COMPASS
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NBI heating modeling for COMPASS-Upgrade tokamak using NUBEAM code

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Motivation

COMPASS-Upgrade is a medium size tokamak which will be build in Prague and replace COMPASS tokamak. The tokamak is designed to operate ITER and DEMO relevant scenarios, crucial for future reactors. The tokamak is expected to operate plasma scenarios with magnetic field up to 5T and electron density up to $10^{21}m^{-3}$. The main plasma heating will be produced by Neutral Beam Injection (NBI) system with injection energy of 80keV .
To have a look on NBI heating performance NUBEAM NTCC simulations were performed for various plasma scenarios.

COMPASS-Upgrade

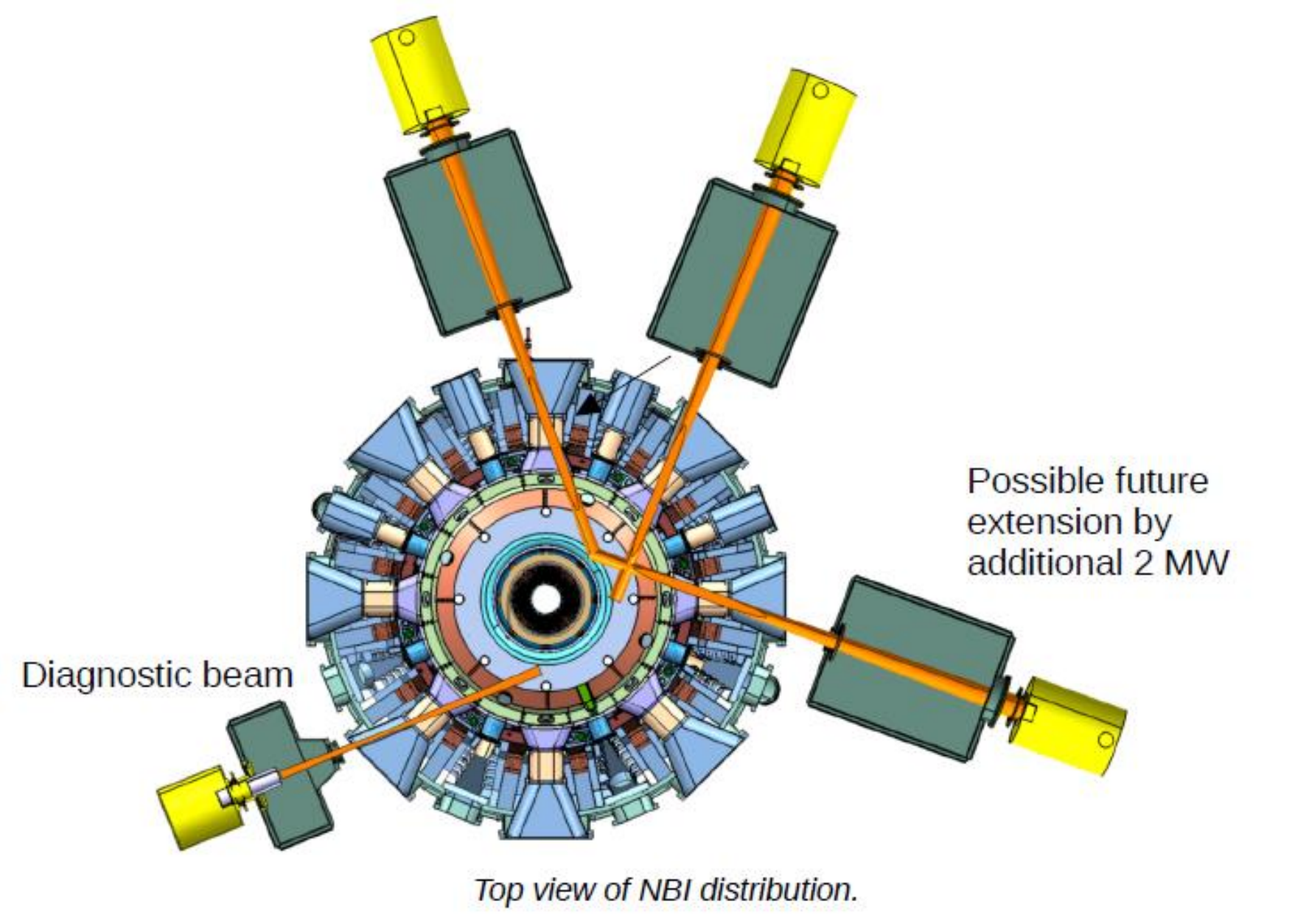


Figure: COMPASS-UPGRADE top view

Toroidal magnetic field B t = 5 T
Plasma current I p = 2 MA
Major radius R = 0.894 m
Minor radius a = 0.27 m
Aspect ratio A = 3.3
Triangularity δ = 0.3-0.6
Elongation κ = 1.8

