TH-C P6
(Indico 2753)

# DEVELOPMENT OF ITER HIGH-FIDELITY PLASMA SIMULATOR BASED ON JINTRAC AND DINA, AND STRATEGY FOR VALIDATION

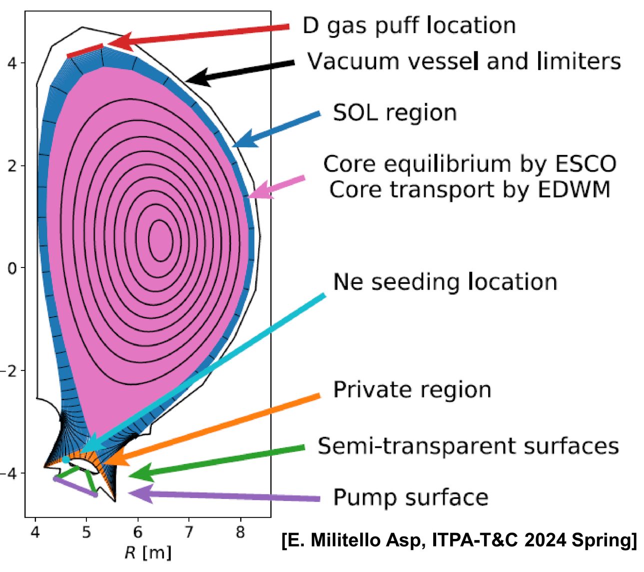
china eu india japan korea russia usa

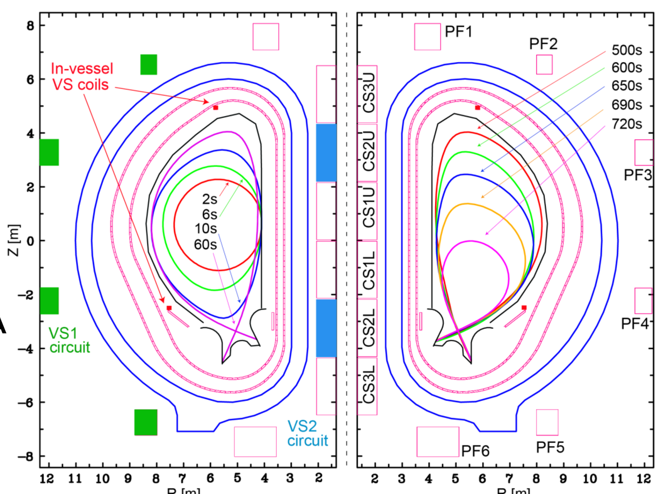
S.H. KIM[1], M. DUBROV[1], F. CASSON[2], G. CORRIGAN[2], P. FOX[2], R. FUTTERSACK[2], Y. GRIBOV[1], O. HOENEN[1], E. KHAYRUTDINOV[3], R.R. KHAYRUTDINOV[3], P. KNIGHT[2], F. KOECHL[1], S. KONOVALOV[3], J.G. LEE[1], A. LOARTE[1], V.E. LUKASH[3], E. MILITELLO-ASP[2], S.D. PINCHES[1], A.R. POLEVOI[1], M. SCHNEIDER[1], Z. STANCAR[2], G. SUÁREZ-LÓPEZ[1,2], D.M.A. TAYLOR[2]   [1]ITER Organization, [2]UKAEA Culham Science Centre, [3]Kurchatov Institute

## 1. High Fidelity Plasma Simulator (HFPS)

A **high-fidelity plasma simulator** is required to model integrated ITER scenarios, including **core-pedestal-SOL transport**, sources and stability, **plasma-wall/target interactions**, and **magnetic/kinetic controls** (incl. PF circuits)

