INSTITUTE OF PLASMA PHYSICS
OF THE CZECH ACADEMY OF SCIENCES

COMPASS
INSTITUTE OF PLASMA PHYSICS ASCR

PRELIMINARY CONCEPTUAL DESIGN OF THE COMPASS UPGRADE ECRH HEATING SYSTEM

O. Bogar[1], M. Farnik[1,2], A. Casolari[1], E. Tomesova[1], M. Mohelnik[1], J. Havlicek[1], M. Hron[1] and R. Panek[1]

[1] Institute of Plasma Physics of the CAS, Prague, Czech Republic
[2] Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, Prague, Czech Republic

bogar@ipp.cas.cz

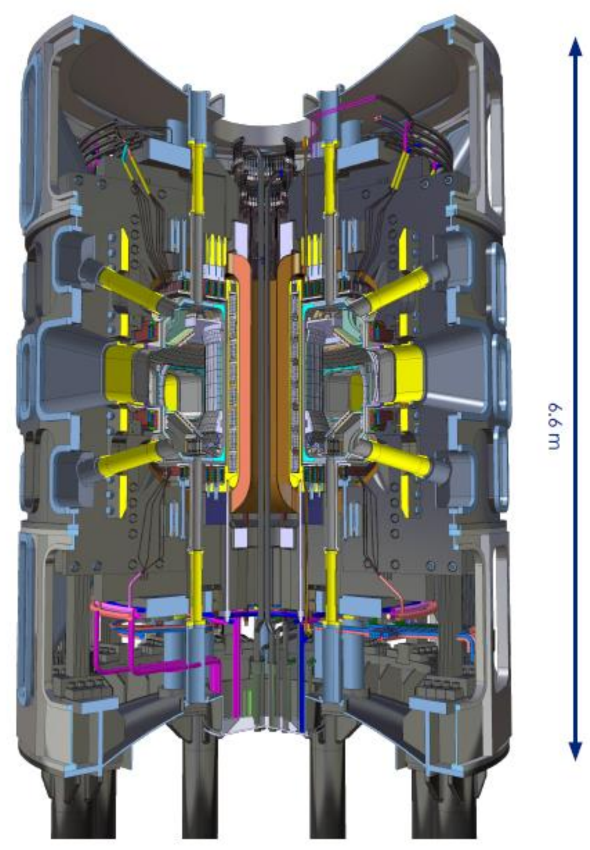
COMPASS UPGRADE

COMPASS upgrade tokamak is currently under design and construction. First plasma end of 2025. **[Vondracek et al., Fusion Eng. Des. 2021]**

Major radius: **0.9 m**
Minor radius: **0.27 m**
Toroidal magnetic field: up to **5 T**
Plasma current: **2 MA**
Flap top: **1-10 s** (**3 s** for 5T and 2 MA scenario)
Line average density: **≈ 2.8×10²⁰ m⁻³**
Central electron temperature: **≈ 4 keV** (up to **7 keV**)

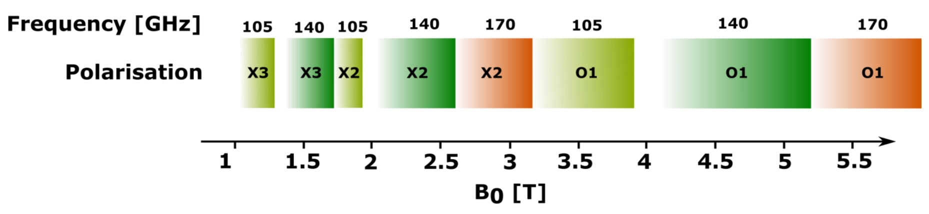
Additional heating
NBI: 3 units with 2 ion sources => **3-6 MW**
ECRH: 2 equatorial ports for heating => **2-6 MW**
incline port for NTM suppression => **1 MW**

Scientific program
edge plasma physics and advance confinement mode research
NTM studies and suppression technique
Runway electrons generation and mitigation
Test of liquid metals divertor concepts
Hot first wall operation (up to 500 °C)