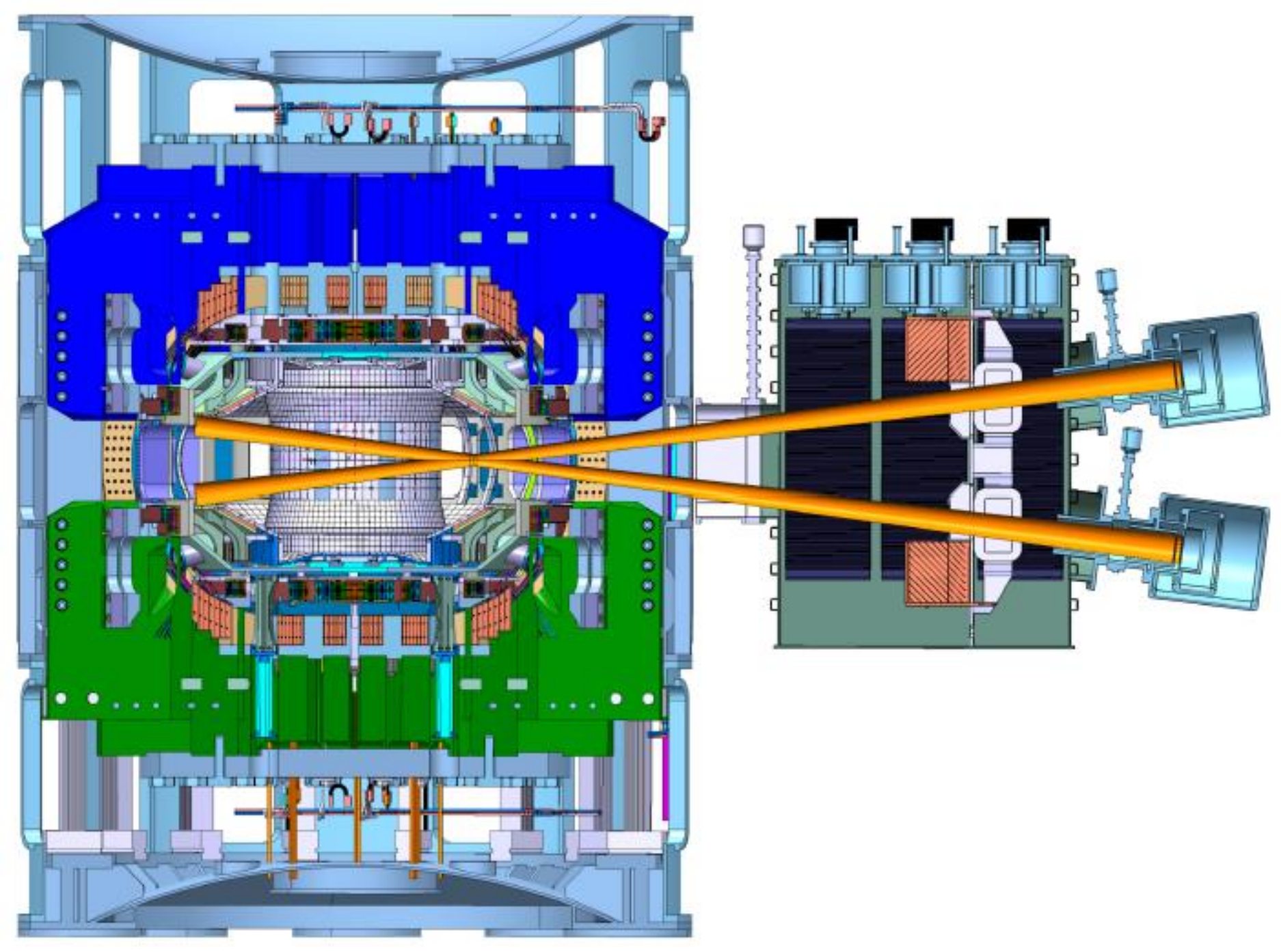


Figure: COMPASS-UPGRADE side view

Heating power :
Phase 1:
P NBI >= 3 MW,
PECRH = 1 MW

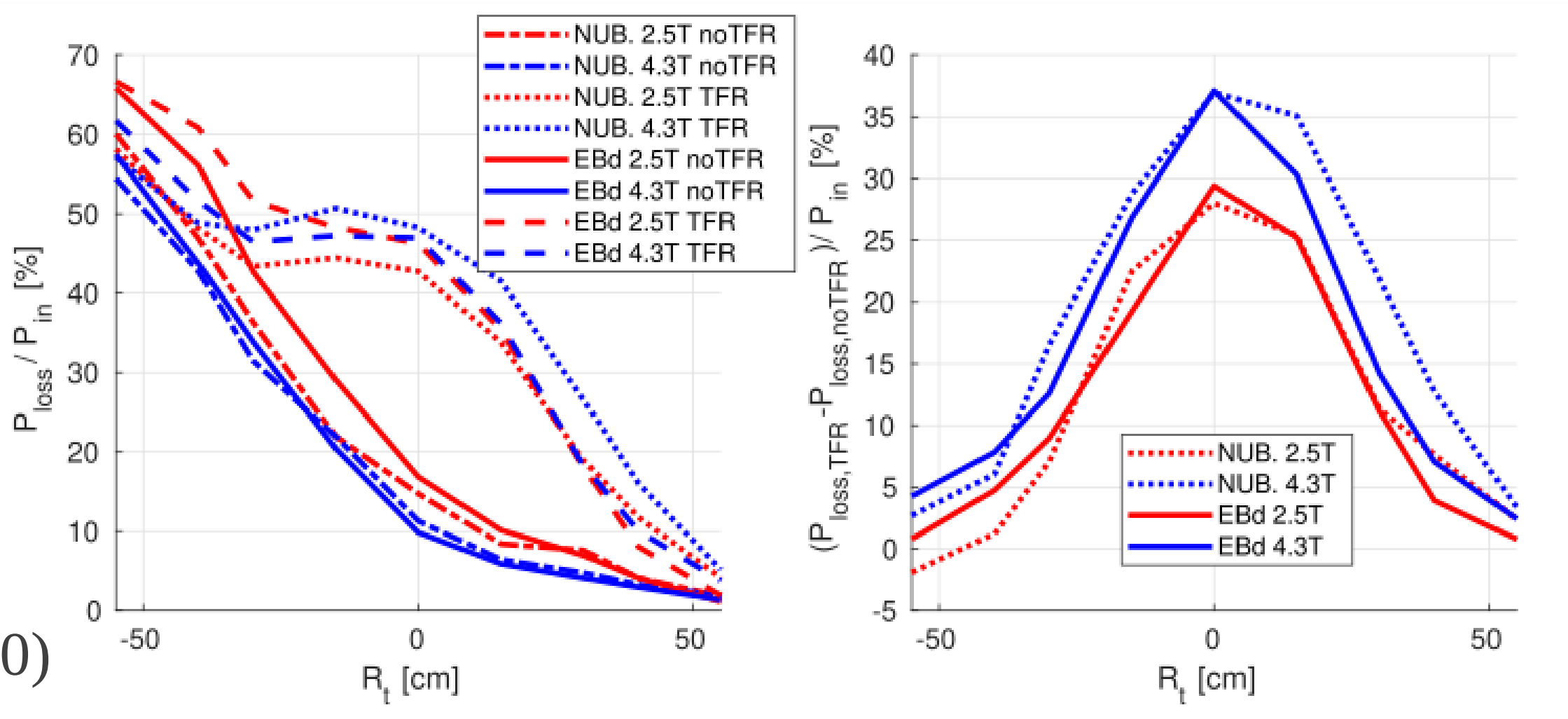