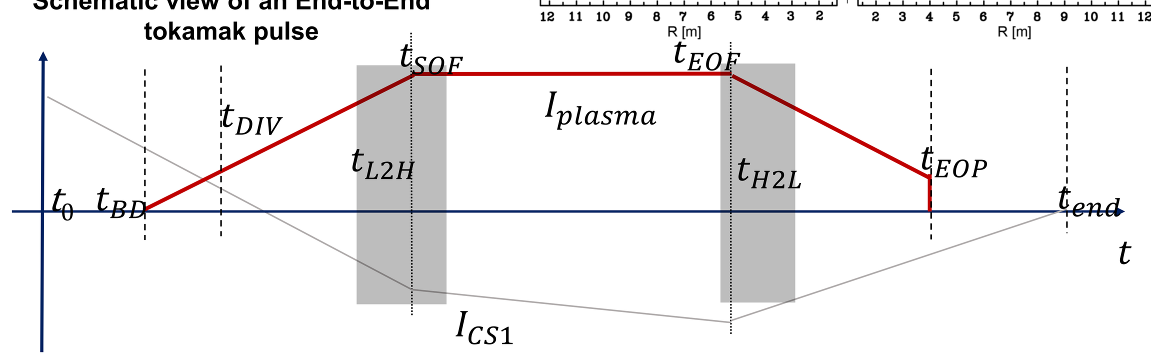
- To prepare **ITER scenarios** for the ITER Research Plan and experimental campaigns
- To support **the validation of ITER systems and components**
- To perform **interpretative modelling of ITER pulses and physics studies**
- Current **ITER HFPS** development is based on
  - **JINTRAC** (core-edge-SOL transport with sources and exhaust, and kinetic control)
    - **JETTO** (core transport and source component of JINTRAC)
    - **COCONUT** (core-edge-SOL coupled transport and source component of JINTRAC)
  - **DINA** (free-boundary equilibrium evolution and magnetic control)



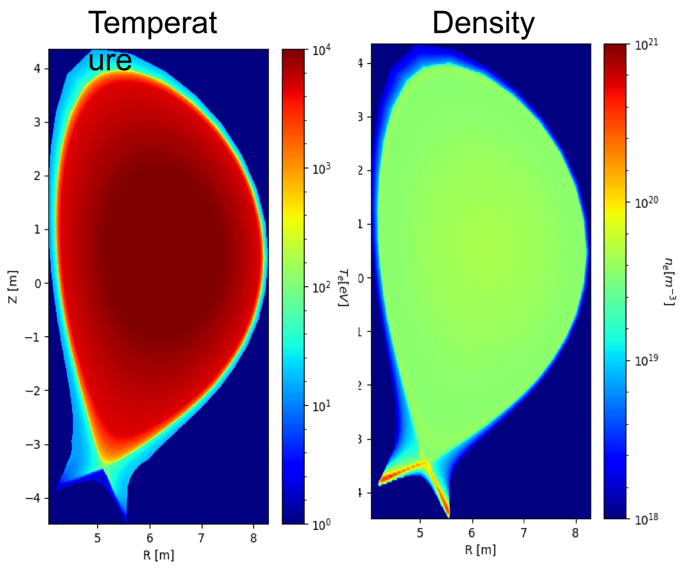




ITER coil systems and conducting structures with plasma boundary shape evolution computed by DINA [S.H. Kim, NF 58, 056013]

Schematic view of an End-to-End tokamak pulse



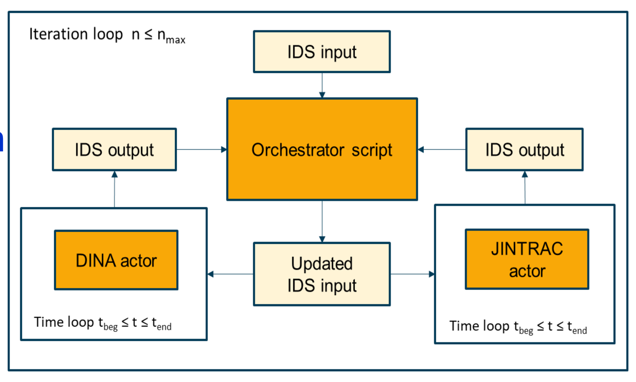

- H&CD workflow (heating and current drive physics) + new features (2D edge grid evolution, W wall source, etc.)
- **A first proto-type HFPS, DINA-JETTO** [S.H. Kim, APS 2023]
  - **Adequate for reasonably fast development of ITER scenarios**
- **Extended demonstration, DINA-COCONUT**
  - **To verify plasma solutions** (free-boundary + core-edge-SOL/targets-wall) **against extended sets of tokamak components and systems** (W wall, divertor, fuelling, pumping)