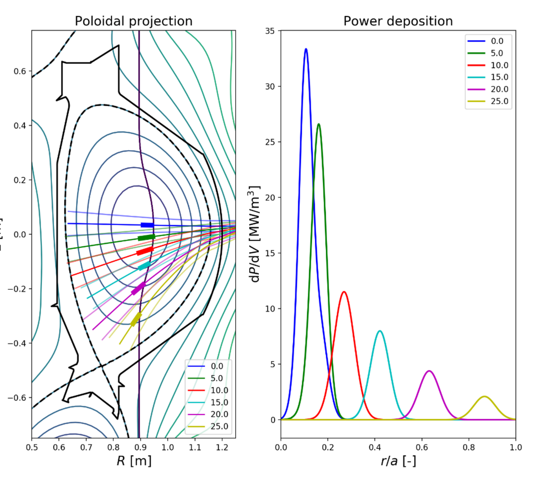
ECRH HEATING SYSTEM

The wide range of toroidal magnetic filed forces us to compose ECRH as a versatile system with different gyrotron frequencies. Inspired by the experiences from TCV, ASDEX, W7-X, KSTAR



Main goals of ECRH system:
core and off axis heating, impurity management, NTM control, assisted breakdown

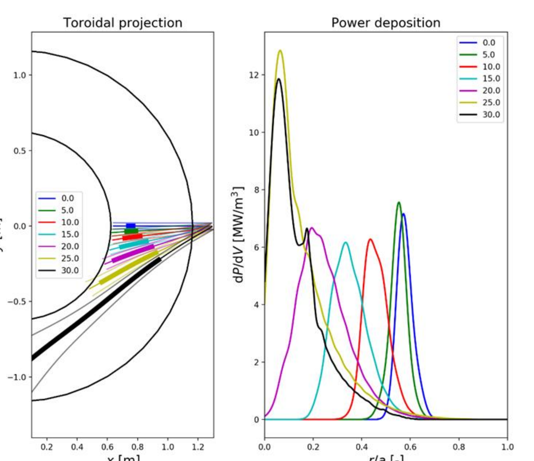
First plasma operation ≈ 3T and full performance at 5T



140 GHz, O1 mode, 5 T, 2 MA, 1.8 × 10²⁰ m⁻³

The reference gyrotron:
1 MW power for **1-3 s** pulse
Gausian output fraction > 95%
Cryogen-free technology of magnet, with a cryo-cooler

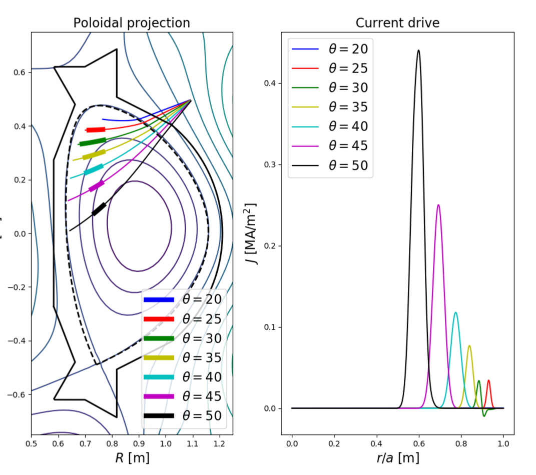
- **105/140 GHz** dual frequency gyrotron
- **170 GHz** gyrotron
- **200+ GHz** gyrotron (DEMO relevant frequency)



140 GHz, O1 mode, 4.3 T, 1.4 MA, 1.5 × 10²⁰ m⁻³

Total power delivered to the plasma will be different for each scenario and depends on the available number of gyrotron with adequate frequency.
Toroidal steering is necessary for 140 GHz, O1 at ≈ 4.5 T.
With the gyrotron available on the market it is not possible to employ ECRH system during the 5T, high density H mode. ECRH is limited by the cut off density
O-mode: **cutoff density ≈ 2.5 × 10²⁰ m⁻³**