Phase 2:
up to P NBI = 8 MW,
PECRH = 10 MW

(Panek 2017, Vondracek 2021)

NUBEAM ripple model

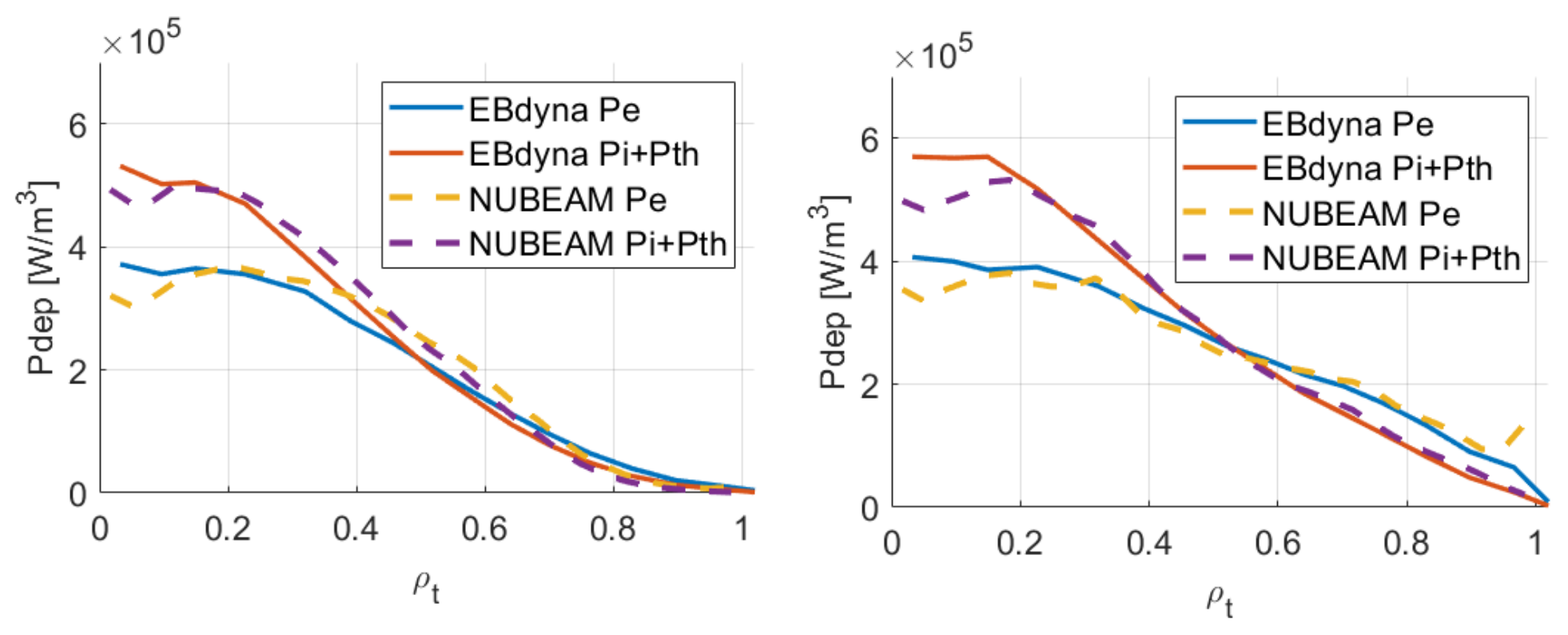
Simulation setup:

- Background Plasmas: METIS+FIESTA
- NUBEAM with ripple losses setup
- Charge exchange losses removed
- No fast ion slowing down in the SOL
- 2 scenarios:
  - B_t=2.5T (#3210), B_t=4.3T (#24300)

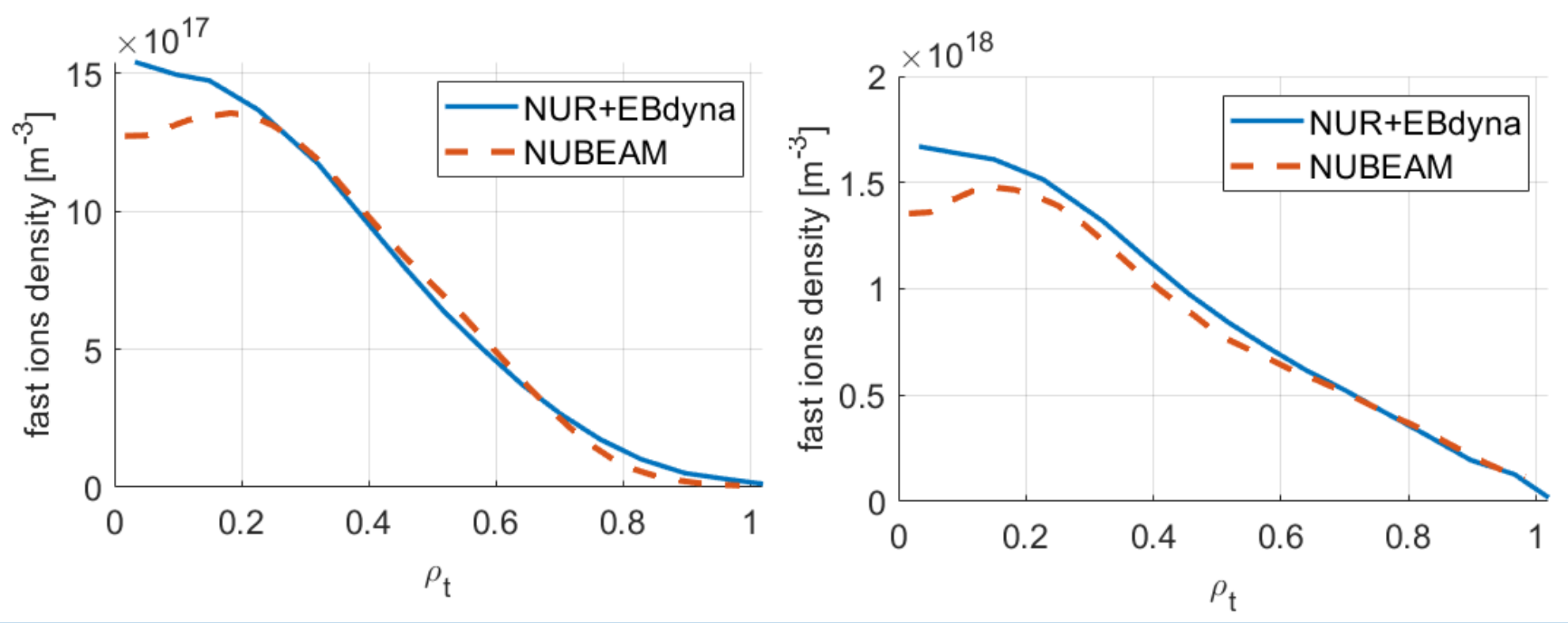


Left: total losses calculated with EBdyna and NUBEAM for 2 scenarios 3210 (2.5T) and 24300 (4.3T) with and without TFR. Right: Difference between losses with and without TFR

#3210 B_t=2.5T



NBI heat power density transferred to electrons (solid lines), to ions (dashed lines) for scenario 3210. Left: simulation with TFR. Right: simulation without TFR