## 2. Integration of codes and physics

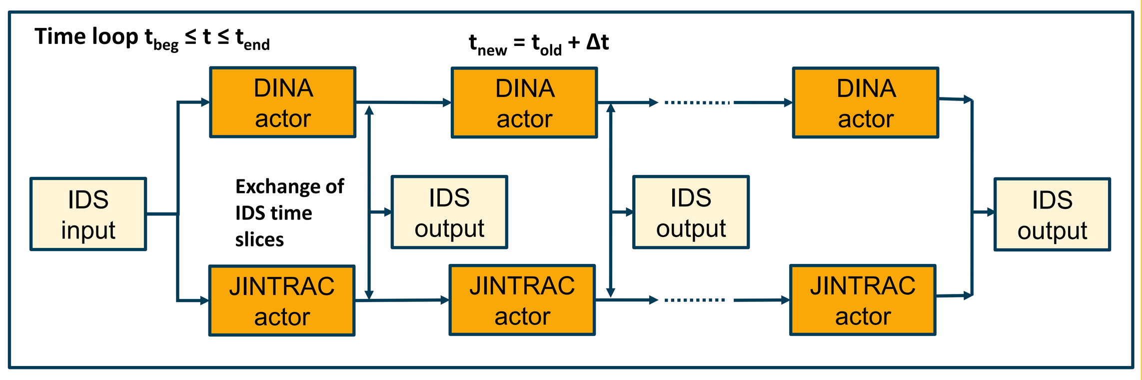
**Loose coupling scheme**

- DINA and JINTRAC exchange stand-alone simulation results at the end of each run (e.g. ~100s)
  - DINA uses plasma profiles computed by JINTRAC and solves free-boundary equilibrium and current diffusion
  - JINTRAC uses DINA plasma boundary evolution and solves prescribed boundary equilibrium, core-edge-SOL transport and sources
  - DINA and JINTRAC executed in an **iterative manner with an *intra-code* convergence check** (to allow inherent off-sets between different codes/models)




**Close coupling scheme**

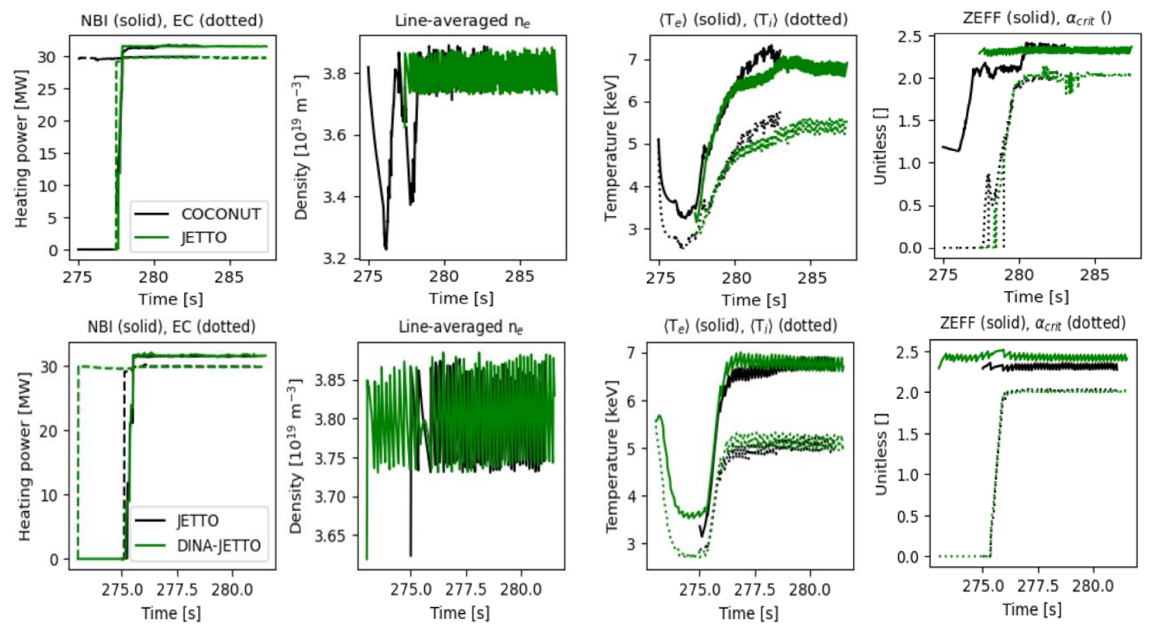
- DINA and JINTRAC exchange simulation results at each data exchange time-step
  - JINTRAC directly uses DINA free-boundary equilibrium and current diffusion without re-computing them
  - DINA uses JINTRAC plasma profile evolution and kinetic control
  - **Iteration loop is not applied, but a small data-exchange time-step (~ a few ms)** is used to maintain required simulation accuracy and performance
  - Close coupling scheme has been demonstrated using **DINA-CH/CRONOS** [S.H. Kim, PPCF 51]




