

A novel Multi-Timescale strategy for Fusion Systems Codes and its impact to Fusion Power Plants parametric analyses

T. Pomella Lobo^{1*}, I. A. Maione¹

¹ Institute for Neutron Physics and Reactor Technology (INR), Karlsruhe Institute of Technology (KIT), Karlsruhe

Fusion Systems Codes (SCs) are fundamental tools that allow for parameter space exploration and evaluation of technology integration through parametric analyses that may identify relevant systemic dependencies in Fusion Power Plants (FPPs). However, current state-of-the-art SCs model each plant system operating within its own inherent timescale, and neglect the dynamic interdependence between them at a power plant level. A multi-year project is underway to illustrate this gap with novel parametric dependencies, e.g. between SOL plasma filaments parameters and the net power production of the plant, or between the First Wall design temperature and aspects of tritium self-sufficiency.

For that, a novel strategy to produce Multi-Timescale (MT) SCs was tested with a EU-DEMO model built in MIRA, a multi-fidelity SC developed at the Karlsruhe Institute of Technology (KIT). This strategy identified three timescales in which most FPP systems are categorized: (a) the Operation of a FPP (a collection of pulses), (b) a single reactor Pulse and (c) the characteristic time in which Plasma dynamics evolve.

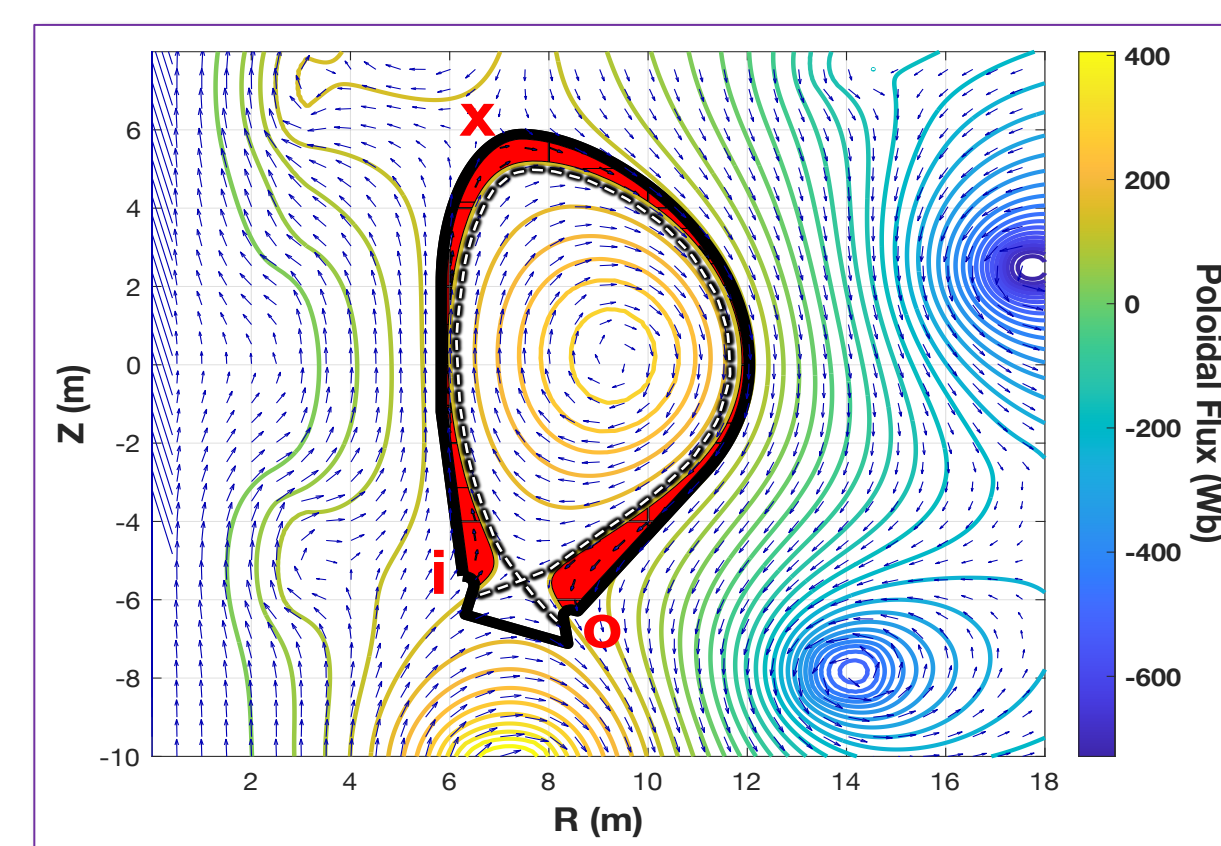
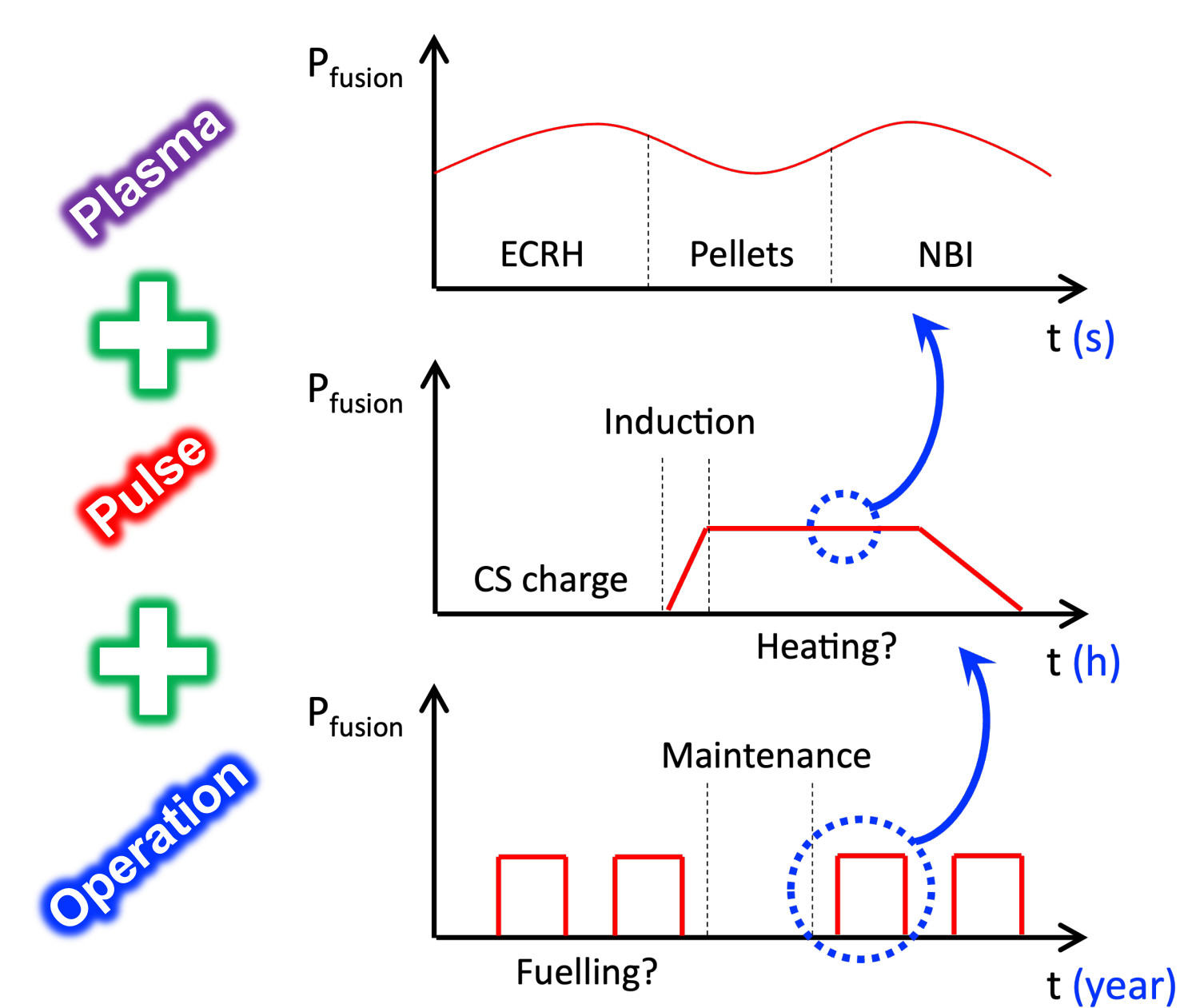
New models have been developed to depict essential phenomena of systems in each timescale. For (a), a multi-species Fuel Cycle module computes fuel accumulation rates using a residence-times (τ) model, with τ -parameters derived from the characterization of selected technologies. For (b), a Power Cycle module computes the net power production by the Balance-of-Plant systems using thermodynamic models. For (c), SOL plasma dynamics are computed with scaling laws and an optimized surrogate of the code TOKES, to estimate heat and particle distributions along the reactor chamber wall. Consistent coupling is ensured by using results from (c) to compute outgassing fluxes with the double-diffusion code TESSIM-X. This impacts the dwell-time, and thus the dynamics of both (a) and (b), which leads to stronger dependencies than those obtained from non-MT codes.