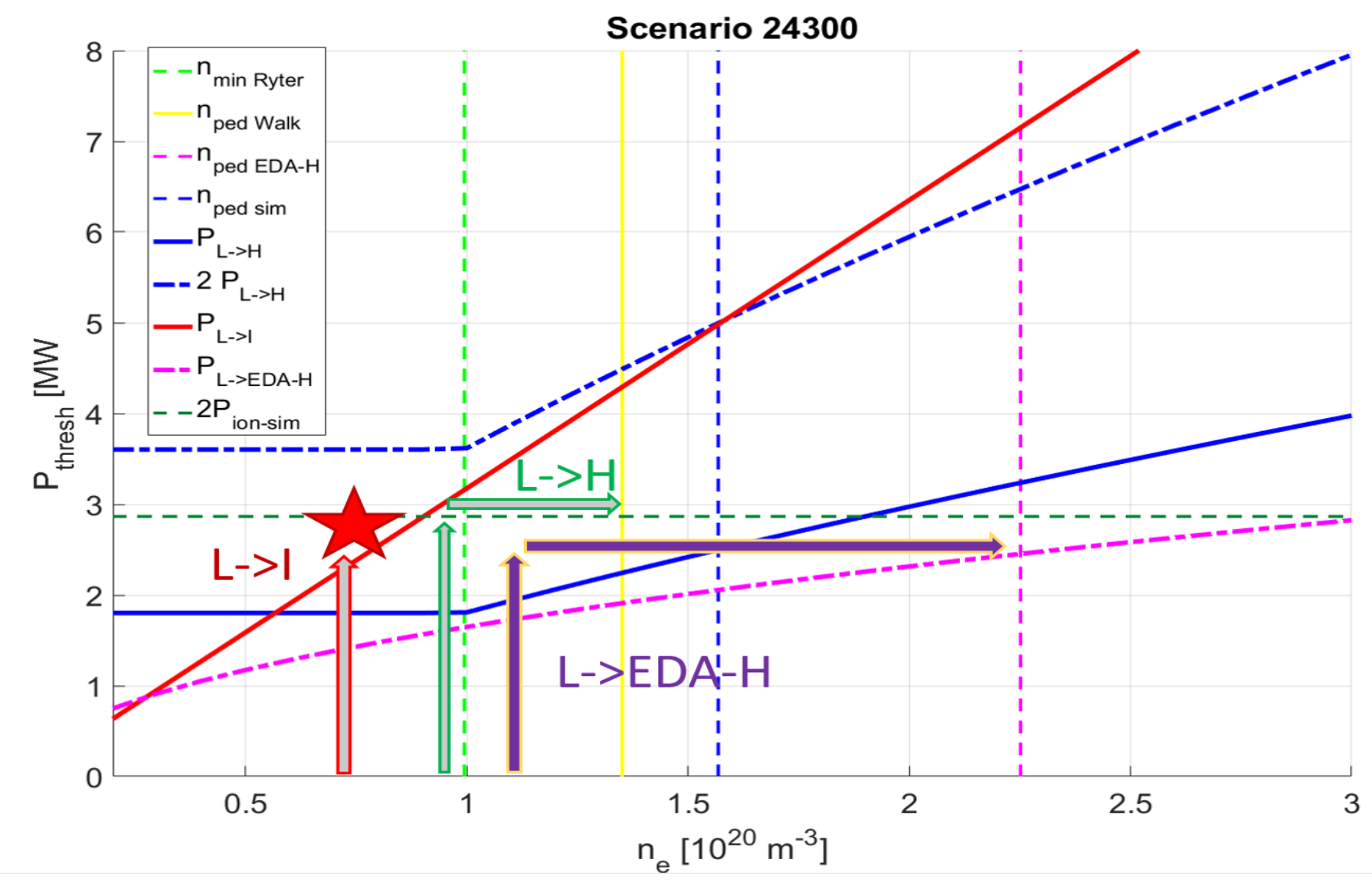
NBI ion density for scenario 3210. Left: simulation with TFR. Right: simulation without TFR

(Jaulmes 2021, Pankin 2004)

