INSTITUTE OF PLASMA PHYSICS
OF THE CZECH ACADEMY OF SCIENCES

ECRH system for COMPASS-U

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

IPP COMPASS INSTITUTE OF PLASMA PHYSICS ASCR

Institute of Plasma Physics

IPP (www.ipp.cas.cz)
- Founded in 1959 (64 years ago)
- Actual director: **Radomir Panek**
- IPP has 3 Divisions and >400 employees

Fusion Plasma Division
(former TOKAMAK department)
- Head: **Martin Hron**
- Deputy: **Michael Komm**
- Created in 1977 (46 years ago)
- Has ~100 employees
- 3 departments:
    - High-Temperature Plasma Physics Dpt. (Michael Komm)
    - Theory and Modelling Dpt. (David Tskhakaya)
    - Technological Development Dpt.(Josef Havlicek)
- Devices:
    - CASTOR (GOLEM) 1977-2006
    - COMPASS 2006-2021
    - COMPASS Upgrade 2026 on

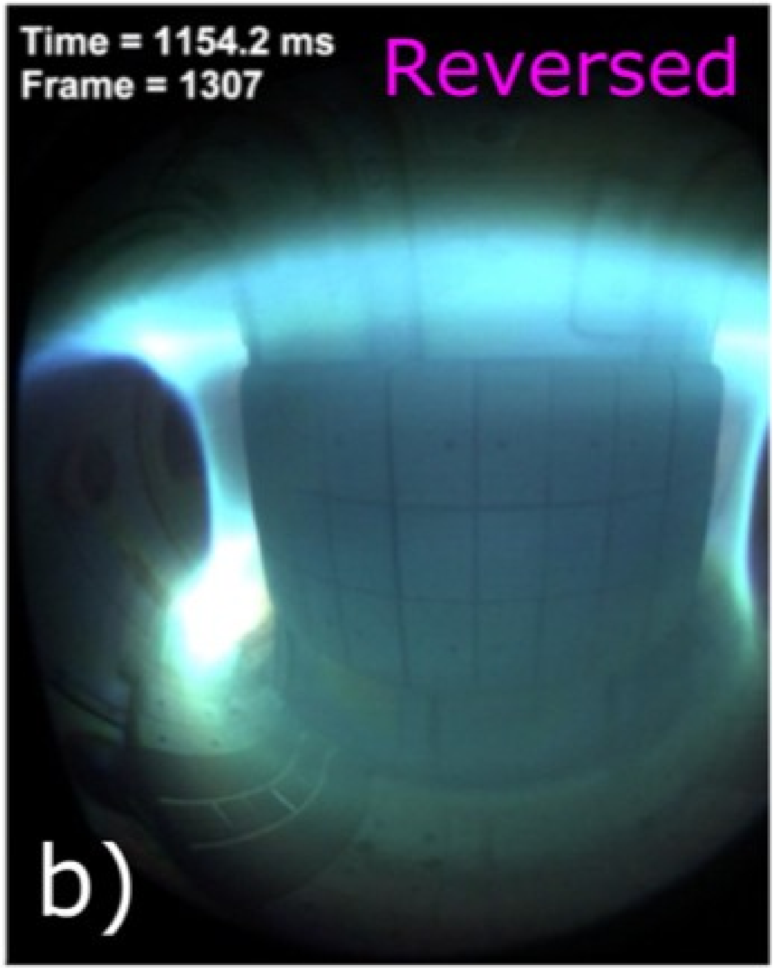
COMPASS

COMPASS was operated in the IPP CAS since 2009 and it was shut down in August 2021. COMPASS was one of few devices with an **ITER-like plasma shape**. Its **flexibility**, extensive set of **diagnostics** and **NBI** contributed in closing the gaps of key issues in fusion research in support of **ITER** and **DEMO**, such as

- edge and SOL physics
- L–H transition
- runaway electrons
- disruption studies
- plasma-wall interaction