## 3. Initial demonstration

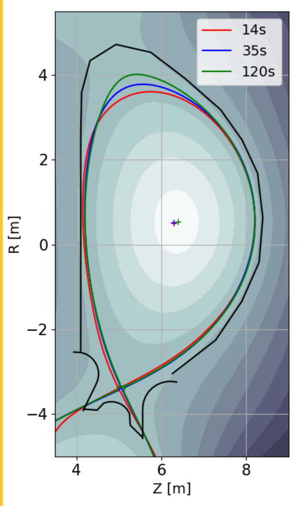
**Close coupling simulation of 7.5MA/2.65T Hyd (+10% He)**

- **COCONUT → JETTO → DINA-JETTO**
- **DINA-JETTO well reproduced the existing scenario (Incl. L-H transition)**

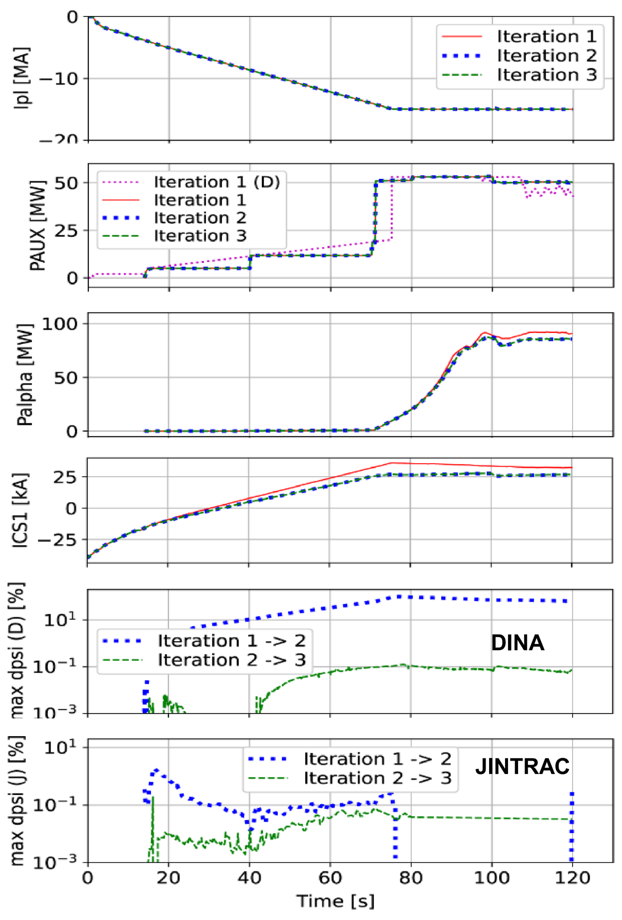



## 4. Loose coupling scheme (15MA/5.3T DT)

- Loose coupling scheme DINA-JETTO simulation produced a converged plasma in 3 iterations
- 1st DINA run (e.g., $P_{AUX}$ and $I_{CS1}$) uses kinetic profiles from an existing scenario (different H&CD settings)




