INSTITUTE OF PLASMA PHYSICS OF THE CZECH ACADEMY OF SCIENCES

COMPASS INSTITUTE OF PLASMA PHYSICS ASCR

CONSTRAINTS OF ECRH FOR HIGH-FIELD AND HIGH-DENSITY TOKAMAK COMPASS-U

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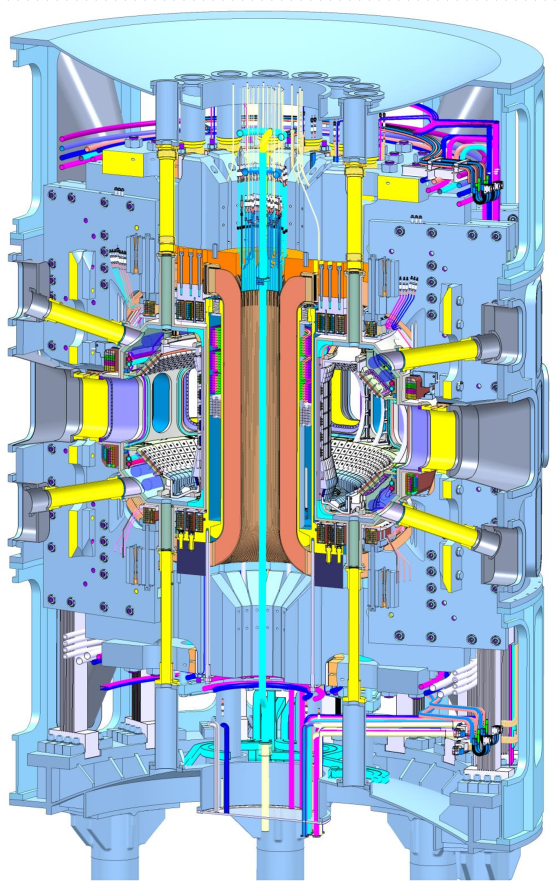
INTRODUCTION



COMPASS-U is a new device in IPP Prague (start 2025)
Compact flexible tokamak with parameters relevant to next step devices
DEMO relevant research

R_0 = 0.894 m, a = 0.27 m, $\mathbf{B_T}$ **= 5 T**, I_p = 2 MA

$t_{flattop}$ = 1-5 s, n_{GW} = 8.3·10^{20} m^{-3}

P_{NBI} = 3-6 MW, $\mathbf{P_{ECRH}}$ **= 2-6 MW**

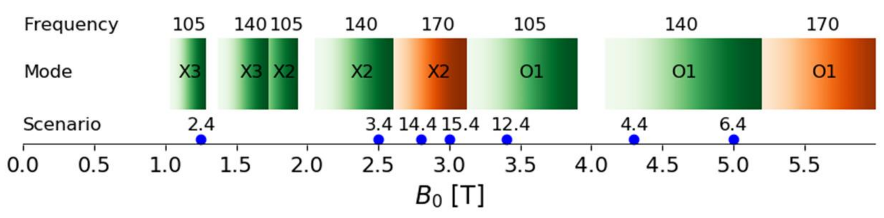
Extreme power fluxes up to 100 MW/m^2 - liquid metal technology
Operation with high temperature first wall – up to 500°C

Program:
Conventional divertors
Edge plasma physics and confinement related activities
Test of advanced PFC materials in the divertor
Test of liquid metals divertor concepts, hot wall operation
Advanced divertor concepts