For more details see poster of M. Farnik



140 GHz, O1 mode, 4.3 T, 1.4 MA, 1.8 × 10²⁰ m⁻³

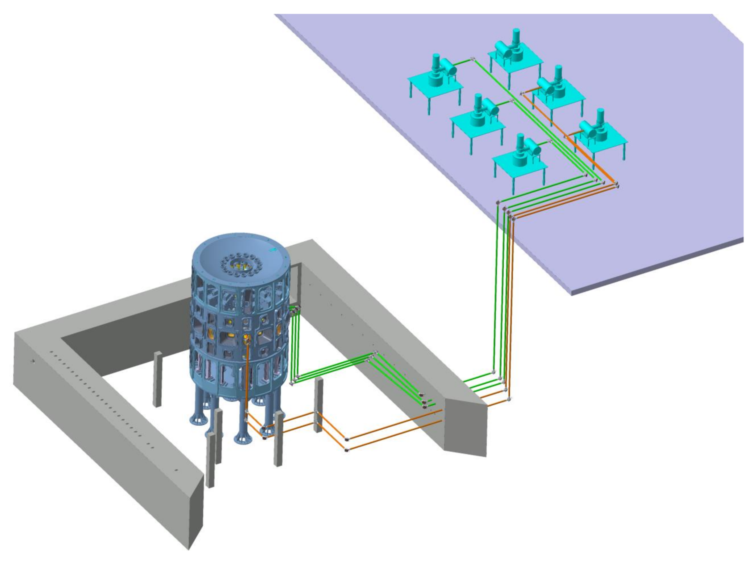
	105/140 GHz gyrotron					
Magnetic field	**1.2T**	**2.5 T**	**3 T**	**3.5 T**	**4.5 T**	**5T**
Mode	105 GHz, X3	140 GHz, X2	105 GHz, O1	105 GHz, O1	140 GHz, O1	140 GHz, O1
Density limit [m⁻³]		**0.8×10²⁰**	**1.4×10²⁰**	**1.4 × 10²⁰**	**2.5×10²⁰**	**2.5×10²⁰**
ρ<0.3, w/o steering	only 30% absorption					
ρ<0.3, with steering						
0.6 <ρ<0.9, w/o steering						
0.6 <ρ<0.9, with steering						

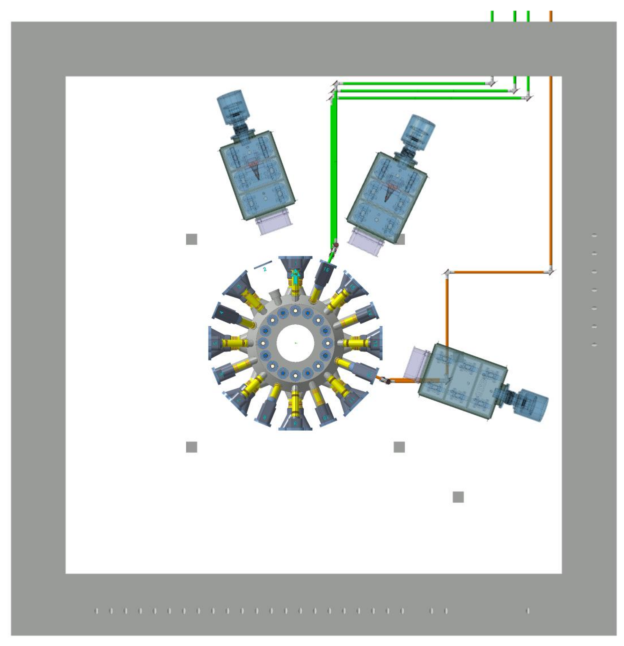
170 GHz Gyrotron		
2.5 T	**3 T**	**5 T**
170 GHz, X2	170 GHz, X2	170 GHz,O1
3.5×10²⁰	**3.5×10²⁰**	**3.5×10²⁰**

