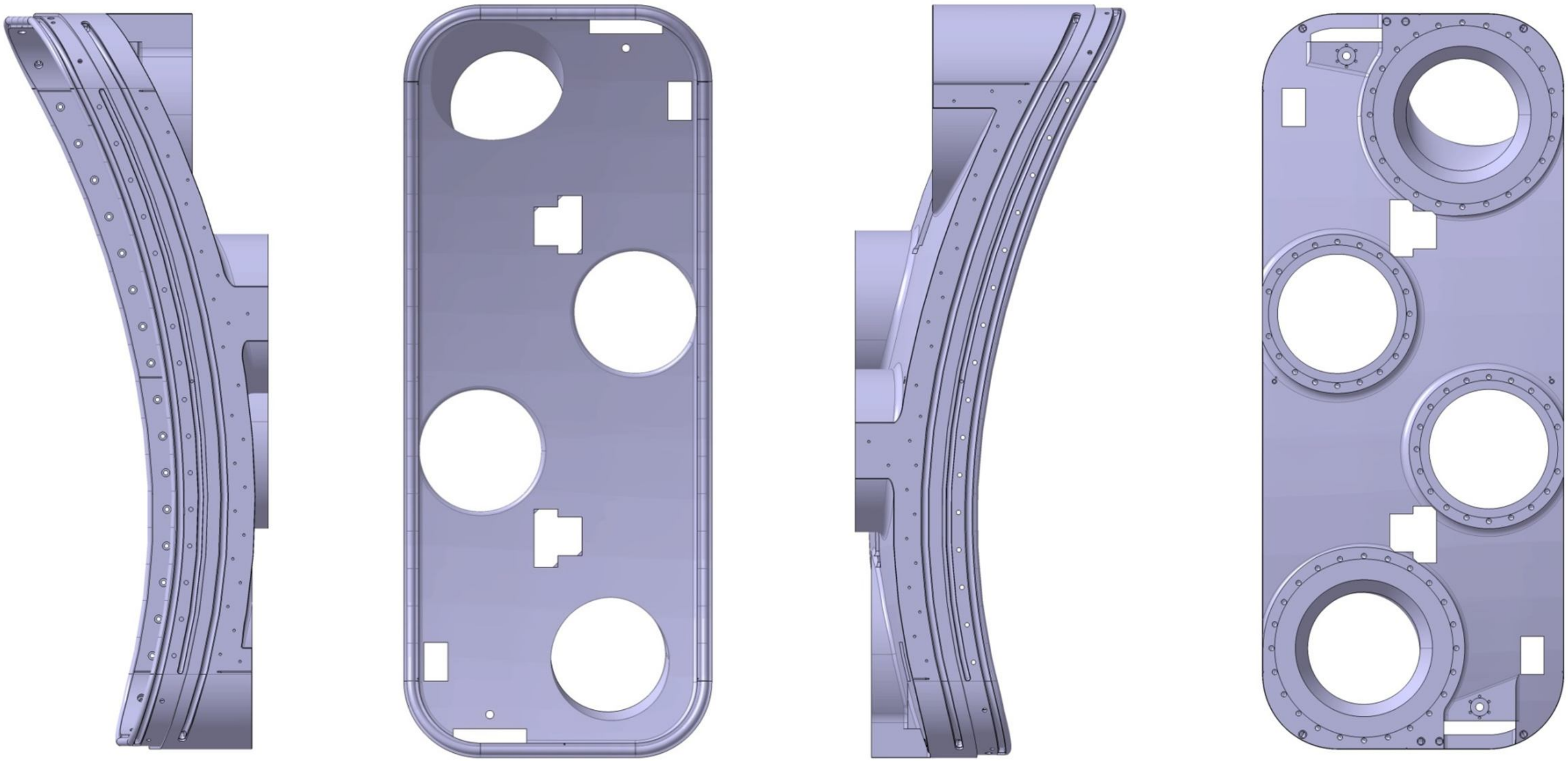
PLASMA HEATING FOR NUCLEAR FUSION

Plasma determines the geometry of the ICRH antenna



PLASMA HEATING FOR NUCLEAR FUSION

ICRH antenna head



PLASMA HEATING FOR NUCLEAR FUSION

ICRH antenna head

To fabricate such a device, one need:

