Predictive integrated modelling simulations in preparation of the JET Deuterium-Tritium campaign

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The main objective of the future JET tokamak experimental campaigns is to prepare the future deuterium-tritium (D-T) scenarios of JET and ITER. Together with these experiments an important effort in modelling is needed to be able to test and improve the predictive capability of integrated modelling tools for D-T burning plasmas. Alpha particles along with isotope effects [1] on plasma confinement need to be further studied and understood. A particular topic of interest is the validity of first principle models for predicting turbulence in D-T conditions. Therefore, a significant effort towards that direction is required by analysing the physics of extrapolated D-T plasmas. Weakness of the models can be mitigated by proposing experiments specifically designed to improve such predictive capabilities in plasmas different than D, for instance in the future T campaign.

To help in the present modelling effort of D-T tokamak plasmas we have carried out integrated modelling simulations with the CRONOS code [2] using TGLF [3, 4] turbulence transport model. A baseline JET shot (92436) has been extrapolated to higher power and D-T plasma conditions. This shot has been chosen because it is one with the highest neutron rate yield from the last campaign, 2016. In the present study we have carried out simulations varying the injected NBI power, first in deuterium and then in D-T plasmas. A scan in plasma current is performed. The results show the improvement of plasma confinement with increasing current and the decrease of transport for D-T plasmas in some particular plasma regions (inner core and edge) compared to pure deuterium. The fusion power calculated from the different D-T plasmas simulations range between 13 and 14 MW for 41 MW of total injected power (6 MW of ICRH and 35 MW of NBI).

Simulation results

To validate the CRONOS code with TGLF transport model for JET shot 92436 we carried out predictive simulations evolving ψ, n_e, T_e and T_i. The results at $t = 50.4s$ are presented in Fig. 1. For these simulations we considered two different rotation profiles due to uncertainties in the toroidal velocity measurements. We observe a stabilization effect with increasing rotation. This is consequence of the $\boldsymbol{E} \times \boldsymbol{B}$ effect present in the TGLF transport model. In general the experimental profiles are well reproduced using CRONOS with TGLF. The pedestal value is different from the fitted profiles because we use a experimental scaling to calculate it [5], this allow us to extrapolate to higher power and toroidal current from the present simulations.

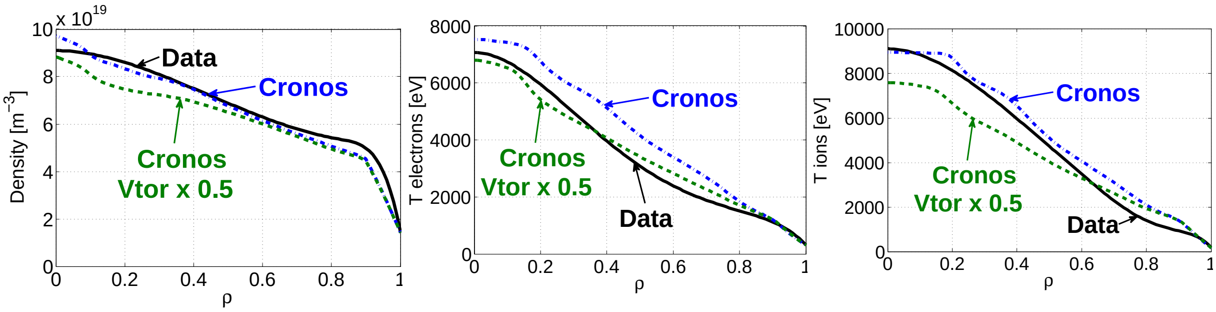

Figure 1: Profiles of n_e (left), T_e (center) and T_i (right) at $t = 50.4$ for JET shot 92436.

Simulation	P_{NBI} (MW)	I_p (MA)	B_{vac} (T)	f_{Gr}	β_N/β_p	q_{95}	H_{98th}
Reference	28	3.0	2.8	0.64	2.28/1.05	3.16	1.06
Extrapol. 3.0	35	3.0	2.8	0.75	2.74/1.22	3.16	1.02
Extrapol. 3.5	35	3.5	3.3	0.81	2.24/1.02	3.11	1.00
Extrapol. 4.0	35	4.0	3.8	0.83	2.14/0.84	3.24	0.92

Table 1: Parameters of extrapolated simulations for deuterium-deuterium (D-D) plasmas.

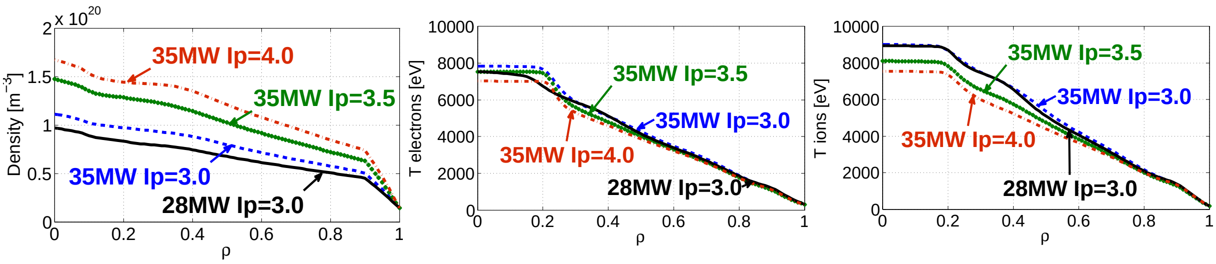

Figure 2: Profiles of n_e (left), T_e (center) and T_i (right) at steady state for the extrapolations to high current.