Keywords: Scrape-Off Layer (SOL), Balance-of-Plant (BOP), Fuel Cycle, Systems-Codes, EU-DEMO

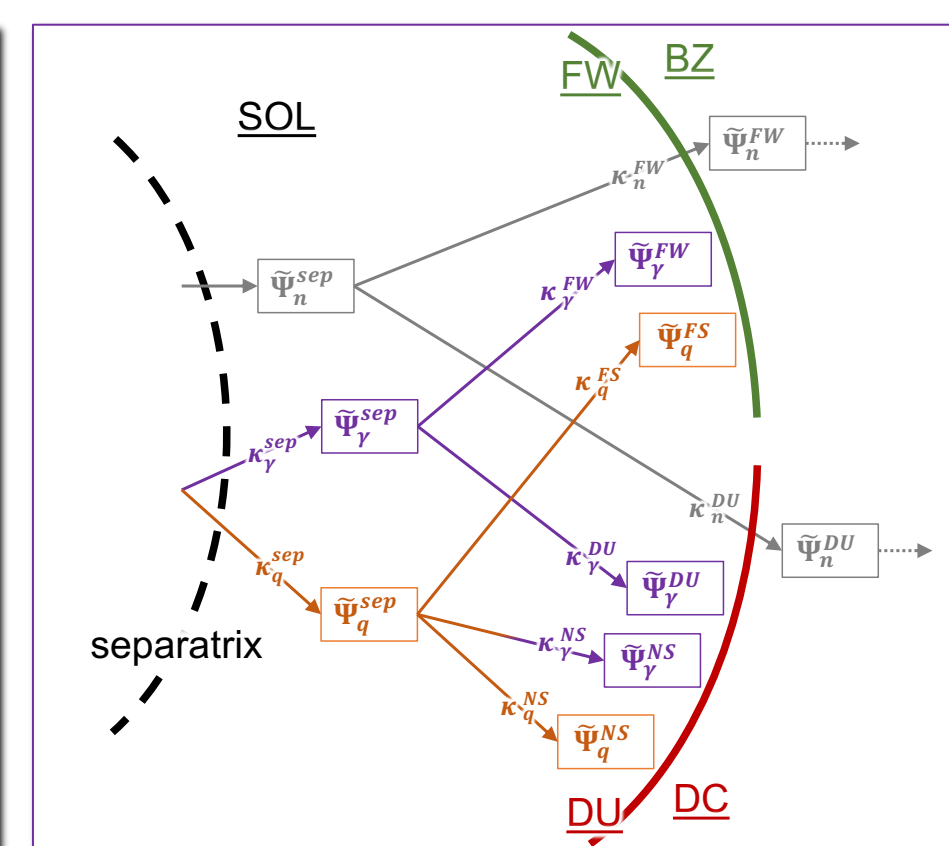
*Contact: t.pomella-lobo@kit.edu