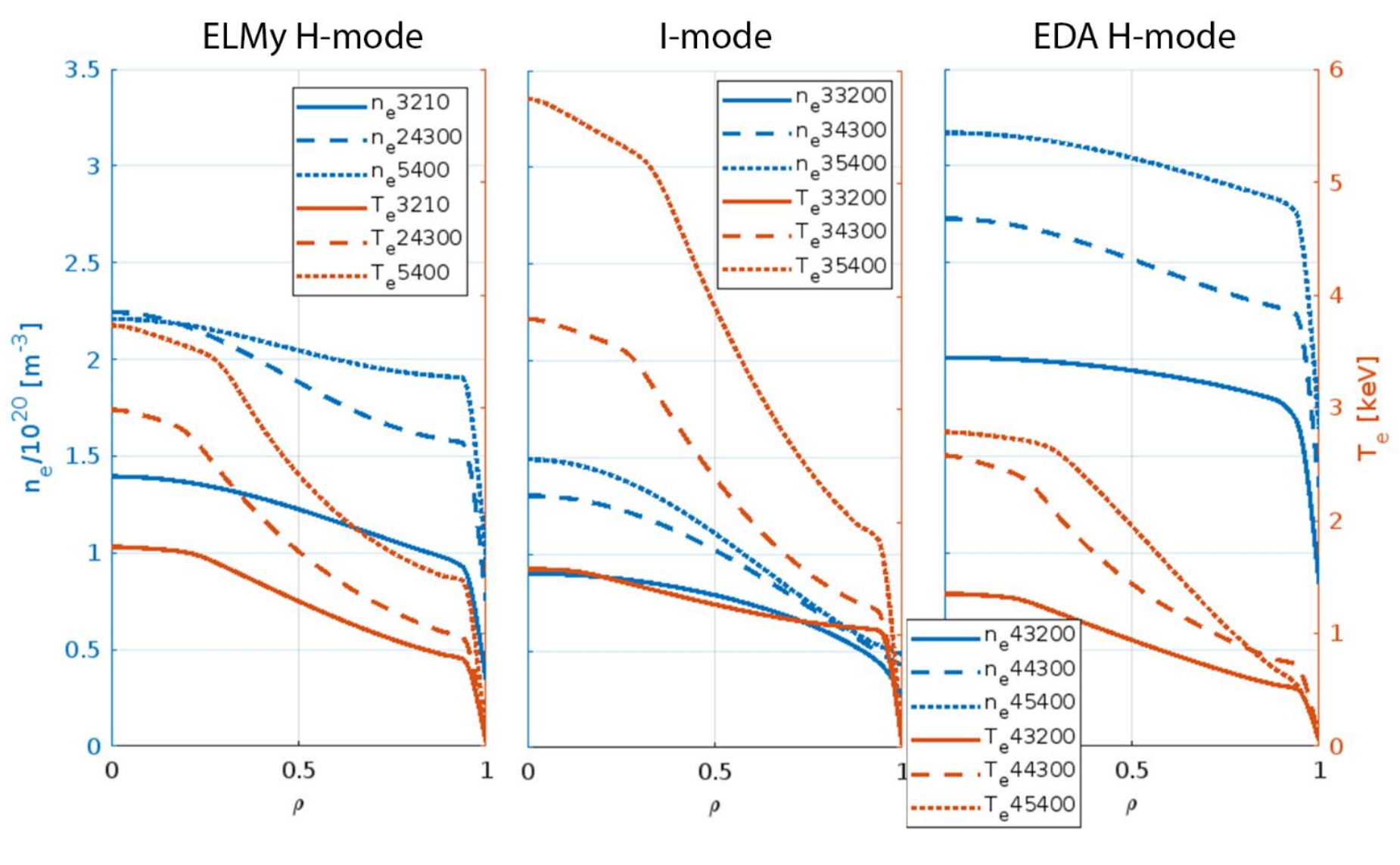
Plasma discharge scenario modeling

Based on the results of Alcator C-mod (Hubbard 2017), we anticipate to be able to access essentially 3 distinct regimes of "improved" plasma confinements when the NBI system is switched on at sufficient power: The **ELMy H-mode**, the **I-mode** and the **EDA H-mode**.

The regime obtained depends on the direction of the gradB drift towards (standard) or away (flipped) from the X-point, on the plasma L-mode density at the time the NBI is started and likely on other factors like edge safety factor (q95) and plasma current. Depending on the confinement type, a large range of pedestal top (or q95 position) electron collisionalities ν∗ will be observed.



Improved confinement modes access diagram



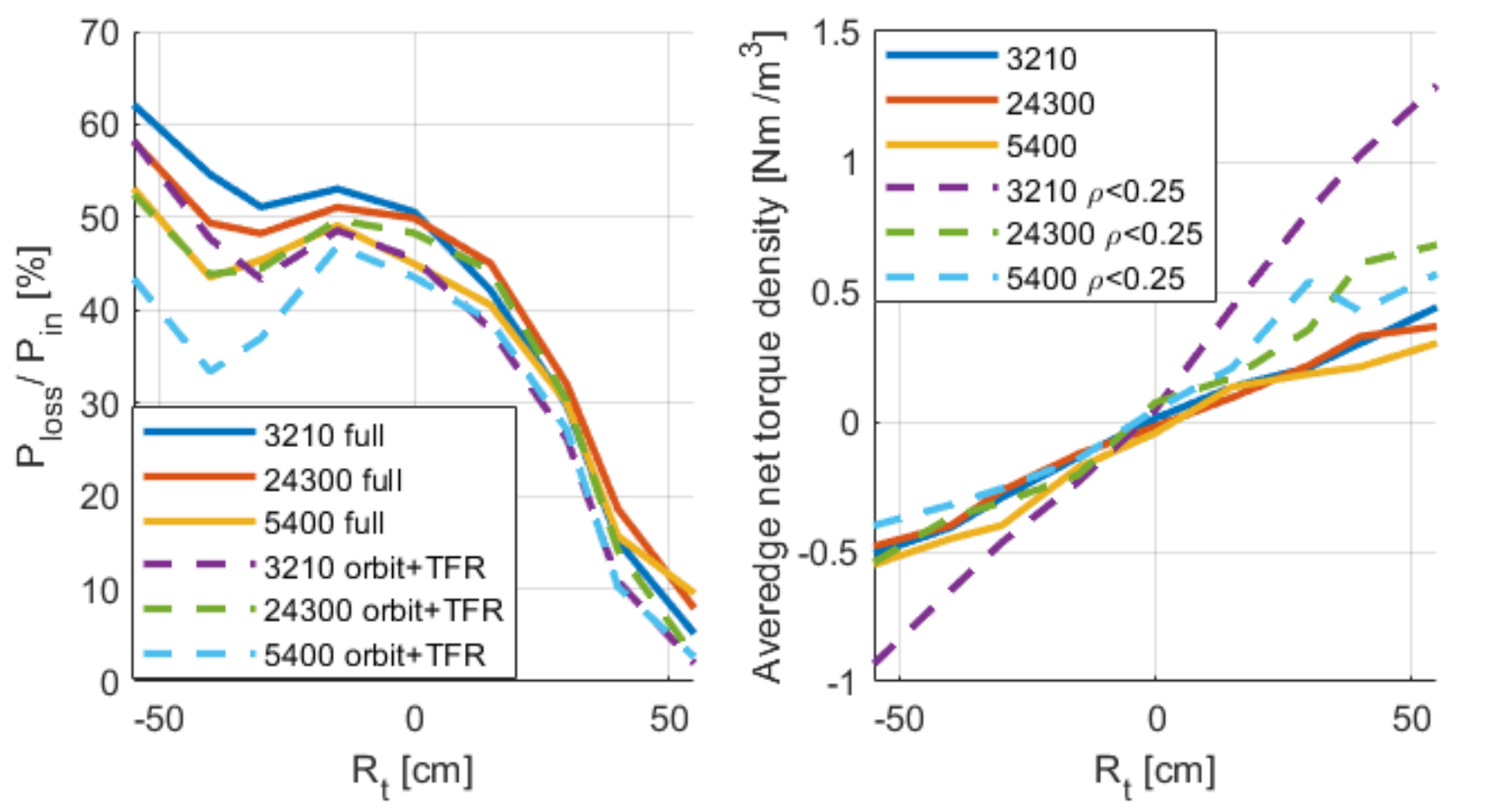
Kinetic profiles of considered scenarios at the flat top phase