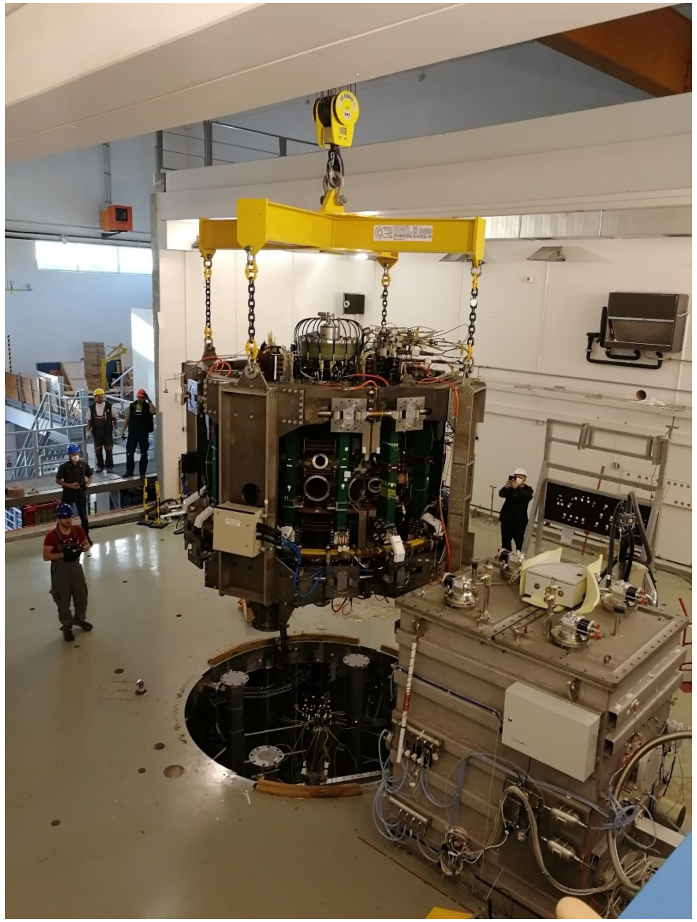
COMPASS was very effective for testing new ideas and concepts in the area of **plasma control** and **diagnostics development**, which were implemented on larger devices.

“Overview of the COMPASS results, ”M. Hron, Nucl. Fusion 62 042021 (2022)



COMPASS

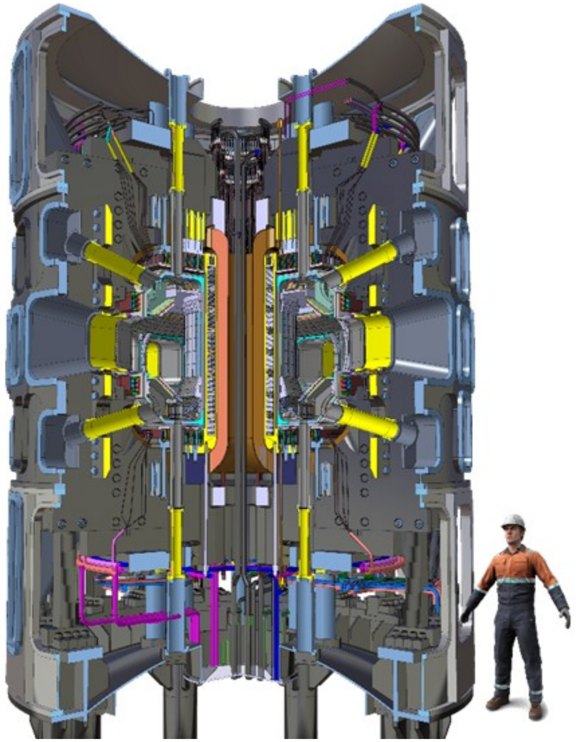
COMPASS officially ended its operation in August 2021, after more than 20k discharges