In Tab. 1 we detail the three extrapolations we studied from the previous JET shot 92436. The Greenwall fraction increases weakly with power and toroidal current I_p. β significantly increases with power but decreases with I_p. This drop in β with I_p is consequence of the increase of the magnetic field. Indeed, the safety factor at the edge (q_{95}) is kept constant by increasing the toroidal magnetic field. Therefore the magnetic pressure increases with I_p and this lowers the β values. The calculated H_{98th} factor is close to unity as expected from a baseline H-mode scenario. In Fig. 2 the profiles at steady state are plotted. We observe the increase of density with the toroidal current. The increase of overall density is principally due to the increase of density at the pedestal top. The decrease of particle neoclassical diffusion with I_p at the pedestal induces the increase of density in this region (see Fig. 3 *left*). High density is accompanied by a decrease of electron and ion temperatures since energy is deposited in a larger number of particles. Therefore ion pressure increases mildly with plasma current (see Fig. 3 *right*).

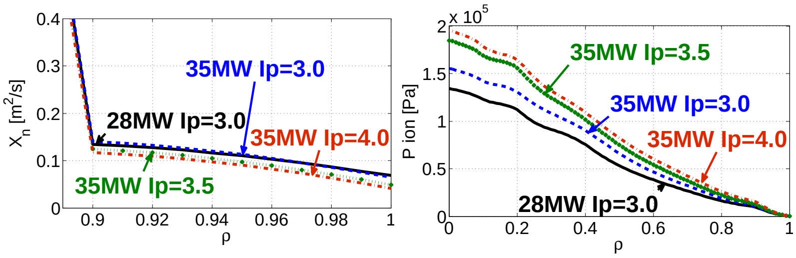

Figure 3: Profiles of pedestal neoclassical density diffusion D_n $[m^2/s]$ (left) and ion pressure P_i (right).

For the deuterium-tritium (D-T) extrapolation the same I_p values used in the deuterium-deuterium (D-D) simulations are considered. In Fig. 4 the density, electron and ion temperatures at the steady state are plotted. The density increases with the input power and toroidal current. As for the D-D simulations de density profile is governed by the value of density at the pedestal top. This value is calculated from an empirical scaling [5], therefore a reliable model for the pedestal calculation is essential for a good D-T prediction. The increase in density is accompanied by the decrease of electron and ion temperatures at high I_p. If we look at the thermal ion pressure (Fig. 5 *left*) the higher values at the axis are obtained for currents 3.5 and 4 MA. These cases correspond to the highest alpha heating of ions and electrons (Fig. 5 *center, right*). The corresponding total fusion power of the three simulations is presented in Tab. 2. The maximum fusion power is obtained for the plasma with $I_p = 3.5$ MA.

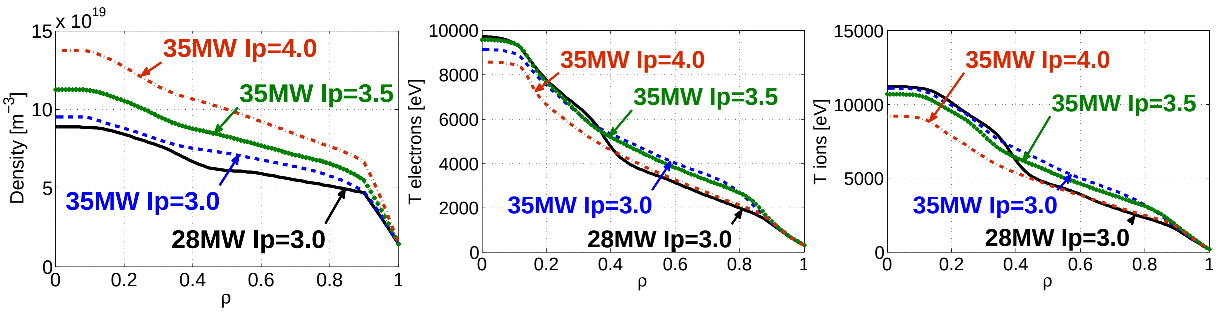

Figure 4: Profiles of n_e (left), T_e (center) and T_i (right) at the steady state for D-T plasmas.

Simulation	$P_{thermal}$ (MW)	P_{beam} (MW)	P_{total} (MW)	β_N/β_p	H_{98th}
Extrapol. I_p = 3.0 MA	7.22	6.12	13.24	2.92/1.30	1.20
Extrapol. I_p = 3.5 MA	8.42	5.67	14.09	2.30/1.02	1.01
Extrapol. I_p = 4.0 MA	6.92	4.43	11.35	1.70/0.77	0.80

Table 2: Fusion power of extrapolated D-T simulations.