scenario	Bt [T]	Ip [MA]	q_{95}	$<n_e>$ [$10^{20}m^{-3}$]	$<T_e>$ [keV]	P_{NBI} [MW]	$\nu*_{ped}$
3210	2.5	0.8	3.5	1.2	1..1	2	0.4
33200	2.5	0.8	3	0.75	1.1	2	0.13
43200	2.5	0.8	3.5	1.9	0.8	2	1.8
24300	4.3	1.2	4.2	1.9	1.5	3	0.59
34300	4.3	1.2	4	1	1.9	3	0.13
44300	4.3	1.2	4.2	2.5	0.8	3	1.46
5400	5	1.6	3.6	2.04	2.0	4	0.28
35400	5	1.6	3.5	1.1	3.1	4	0.05
45400	5	1.6	3.5	3	1.4	4	2.1

NUBEAM simulations results

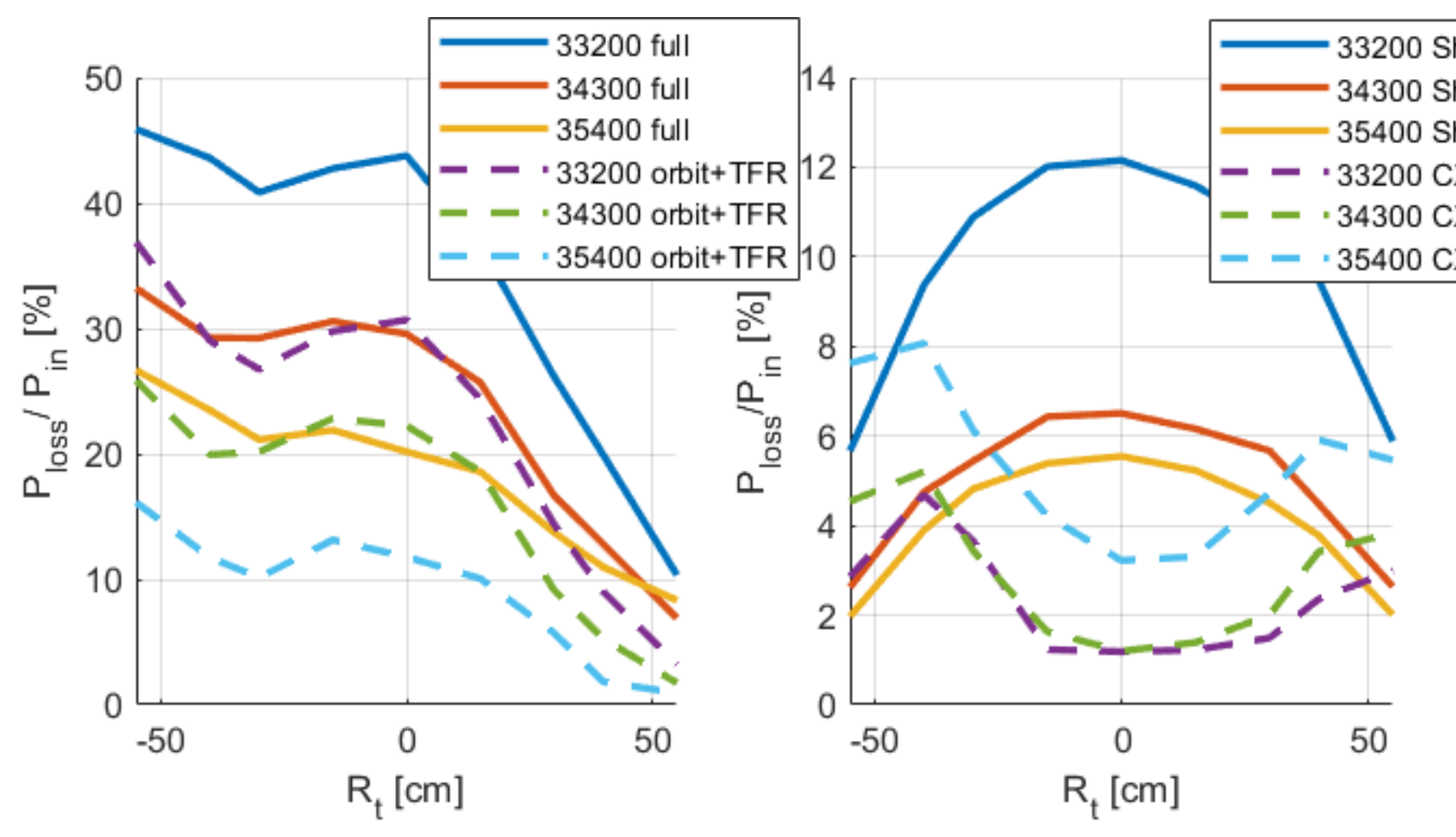
ELMy H-mode results.