Good *intra-code* convergence (iter. 2→3) achieved in both DINA and JINTRAC

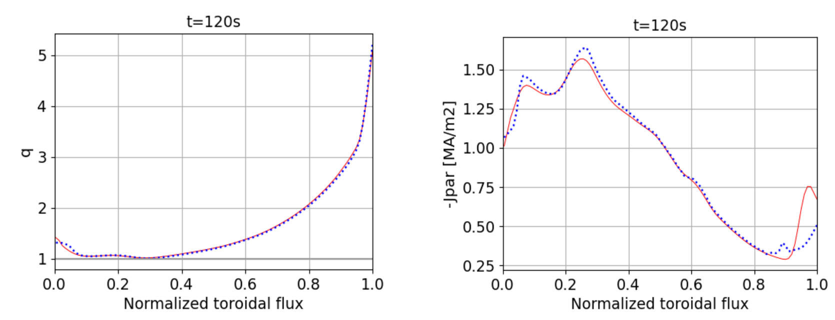



## 5. Close coupling scheme (15MA/5.3T DT)

**Improvement of close coupling scheme**

- Initial studies on the convergence and validity ranges revealed that the current density profile should be exchanged (instead of the safety factor profile) to improve the consistency

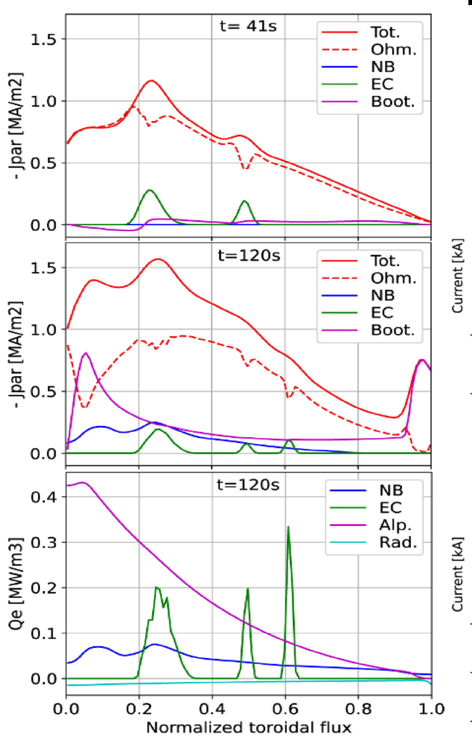
❖ Note that $J_{||}$ is 2nd derivative of the poloidal flux, while q is 1st derivative

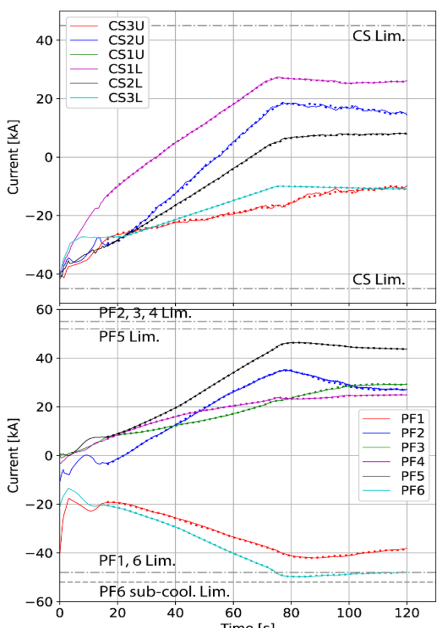



DINA q profile is used to update JINTRAC q profile (then $J_{||}$ computed)
DINA $J_{||}$ profile is used to update JINTRAC $J_{||}$ profile (then q computed)