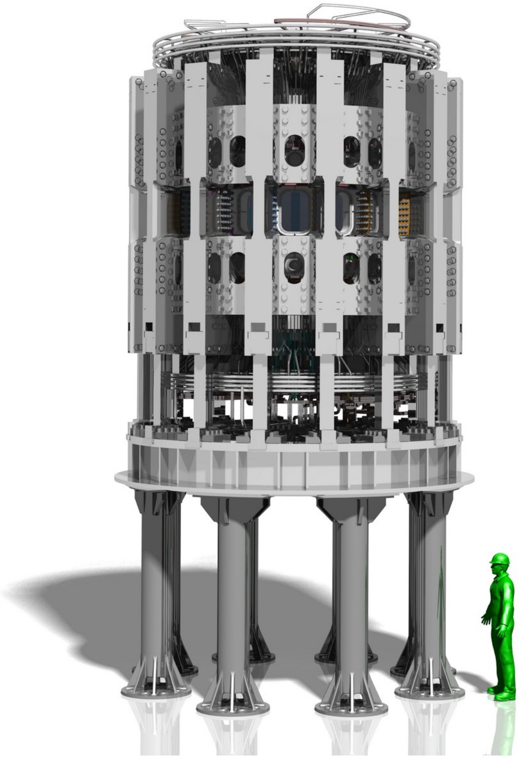


COMPASS-U

- **Project status**: final design review, tenders
- **Individual systems:**
  - Cryostat
  - Support structure
  - TF coils
  - PF coils + central solenoid
  - Vacuum vessel
  - Plasma facing components
  - Cryogenics
  - Power supply system
- **Plasma heating:** NBI, ECRH
- **Diagnostics design:** ongoing

- **Timeline** of the project:





2024 | 2025 | 2026 | 2027

Manufacturing of main components (2024–2026)

Assembly and installation (2024–2026)

Integrated commissioning (2025–2027)

COMPASS-U

Main parameters

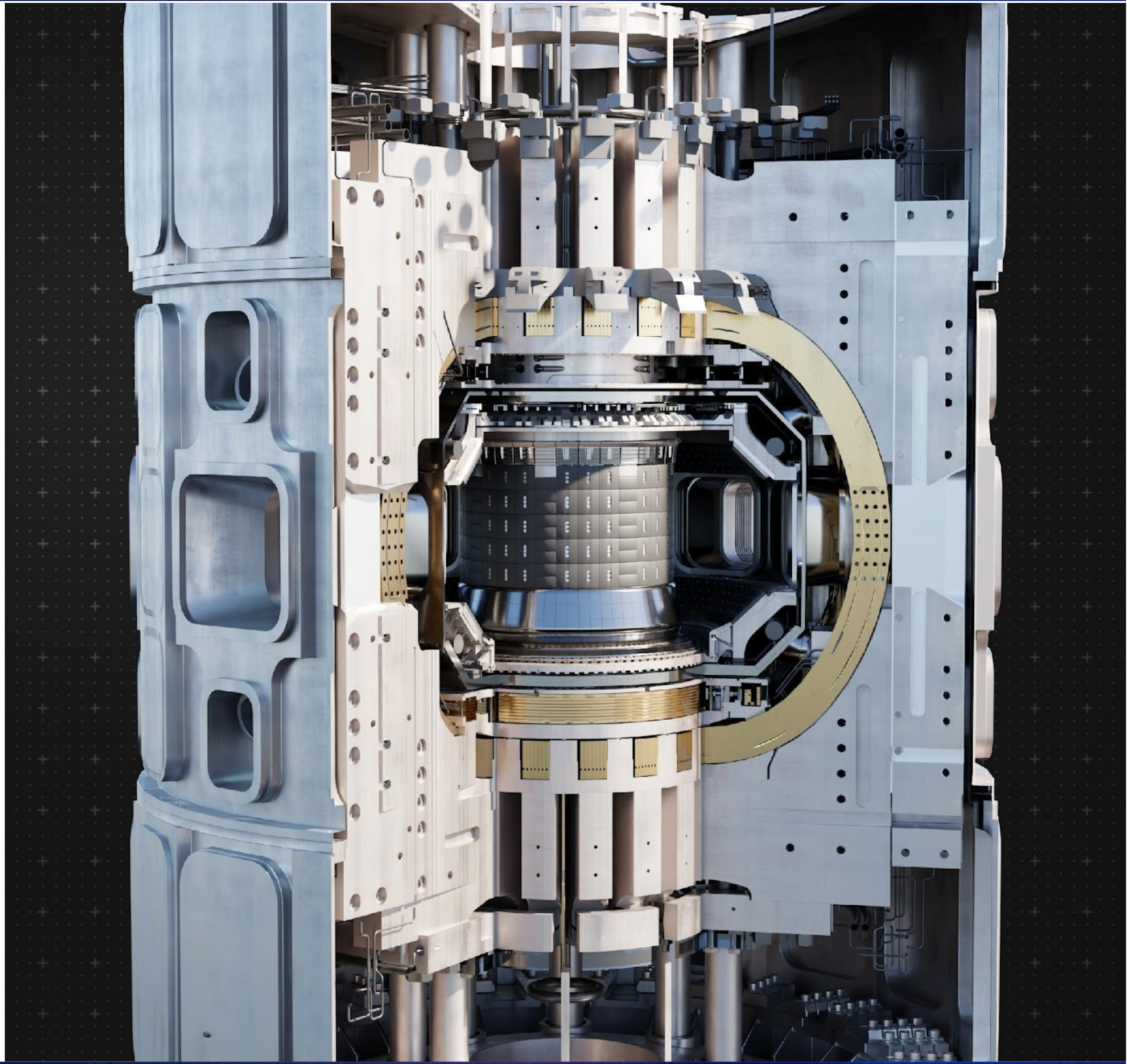
- Toroidal magnetic field $B_t = 5$ T
- Plasma current $I_p = 2$ MA
- Major radius $R_g = 0.894$ m
- Minor radius $a = 0.27$ m
- Aspect ratio $A = 3.3$
- Triangularity $\delta = 0.3\text{-}0.6$
- Elongation $\kappa = 1.8$
- Enough space for different divertors
- Metallic first wall
- Vacuum vessel operation temperature up to 300°C (goal 500°C)