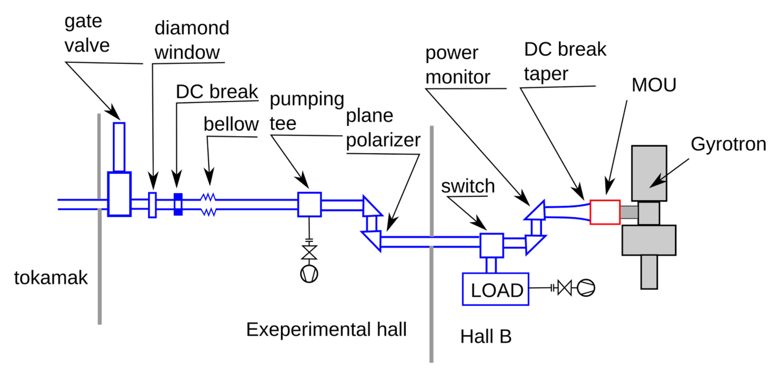
TRANSMISSION LINE

Sectors allocated for ECRH are the midplane narrow ports #16 and #12

Gyrotrons will be located on the third floor of the new building. Waveguides will enter the hall from the floor bellow and will reach the tokamak from below.





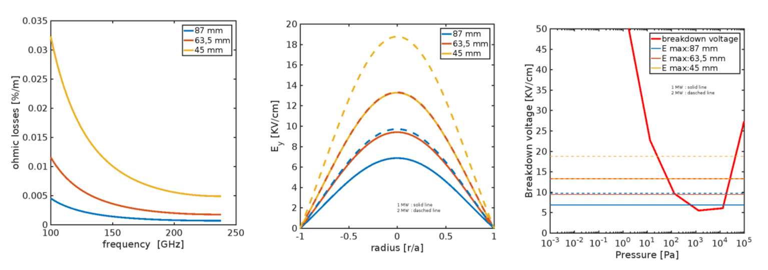


Transmission line components placement

	length [m]	miter bend	losses [%]
Port # 16	40	8	~4,5
Port # 12	47	9	~4,8

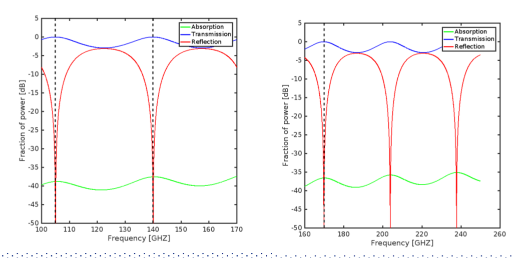
Waveguide:
Evacuated corrugated waveguide: optimizes for the 140 GHz, period: 0.63 mm ($0.3*\lambda_{140}$), depth 0.52 mm, width 0.44 mm
material Aluminium and SS

waveguide ohmic losses	0.004 % / 1m
MOU losses of axial offset (2 mm)	0.9 %
MOU losses of tilted (0.2 deg)	1 %
Misalignment losses of axial offset (2 mm)	1. %
Misalignment losses of tilted (0.2 deg)	1.1 %
Miter bend ohmic losses	0.25 % (E plane), 0.07 % (H plane)
Miter bend mode conversion losses	0.07 %
Polarizer ohmic losses	0.5 % (E plane), 0.14 % (H plane)
gap losses (below, pumping tee)	0.008 % (25mm) 0.002 % (2,5mm) 0.2 % (50 mm)

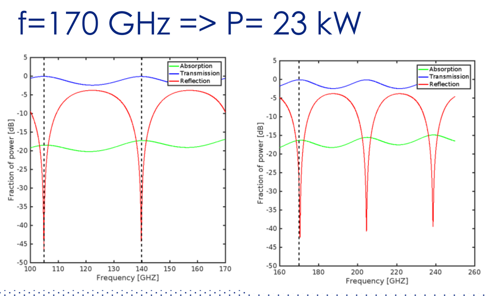


Losses, electrical field and breakdown voltage for different waveguide diameter and 140 GHz.

CVD diamond disc
d=1.8 mm/1.85 mm, $\tan\delta = 1 \times 10^{-5}$, $\varepsilon = 5.67$
f=105 GHz => P= 130 W, f=140 GHz => P= 180 W
f=170 GHz => P= 220 W

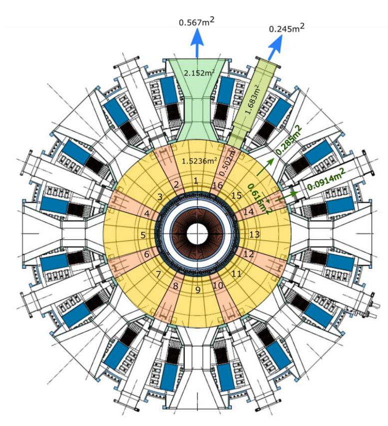


BN disc
d=1.98 mm/2.03 mm, $\tan\delta = 115 \times 10^{-5}$, $\varepsilon = 4.7$
f=105 GHz => P= 14 kW, f=140 GHz => P= 18 kW
f=170 GHz => P= 23 kW



STRAY RADIATION

After multiple reflections of the unabsorbed beam from vacuum vessel and plasma, stray microwave radiation builds up. During the flat-top phase, a polarization mismatch of the launched wave is the main source of stray microwave radiation.