**Close coupling of sources and to the PF coil systems**

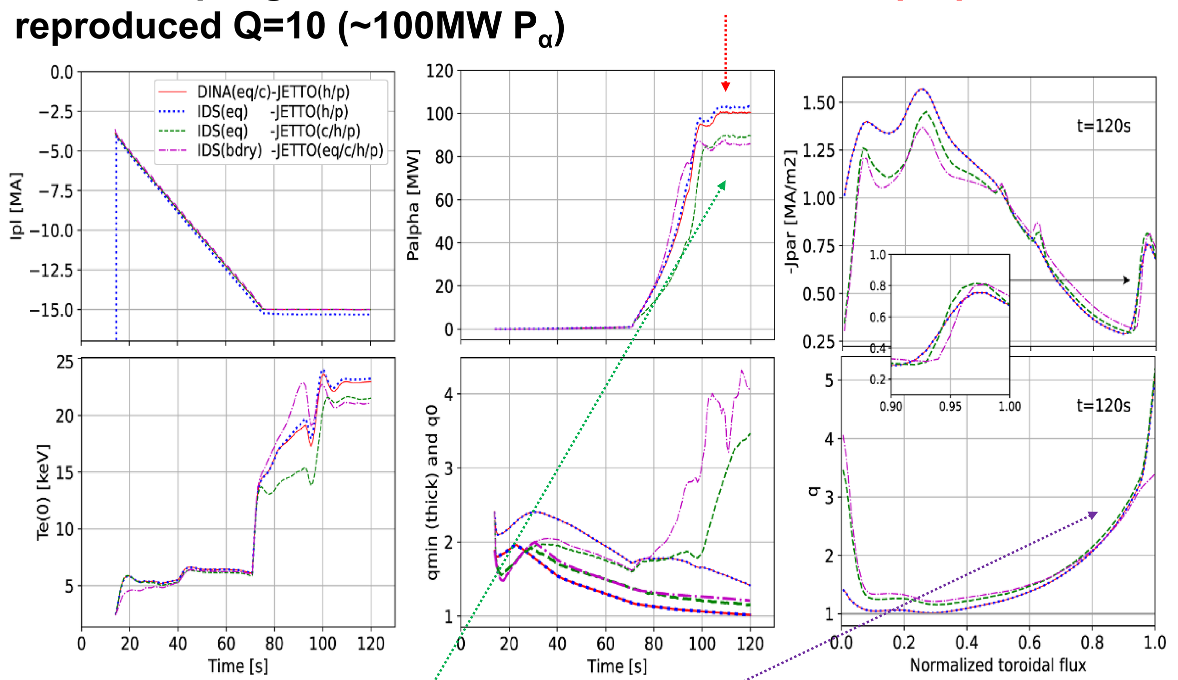
- The external current sources (e.g. EC) computed by JINTRAC are consistently included in DINA current diffusion