ECRH FOR COMPASS-U

1st harmonic heating (high B)
→ Higher harmonic heating not possible

Difficult to develop a versatile ECRH system
→ **140/105 GHz tunable** gyrotrons



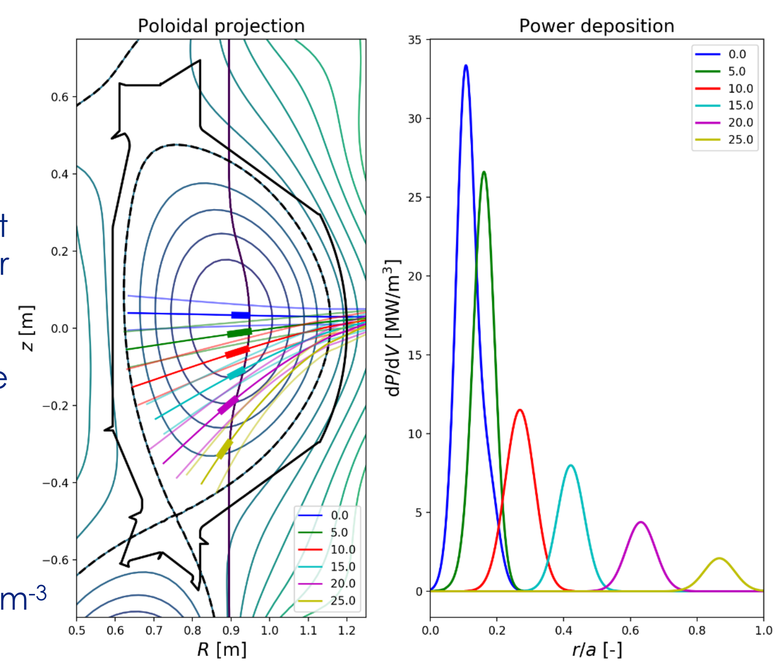
O-mode: **cutoff density ≈ 2.5·10^{20} m^{-3}**
X-mode: only for 2nd harmonic heating (2.5 T)

Far future **upgrade for 200+ GHz** tubes

Natural H-mode density (type I ELMy H-mode) not understood enough to make reliable predictions for COMPASS-U.

Due to expected fraction of Greenwald in H-mode flattop $\mathbf{I_p}$ **should be lowered** to avoid cutoff.

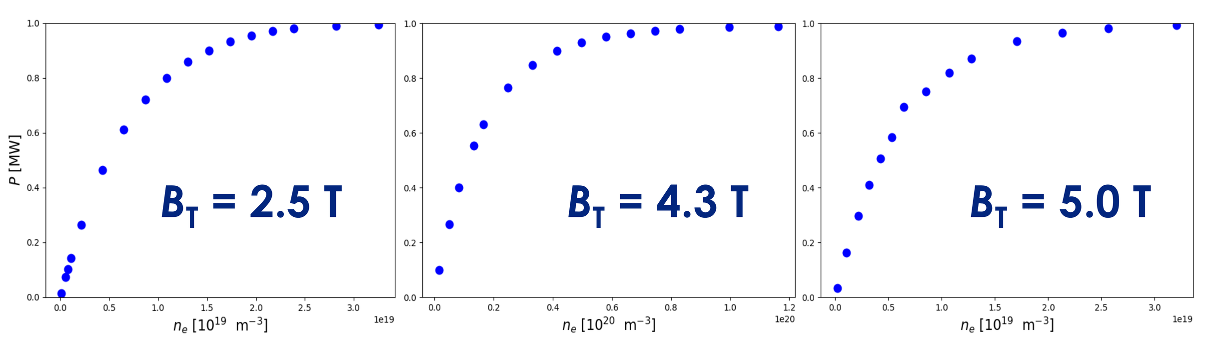
For more details see poster of O.Bogar



140 GHz, O1 mode, 5 T, 2 MA, 1.8·10^{20} m^{-3}

TORBEAM SIMULATIONS

Shinethrough and absorption efficiency



>98 % absorption in relevant densities no imminent threat of shinethrough during ordinary operation

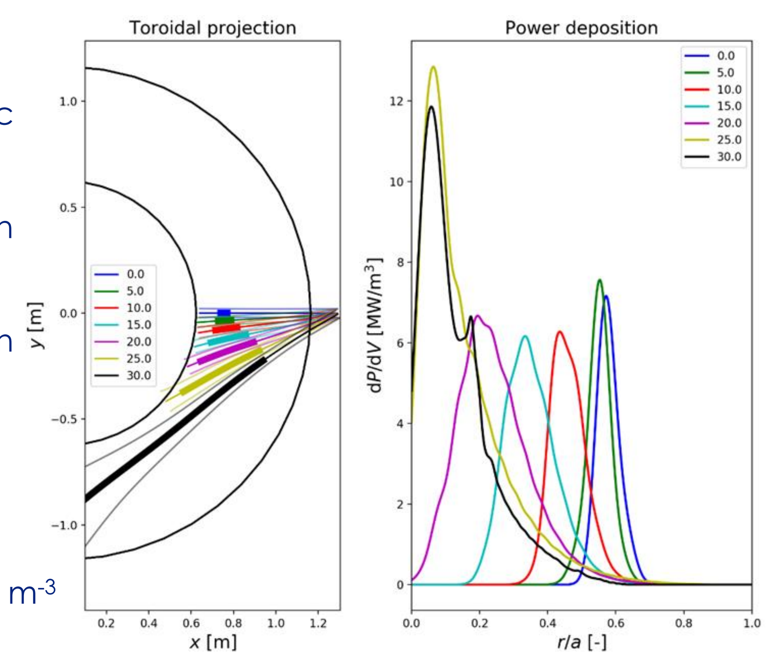
Low magnetic field (1.25 T) scenario **cannot be heated** via X3 harmonic. Only 30 % absorbed power