Plasma shapes

- single lower null, neg. triangularity with limited parameters (Phase 1-2)
- double null (Phase 2-3)
- snowflake, negative triangularity (Phase 3-4)

Plasma heating power

- Phase 1 P_{NBI} >= 3 MW, $P_{ECRH} = 1$ MW (P*B/R ~ 25)
- Phase 2 up to $P_{NBI} = 8$ MW, $P_{ECRH} = 10$ MW (P*B/R ~ 100)



Infrastructure

Planned construction works

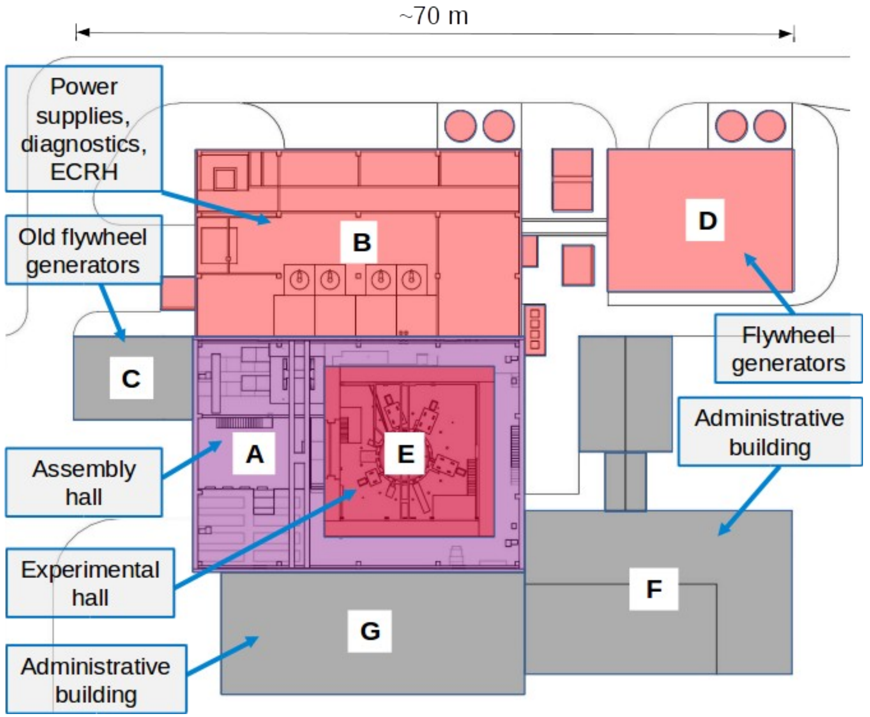
Phase 1:

- modification of the existing experimental hall
- Additional 90 cm of concrete (1.5 m in total)
- New 0.8 m thick base concrete slab
- new concrete floor, new concrete ceiling
- Additional steel floor in the assembly hall