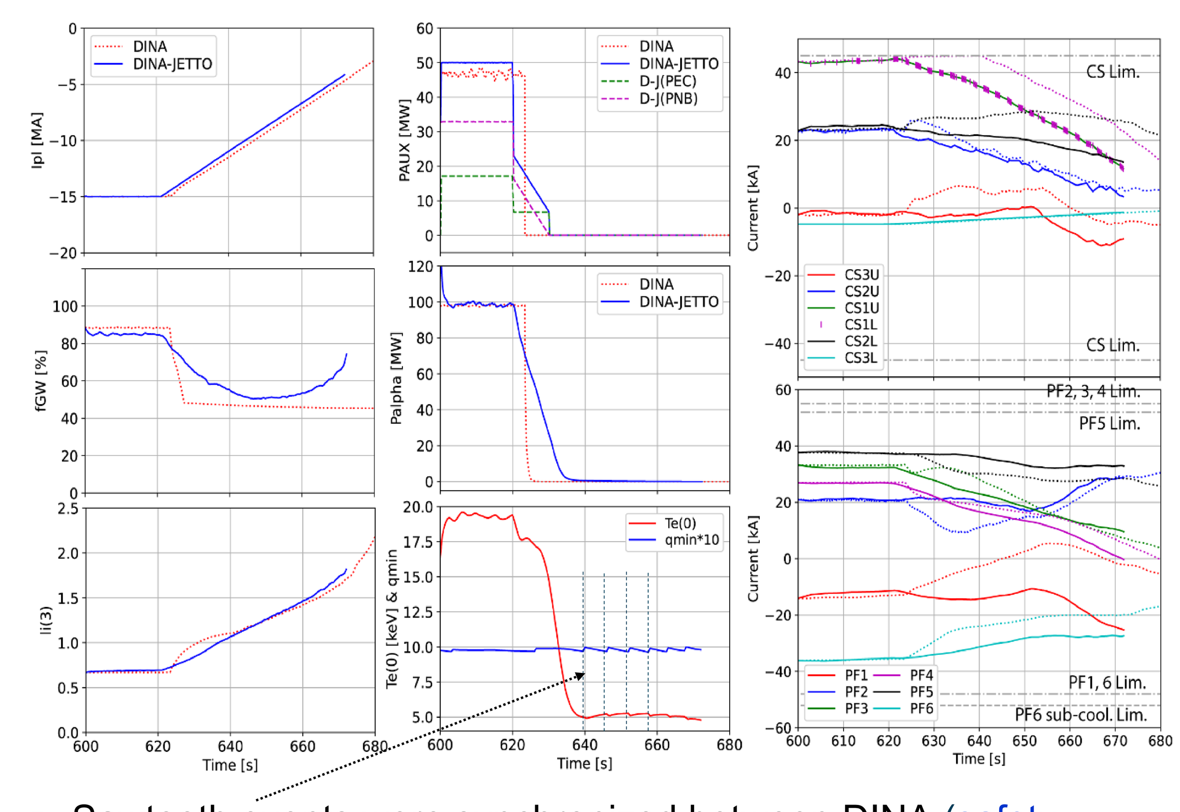

- DINA-only interpretative simulation very well reproduced DINA-JETTO close coupling simulation.

**Close coupling scheme DINA-JETTO current ramp-up well reproduced Q=10 (~100MW $P_\alpha$)**




- Several JETTO-only interpretative mode simulations revealed that
  - JETTO current diffusion modified central q profile ➔ lower Q
  - JETTO equilibrium (ESCO) shows difference in q at the edge
  - These observations (indirectly) support the DINA-JETTO close coupling scheme, but better to have more investigation.

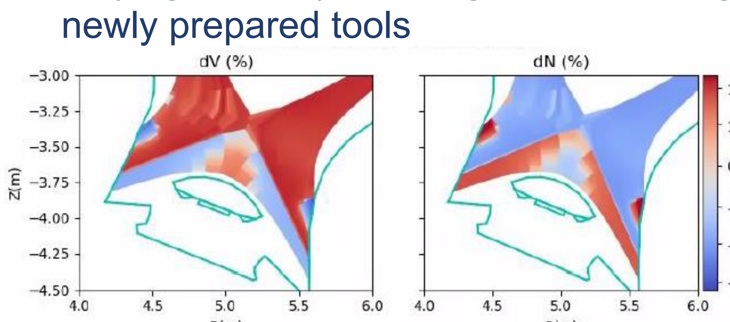
**Close coupling scheme DINA-JETTO current ramp-down**



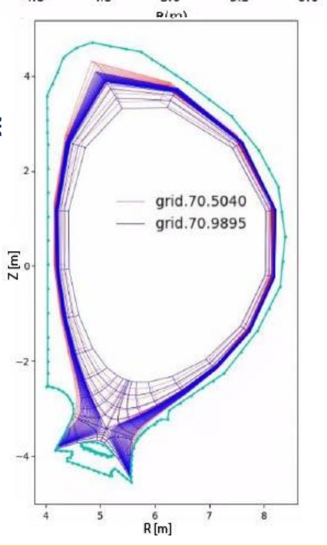

- Sawtooth events were synchronized between DINA (safety factor) and JETTO (electron temperature)