Regions of absorption

Poloidal angle enables target specific magnetic surface

Toroidal angle can shift the resonance region towards LFS

Electron temperature largely influences absorption region width in toroidal angle injection



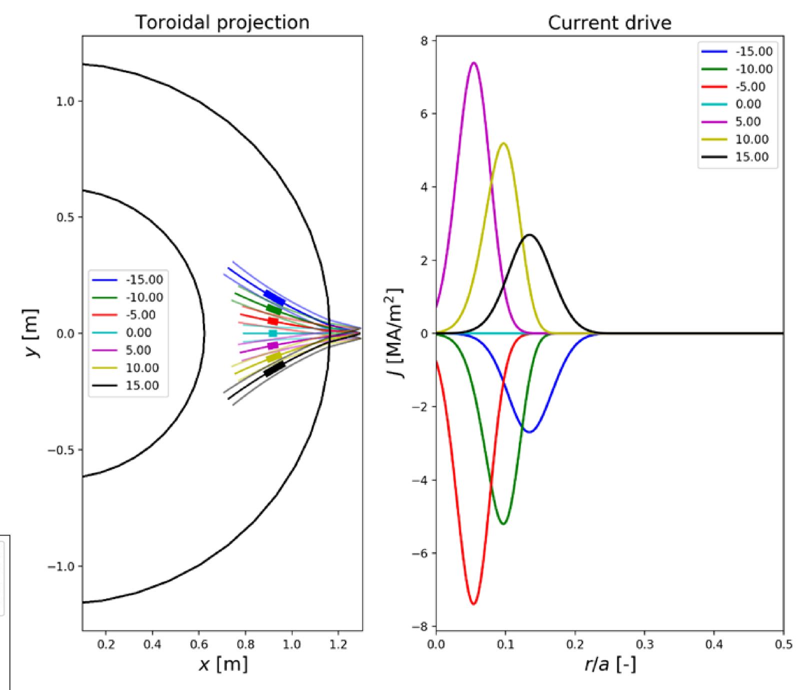
140 GHz, O1 mode, 4.3 T, 1.4 MA, 1.5·10^{20} m^{-3}

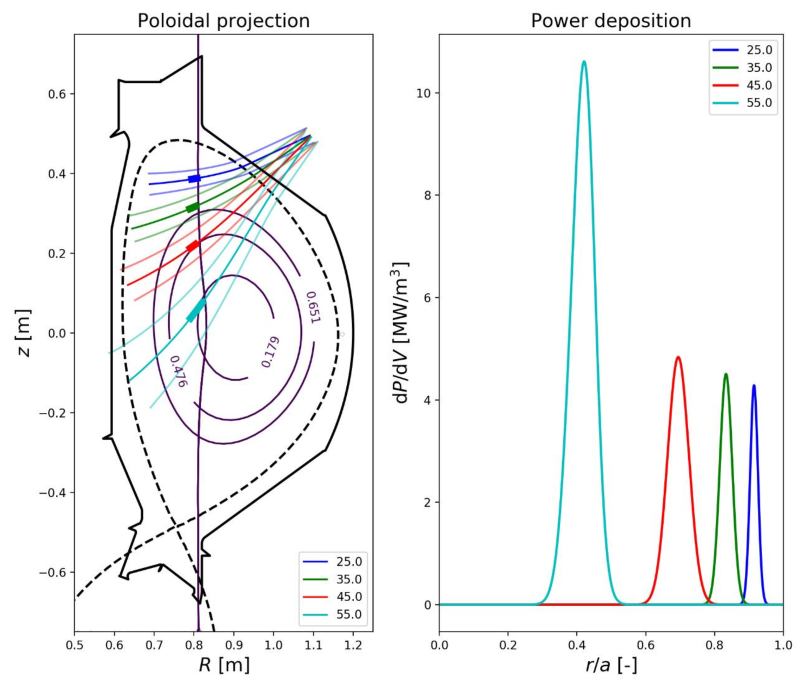
OTHER FEATURES

Current profile tailoring

Co- and counter-current injection for the profile tailoring

Max I_{ECCD} around 50 kA (approx 3 % of I_p)