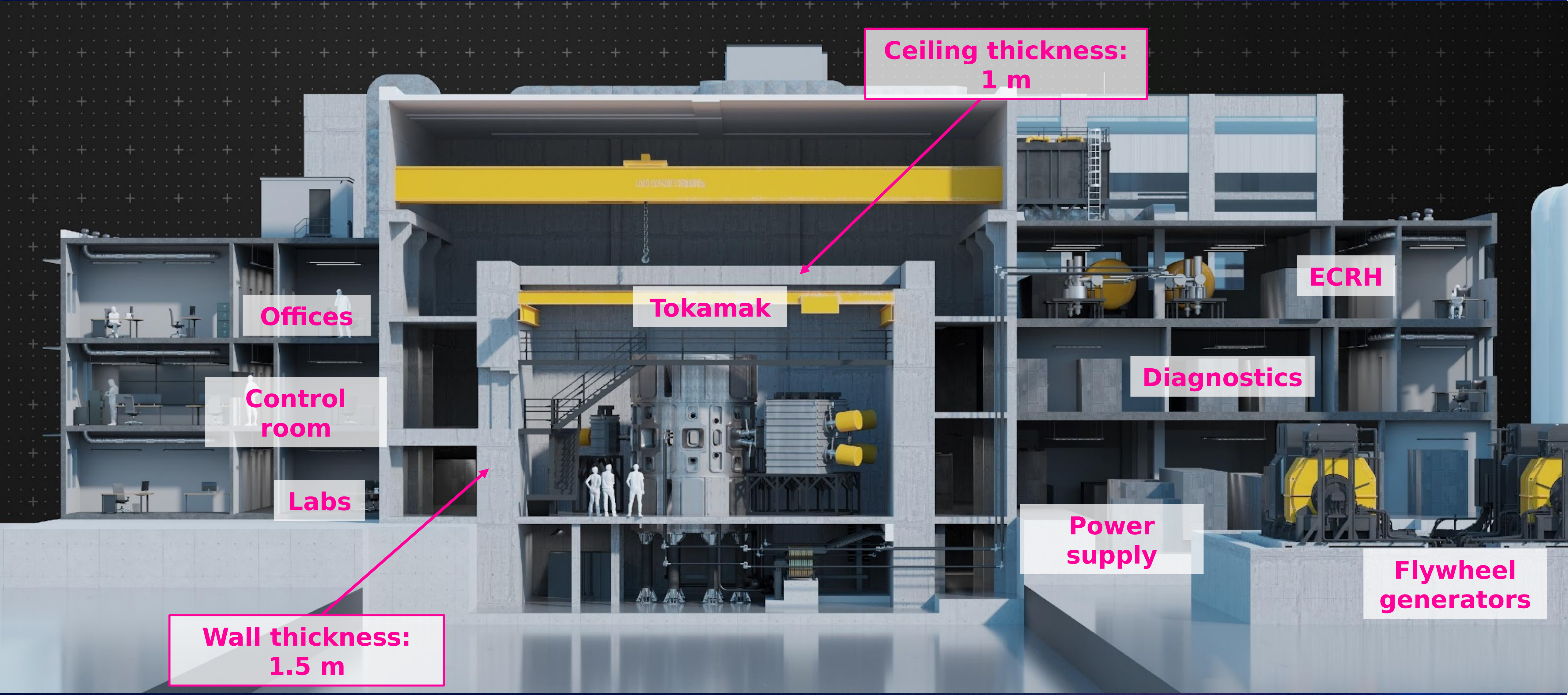
Phase 2:

2023-2024

- New hall for power supplies, diagnostics and ECRH
- New hall for flywheel generators
- New liquid nitrogen reservoirs, cooling stations, transformers etc.