- CAD/CAM
- Special joining technologies
- Metallography
- Surface technologies
- Automatization

Project starts in spring 2016

We expect to deliver the ICRH antenna (ready for mounting @ W7X) in summer 2019

PLASMA HEATING FOR NUCLEAR FUSION

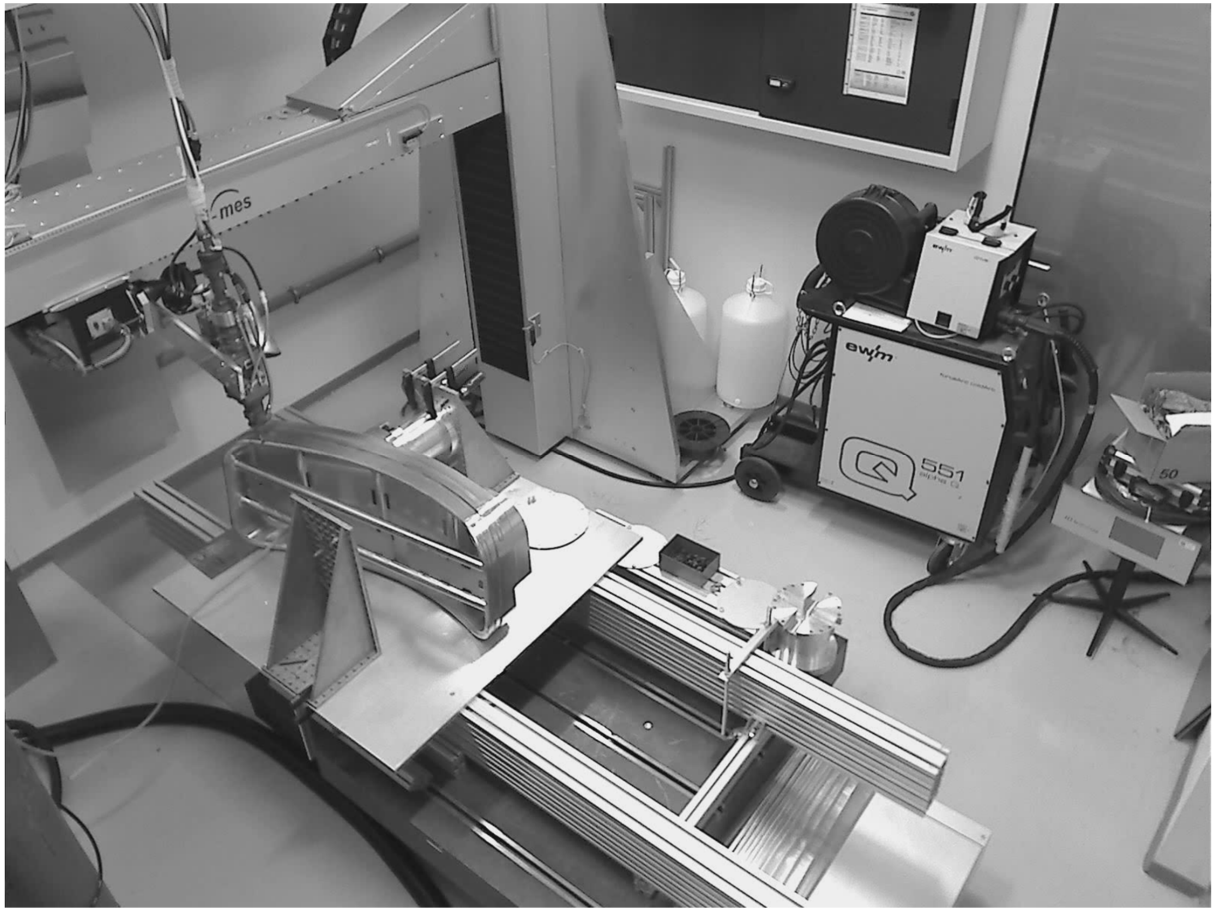
ICRH antenna – fabrication

- Material: ca. 1 ton stainless steel with very low magnetic permeability (1.4429)
  (90 % of the metal is converted into metal chips)
- CAD/CAM technologies
- Special joining technologies
- Metallography
- Surface technologies
- Automatization