A comparison between D-D and D-T simulations for $I_p = 3.5$ MA is presented in Fig. 6. In this figure we observe a small isotope effect. The D-T simulation shows a better confinement for

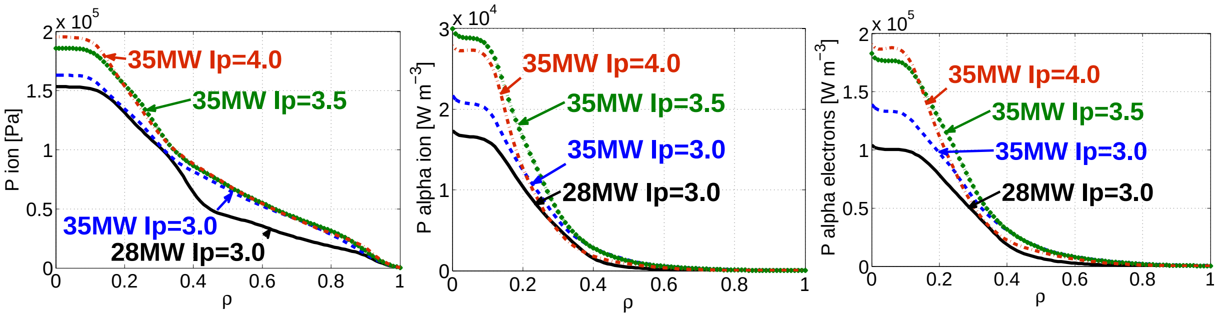

Figure 5: Profiles of P_i (left), P_α on ions (center) and P_α on electrons (right) at the steady state for D-T plasmas.

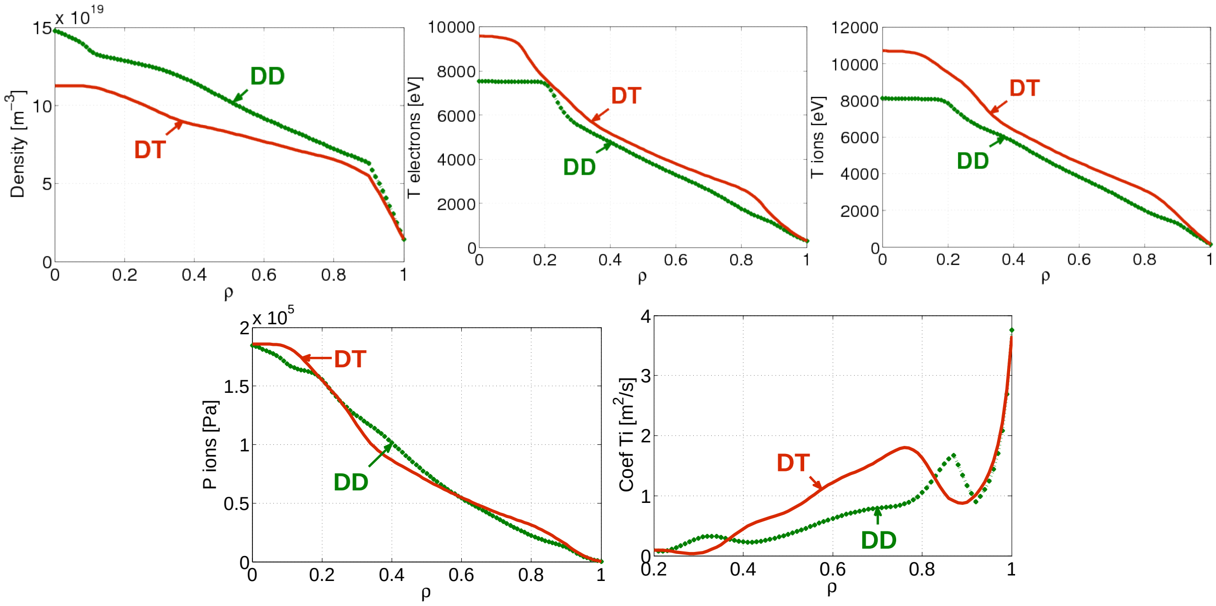

Figure 6: Profiles of n_e (up, left), T_e (up, center), T_i (up, right), P_i (low, left) and χ_{T_i} (low, right) at the steady state for $Ip = 3.5$ MA.

ion and electron thermal energy. The diffusion coefficient profile for the ion temperature shows a decrease in transport at the core and around $\rho = 0.85$ (Fig. 6 *low, right*). On the other hand density decreases for the D-T simulation. Therefore the ion pressure is comparable between the D-D and D-T computations (Fig. 6 *low, left*). The observed localized improvement of the confinement for thermal energy need to be further studied but it could be strongly related to the stabilizing effect of $\boldsymbol{E} \times \boldsymbol{B}$ with mass [6].

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