## 6. Coupling of free-boundary equilibrium to update 2D edge/SOL grids

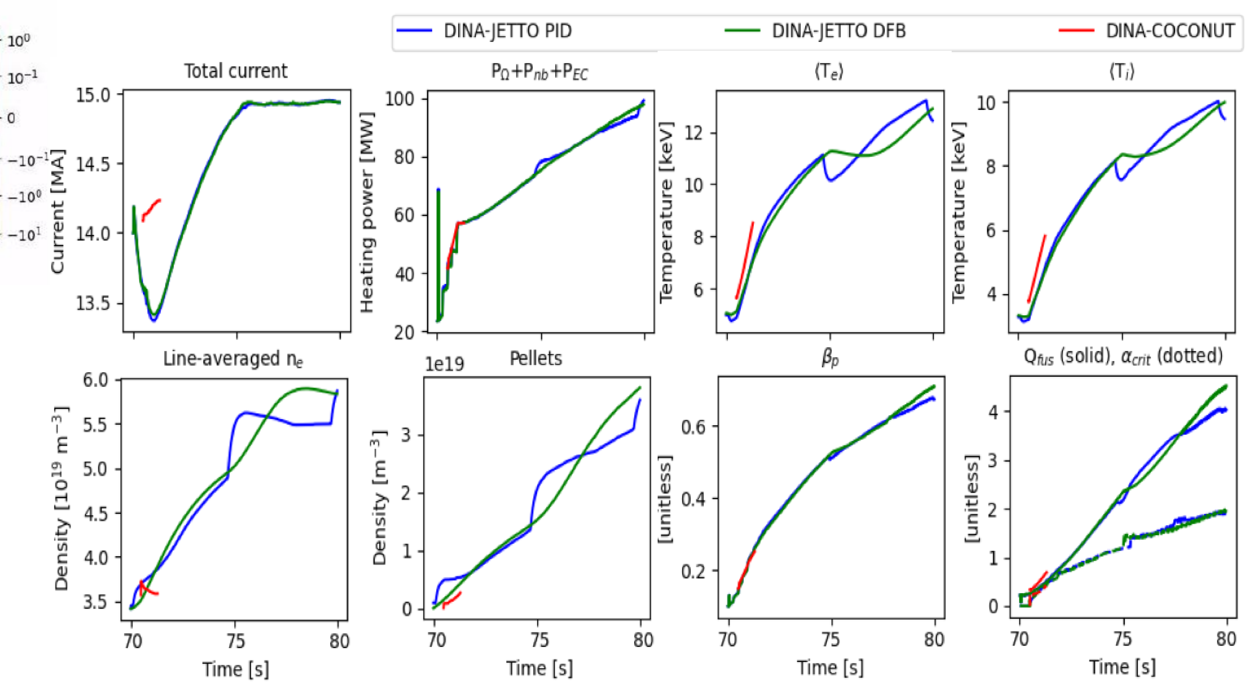
- Pre-prepared sequence of grids (with varying volume) can be generated using newly prepared tools



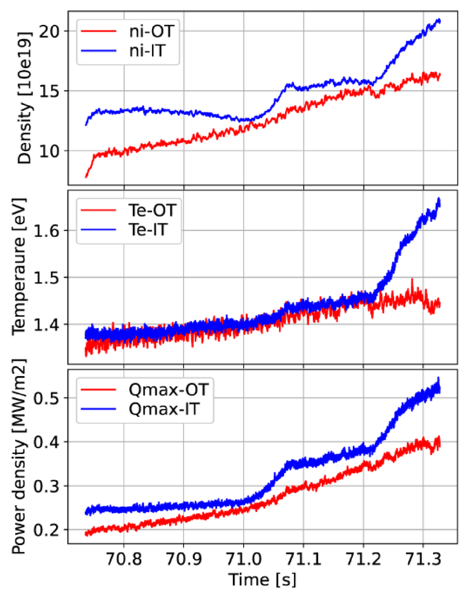

- Dynamic Grid Generation (from the coupled DINA free-boundary equilibrium) is also implemented in JAMS (JINTRAC interface)




- DINA-COCONUT simulations applied to L-H transition phase to verify the plasma solutions against the target and gas-puffing/pumping specification.




Ion density, electron temperature and maximum power load on inner/outer targets




- **An advanced scheme conserving physics** quantities during the 2D edge/SOL grid update is now being implemented [J.G. Lee, APS 2024, EPS 2025]

## 7. Strategy for staged ITER HFPS (DINA+JINTRAC) validation

1. Deployment of stand-alone DINA and JINTRAC (but incl. coupling capabilities) – initial activities started in 2025
2. Preparation of input data / IDSs though IMAS data mapping for machine description, experimental inputs (control signals), measured / processed data – in connection with the IMAS Data Mapping activities
3. Demonstration of magnetic (DINA) and kinetic (JINTRAC) plasma control modelling – 2026/2027
   - DINA free-boundary plasma modelling – verification of the implemented machine description (wall, coils, passive structures) and computed electro-magnetic models
   - DINA magnetic control simulation – verification of implemented magnetic controllers and actuators
   - JETTO core transport and kinetic control modelling – verification of H&CD configurations and power absorption
4. DINA-JETTO and DINA-COCONUT modelling for validation – 2027/2028
   - DINA-JETTO for interpretative experimental discharge modelling
   - DINA-COCONUT for verification of the DINA-JETTO plasma solutions against the edge-SOL/divertor-wall conditions.
5. ITER HPFS modelling for further experimental validation and predictive scenario simulations (contribution to ITER Members' fusion programmes)