Infrastructure



ECRH system

Specifications for the components of the ECRH system

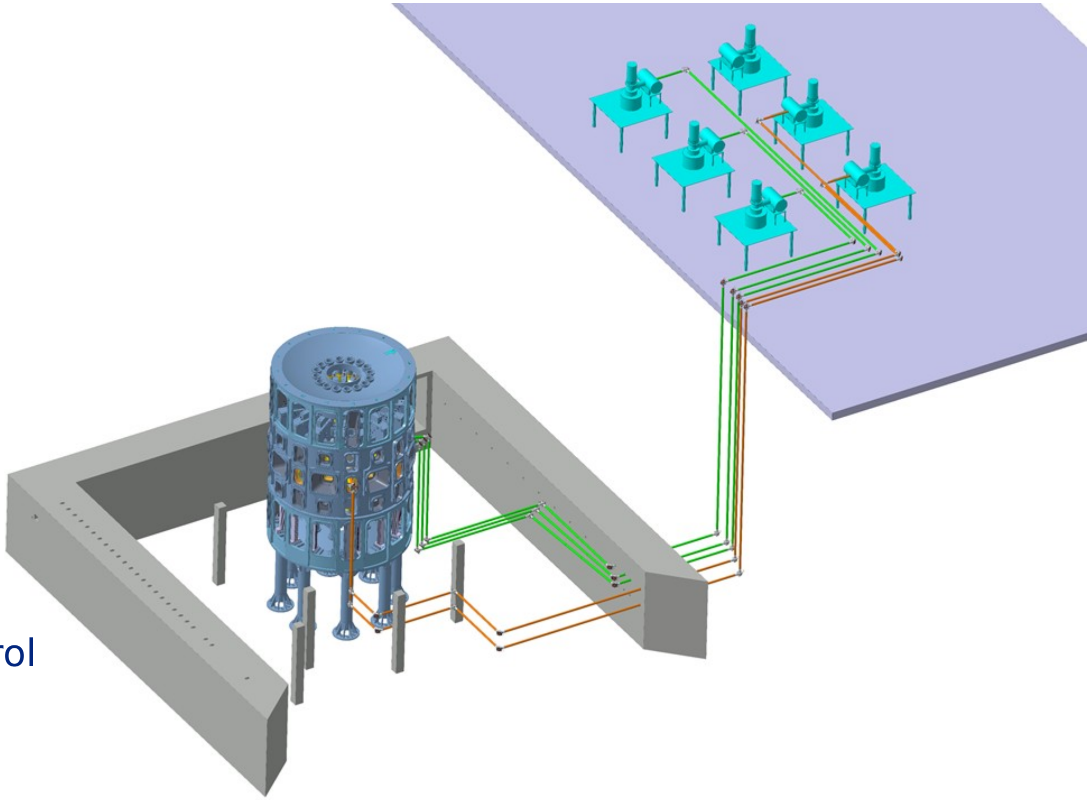
Gyrotrons:
multiple freq, 140 GHz main, possibly also 105, 170
>1MW, ~10 s pulse length

Waveguides: 63.5 mm diameter, total length < ~30 m

Launchers: large equatorial port, steering mirrors

Deposition on-axis is achieved for B_t 2.5 and 5 T

Control system, sniffer probes, arc detectors



Main **physics applications** of ECRH system:

Central power deposition for central plasma heating

Assisted **plasma breakdown**

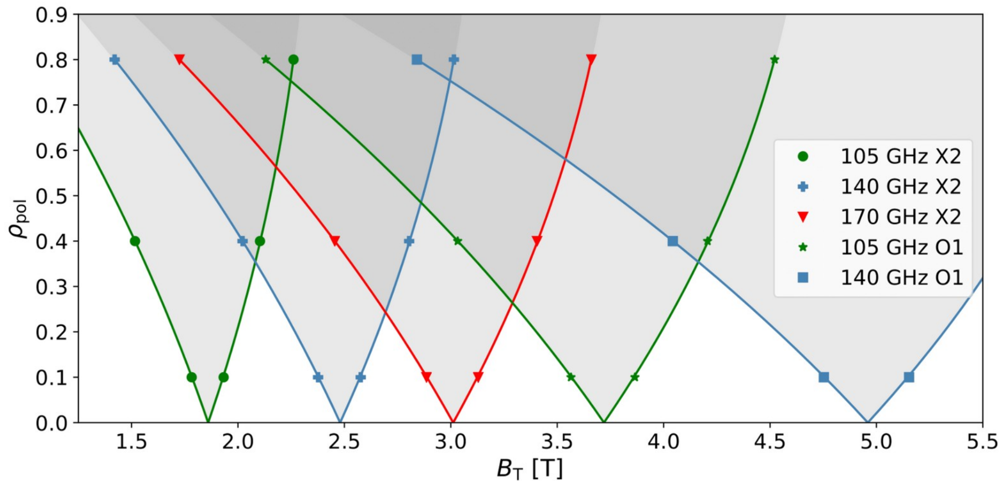
Control of MHD instabilities by ECCD and current profile control