Left: Total losses – solid lines,
Orbit and TFR induced losses – dashed lines.
Right: NBI torque density: Volume average – solid lines, ρ<0.25 average – dashed lines



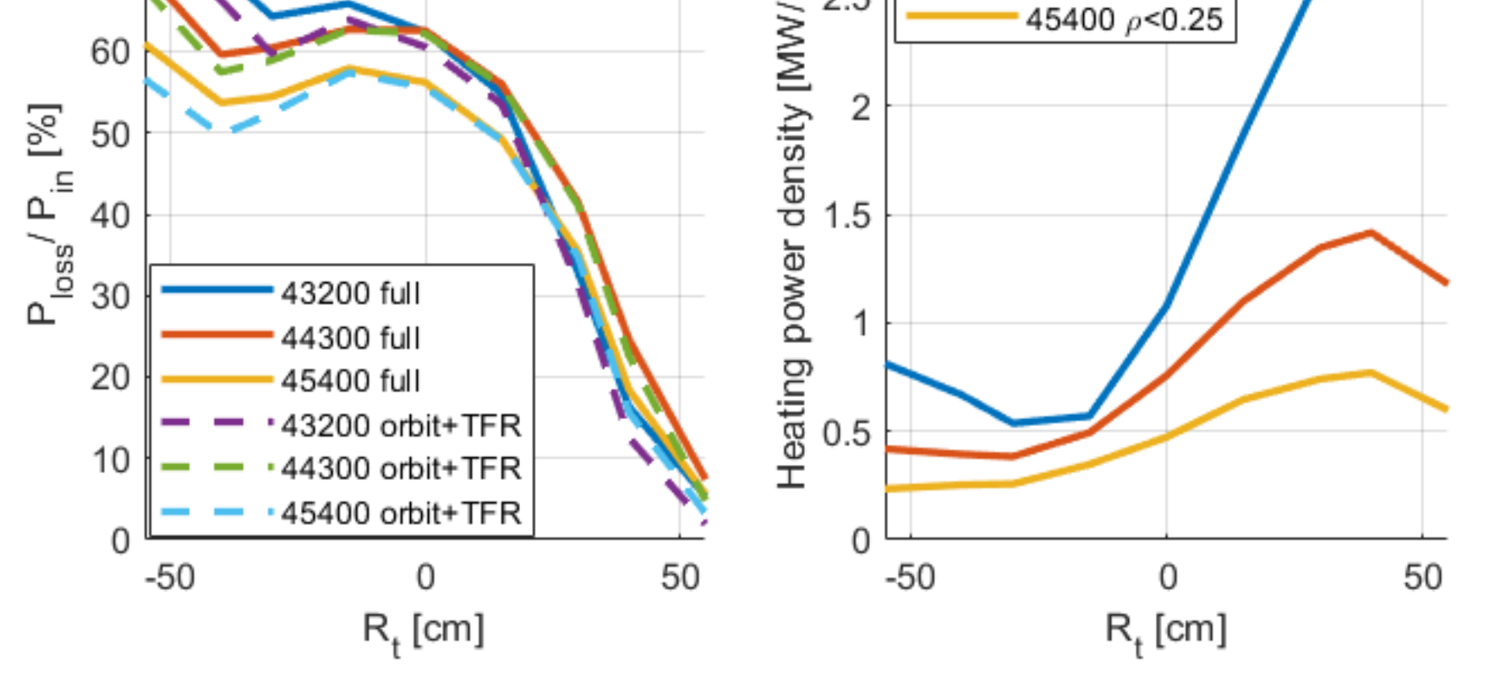
I-mode results.

Left: Total losses – solid lines, orbit and TFR induced losses – dashed lines. Right: Shine-Through losses - solid lines, Charge Exchange losses – dashed lines



EDA H-mode results.

Left: Total losses – solid lines, orbit and TFR induced losses – dashed lines. Right: NBI heat power density In the plasma core (ρ <0.25)



CONCLUSION

- NUBEAM simplified model for ripple induced losses can deliver an acceptable precision when it is properly adjusted
- NBI system show good performance with total losses less than 25%, when R_t>40 cm
- Orbit losses are the main source of losses. Charge exchange and shine through losses are becoming important only when $<n_e> < 10^{20}$ m^{-3}
- Torque deposition in H-mode scenarios is still significant at counter-current injection despite high power losses. This result show balanced injection feasibility
- Simulations for I-mode scenario with high magnetic field (#35400) show relatively small power losses even with counter current injection.
- For EDA H-mode injection Rt=40cm is the most efficient for NBI plasma core heating

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