Main materials inside vacuum vessel: Inconel 625 and 718, SS 316, Tungsten

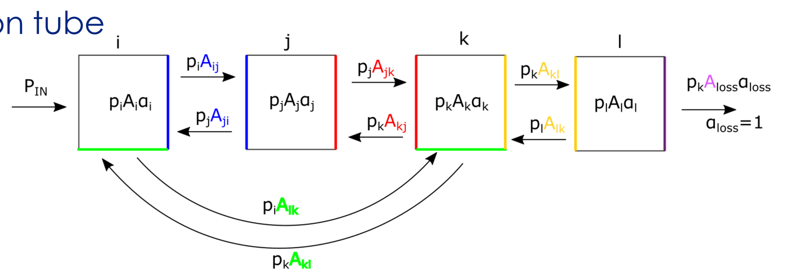
Power balance in multi cell model

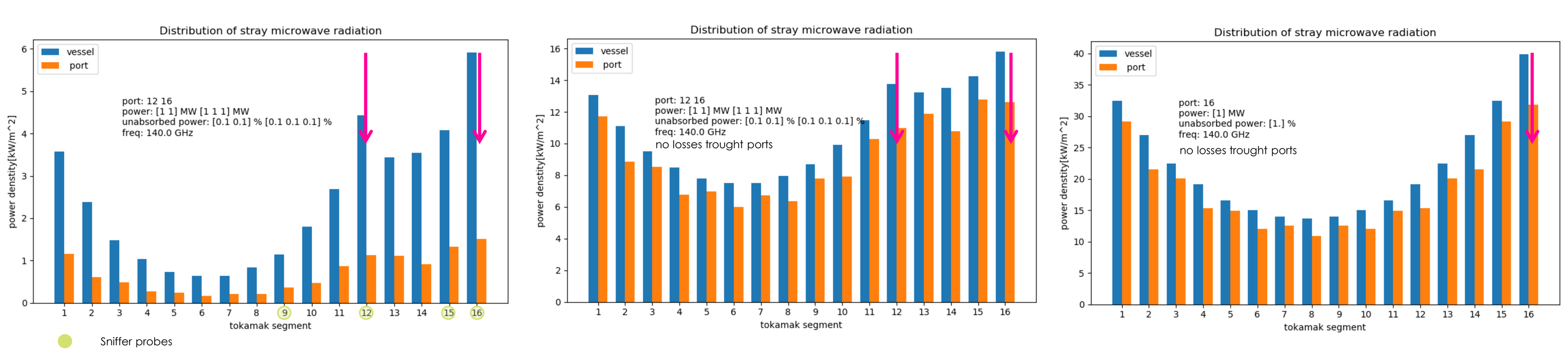
16 cell for invessel sector + 16 cells fot port extension tube

$$(P_{in})_j + \sum_{bordering} p_n A_n = p_j \sum_{bordering} A_n + p_j \sum_{bordering} L_n$$

$$L = A_{loss} + \beta A_{wall} + \alpha A_{plasma}$$

$$\vec{B} \cdot \vec{p} + \vec{L} \cdot \vec{p} = \overrightarrow{P_{in}} + \hat{A} \cdot \vec{p}$$





EUROPEAN UNION
European Structural and Investment Funds
OP Research,
Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS

The authors would like to acknowledge the valuable and significant help from the ECRH group members at the ASDEX and W7-X

This work has been carried out within the framework of the project COMPASS-U: Tokamak for cutting-edge fusion research (No. CZ.02.1.01/0.0/0.0/16_019/0000768) and-funded from European structural and investment funds.