NTM suppression

Possibility of 3/2 and 2/1 tearing mode mitigation is being investigated.

j_{ECCD}/j_{boot} = 0.1-0.5

When j_{ECCD}/j_{boot} not sufficient power modulation can improve suppression efficiency.

PLASMA RESPONSE

L-H threshold

Magnetic field [T]	1.25	2.50	2.80	3.00	4.30	3.45	5.00
$P_{\mathrm{thresh,Martin}}$ [MW]	0.5	1.2	1.3	1.5	1.9	2.5	3.3
$P_{\mathrm{thresh,Hughes}}$ [MW]	0.5	1.1	1.2	1.3	1.6	2.1	2.6

The estimate of the loss power needed for L-H transition is not based on analytical model. Multimachine scaling is needed.

$$P_{\mathrm{L}} = P_{\mathrm{tot}} - \frac{\mathrm{d}W}{\mathrm{d}t}$$

Large database scaling for ITER

$$P_{\mathrm{thresh,Martin}} = 2.15\ \mathrm{e}^{\pm 0.107} n_{\mathrm{e}}{}^{0.782\pm 0.037} B_{\mathrm{T}}{}^{0.772\pm 0.031} a^{0.975\pm 0.080} R^{0.999\pm 0.101}$$

EDA H-mode on Alcator C-Mod

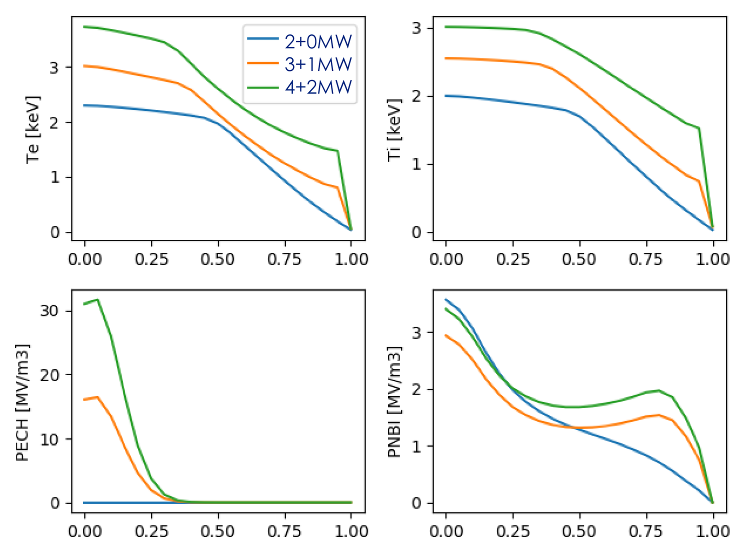
$$P_{\mathrm{thresh,Hughes}} = 0.054\ n_{\mathrm{e}}{}^{0.49} B_{\mathrm{T}}{}^{0.85} S^{0.84}$$

Ideal heating scenario for L-H transition has to be investigated. **Initial 4 MW NBI + 2 MW ECRH is sufficient.**

METIS simulations

Both heating systems effectively influence central electron and ion temperature.

Further ASTRA simulations in respect to impurity accumulation and its diffusion are needed.



140 GHz, O1 mode, 5 T, 1.6 MA

CONCLUSION

- The simulations and calculations of the features and possible utilization of the system show important constraints of ECRH utilization.
- The solution of 140/105 GHz tunable gyrotrons is preffered with the future upgrades to 200+ GHz tubes
- Serious effort should be made to prevent high density discharges and avoid cutoff conditions. It will be necessary to lower the plasma current thus the Greenwald density of some scenarios for the stable operation.
- The proposed 140/105 GHz heating can reliably heat the majority of scenarios except the very low (<1.7 T) and intermediate (2.6−3 T) magnetic-field discharges.
- The initial heating mix should be sufficient to reach L-H threshold

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