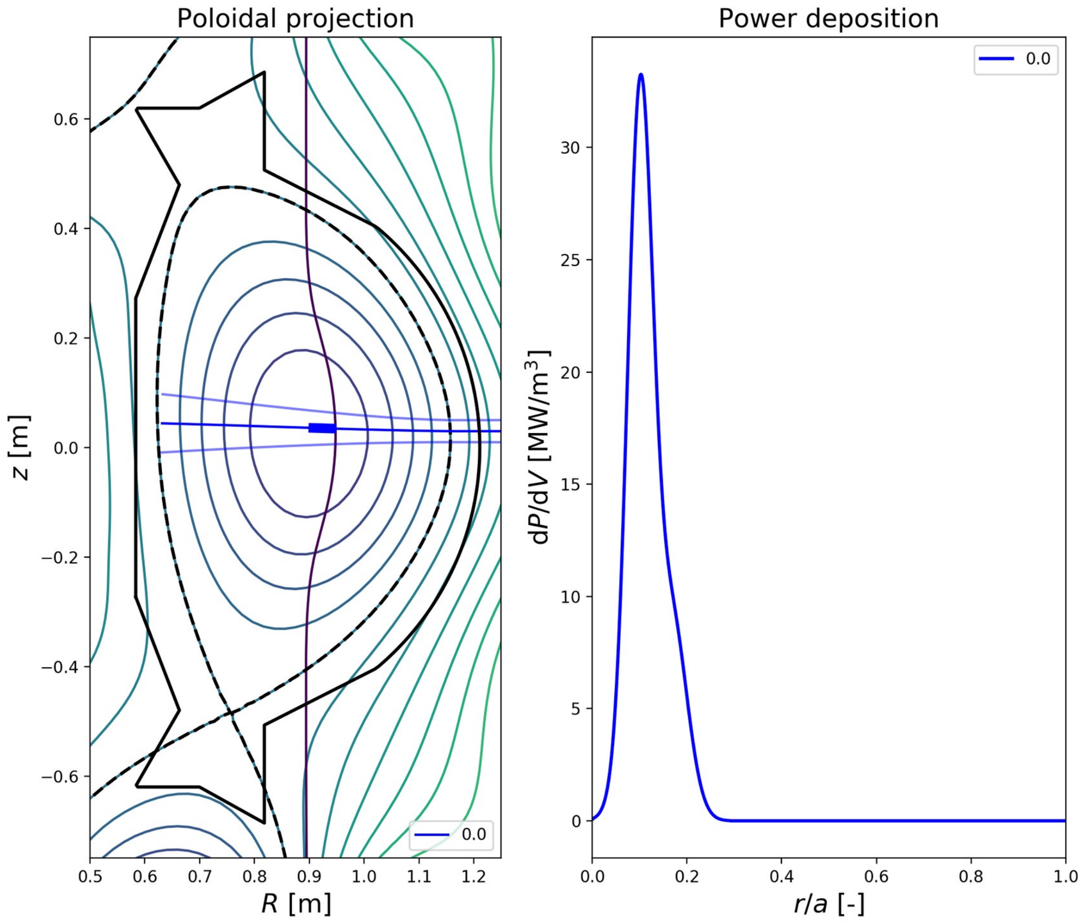
Prevent heavy **impurity accumulation** in the core

Heating strategies

B_t [T]	⟨n_{co}⟩ [m^{-3}]	Operation mode	f [GHz]
2.5	$1.1x10^{20}$	X2	140
3.0	$1.7x10^{20}$	X2	170
3.8	$1.3x10^{20}$	O1	105
4.3	$2.0x10^{20}$	O1, toroidal steering	140
5	$2.3x10^{20}$	O1	140

Different frequencies allow wave deposition with different magnetic fields and at different radial locations





HVPS and control system

HVPS for ECRH will be placed on ground level of new building (see slides 7-8)

