WEST long pulse L-mode plasma predictive modelling

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Introduction

The achievement of Long Pulse Operation [1] is a critical milestone towards operating forthcoming reactors like ITER and for addressing issues on the ageing of plasma-facing components. WEST [2] is a Tungsten (W) environment tokamak designed to explore such regimes with superconducting magnets, actively cooled tungsten plasma-facing components and a Lower-hybrid Heating and Current Drive (LHCD) system. In 2024, a WEST record in terms of plasma duration (364 s) and injected energy (1.15 GJ) was established and assisted by integrated modeling. The High Fidelity Plasma Simulator (HFPS), the European IMAS-coupled version of JINTRAC [4], integrates physics-driven modules into a single framework. In particular, the workflow integrates a self-consistent derivation of full-radius heat and particle turbulent transport and LHCD source. Using this set of codes, a reference 100s-long plasma is reproduced. In order to preparing fully non-inductive experiments, actuators such as various plasma parameters (I_P, n_e, P_{LHCD}) and additional Electron Cyclotron Current-Drive (ECCD) are investigated. Subsequent predictions are compared to post-simulations experiments.

HFPS integrated modeling workflow

HFPS enables plasma predictions with self-consistent evolution of different physics modules:

- Current diffusion, electron and ion heat and particle transport equations are evolved in JETTO, a 1.5D transport code, leading to prediction of j, n_e, T_e, T_i.
- The equilibrium is determined with the fixed-boundary equilibrium solver ESCO [4].
- Boundary conditions (n_{sep}, T_{sep}) are fixed using a 2-point model-like condition. Target n_{el} is obtained with a feedback control neutrals puffing model at the separatrix.
- Transport coefficients are approximated using NCLASS for the neoclassical part and TGLF-sat2 for the turbulent one, as it has been validated for L-mode discharges on ASDEX-U [5]. A Gaussian central ad-hoc transport peaking at $1 m^2 s^{-1}$ is added.

- The LHCD is computed using a physics-based heuristic model extracted from METIS [6,7], together with a scaling law for the current drive efficiency derived from Tore Supra and JET plasmas [8]. This scaling law links the LHCD current drive to the energy confinement time, highlighting the complexity of capturing these non-linearities.

Operational domain predictions

The previously introduced workflow was first used to reproduce a reference 100s-long discharge at low loop voltage identified with I_P = 380 kA, P_{LHCD} = 3 MW, n_{el} = 3.10^{19} m^{-3}, V_L = 50 mV. In particular, synthetic signals reconstructed from predicted electron profiles are in good agreement with experimental measurements (Fig. 1 a-c), current profile from which polarimetry is reconstructed is close to the experimental equilibrium reconstruction (Fig. 1d) and LHCD deposition is consistent with Hard-X Rays measurement (Fig. 1e). In addition, energy confinement time lies within the error bars and predicted loop voltage matches experiment within a 10 mV error range.

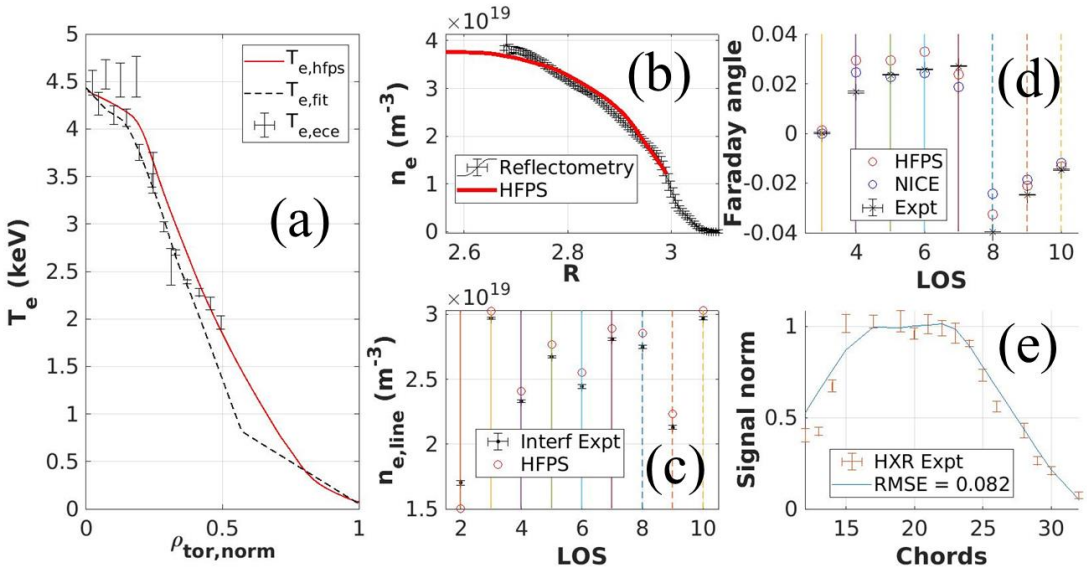

Fig 1. WEST #57757 reference shot experimental against synthetic signals for ECE (a), Reflectometry (b), Interferometry (c), Polarimetry (d), Hard X-Rays (60-80 keV) (e).

The workflow being validated against a reference discharge, simulations exploring WEST range of parameters were performed to give insights on the operational domain of fully non-inductive scenarios. To align with the experimental strategy, I_P scan (200 kA to 400 kA) predictions were performed and later compared to experiments where V_L ramp-down towards zero is feedback-controlled with I_P ramp-down. I_P dependence for energy confinement time and V_L are retrieved and shot #59182 confirmed predicted non-inductive discharge around 320 kA, for similar plasma conditions (Fig. 2 a-b). Then, additional simulations were performed around