PLASMA HEATING FOR NUCLEAR FUSION

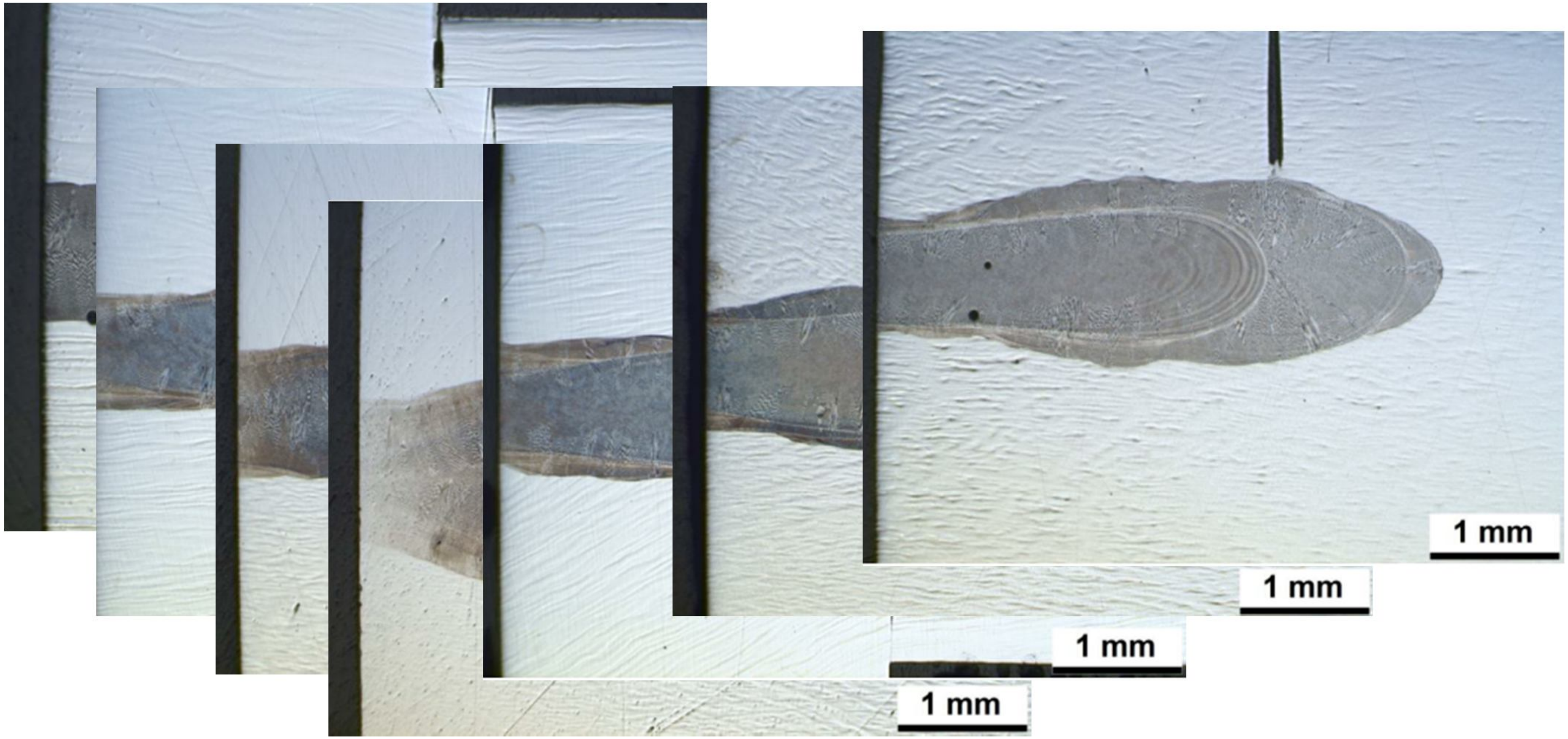
ICRH antenna – joining technologies

Laser beam welding



PLASMA HEATING FOR NUCLEAR FUSION

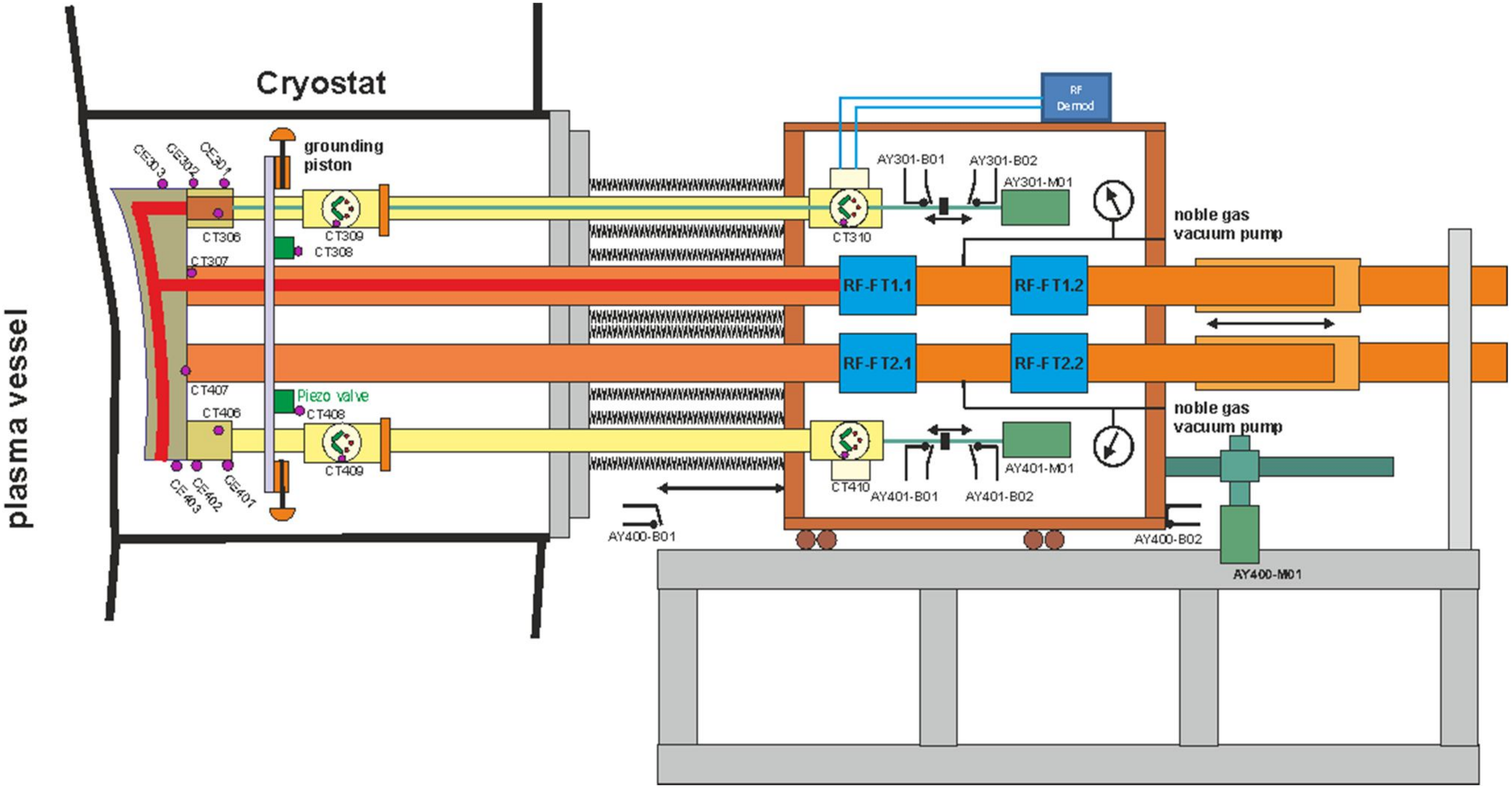
ICRH antenna - metallography



Example of ships of different weld seams
He leakage test show leakage rates ≤$1 \cdot 10^{-9}$ mbar·l/s

PLASMA HEATING FOR NUCLEAR FUSION

ICRH antenna - automatization



SUMMARY

ZEA-1 is specialized in the design, construction and fabrication of unique instruments and setups for world class science

Thank you very much for your attention