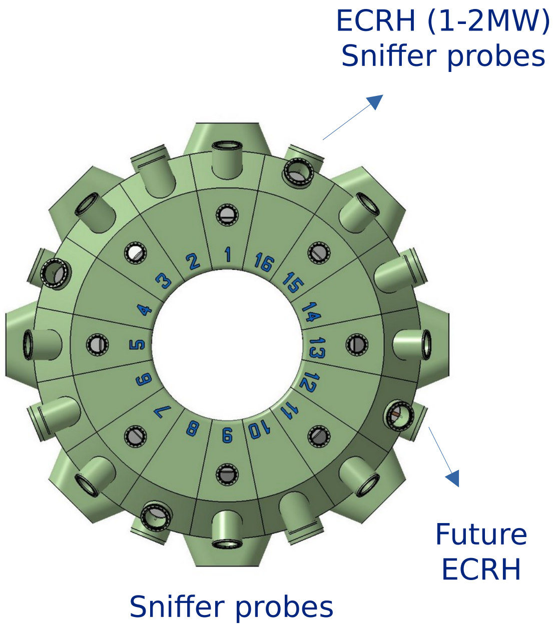
The system must be equipped with real-time control for failures

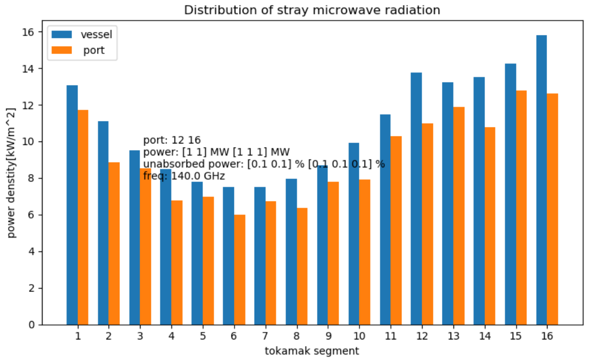
- sniffer probes will detect stray radiation in the plasma volume
- arc detectors will be installed in critical points along the transmission line

Sniffer probes and arc detectors represent the main interlock systems

Additional control parameters:

- polarization measurements in dedicated miter bends and at mirrors
- control of voltage in power supply and body current (at gyrotron)





Prepared proposal

We submitted a new project which will be evaluated soon

- Includes investment funding for the new ECRH system
- Evaluation in progress: expected for the end of the year
- Proposal contains:
  - 1+ MW multifrequency gyrotron for 140 GHz
  - transmission line, launcher
  - power supply
  - related diagnostics, auxiliaries, etc.

2024 | 2025 | 2026 | 2027 | 6/2028

Development and design of the ECRH system

Tendering and delivery of the ECRH components

Commissioning and integration

Operation with ECRH

Specifications

Summary of the requirements for the gyrotrons

- Multifrequency system necessary
  Main frequency 140 with extension (105, 170 GHz)
- Nominal output power 1-1.5 MW at 140 GHz
  as much power as possible in the other frequencies
- Pulse length 5 - 10 s
- Duty cycle 2 %
- Mode purity >95 % at the end of MOU (how high can you reach?)
- Frequency variation ± 0.5 GHz and stable during discharge
- Efficiency at maximum output power >45 % at 140 Ghz (how high can you reach?)
- Power modulation 1 kHz (up to 25 kHz) (how high can you reach?)

Specific questions

- What is the surface occupation by one single gyrotron and the recommended distance between gyrotrons?
- Will you provde specifications for water consumption and pressure for gyrotron cooling circuits?
- What is the maximum tolerance for stray magnetic field (vertical and horizontal components)?
- Will the auxiliary power supply, cooling circuit and MOU be provided together with the gyrotron?
- Does the magnet comes with the coldheads and compressor? And the MOU with the diamond windows?
- What kind of warranty service and support can you provide?
- Do you provide service and support after the warranty?
- What bank guarrantees (for execution of the Object, for warranty of the Object) are acceptable?
- What contract penalties (to be proposed by the Buyer) are acceptable?
- What is the life expectancy of the main components?
- In what form do the SAT and FAT tests take place?
- On what parameters are you able to perform FAT (power, pulse length)?
- How do you perform measurements of output power and mode purity?
- What parts of the control system and interlocks are delivered with the gyrotron?
- Is some training for technicians, for use and maintenance of the gyrotrons, included

Extra: stray magnetic field