Context & Objectives

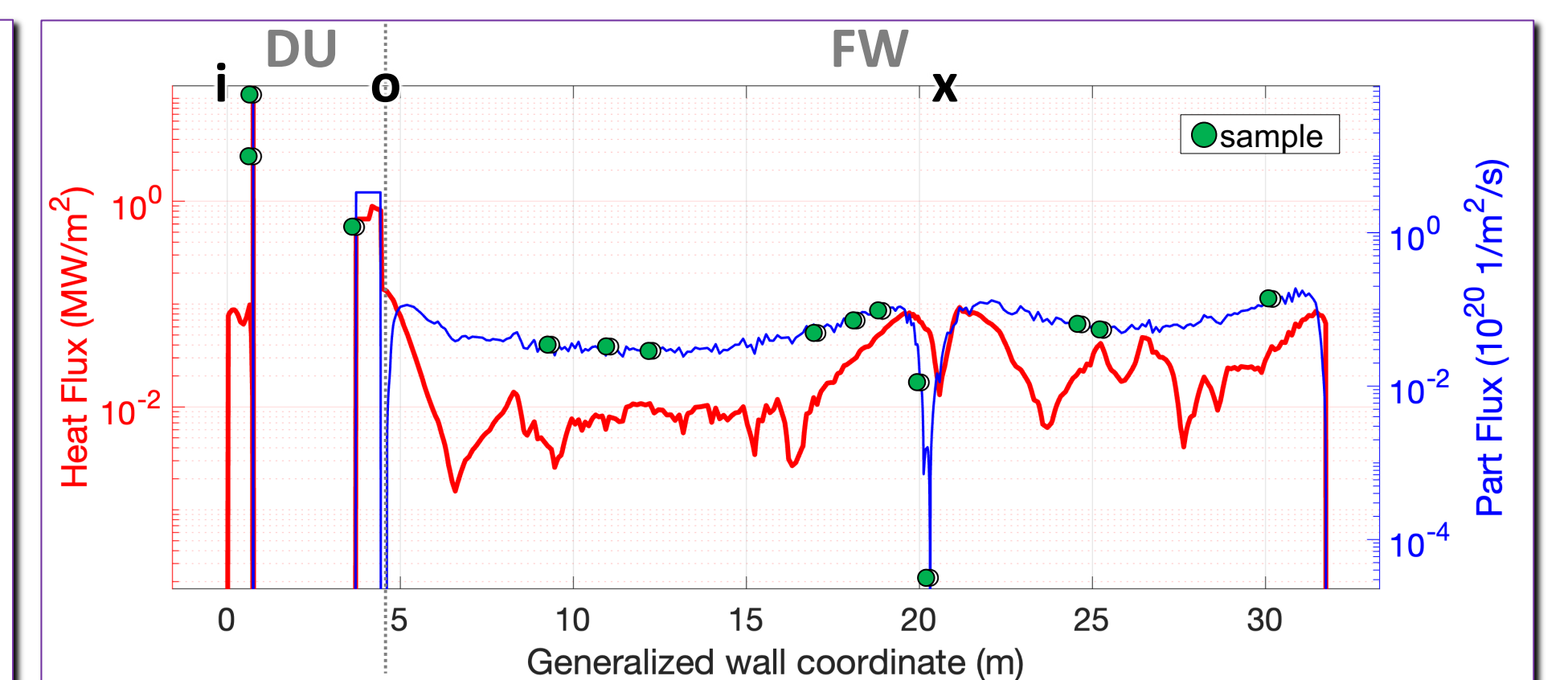
- reactor design → power plant design
- study-case: impact of **dwell time**
- expand MIRA (inherited reactor code [1])



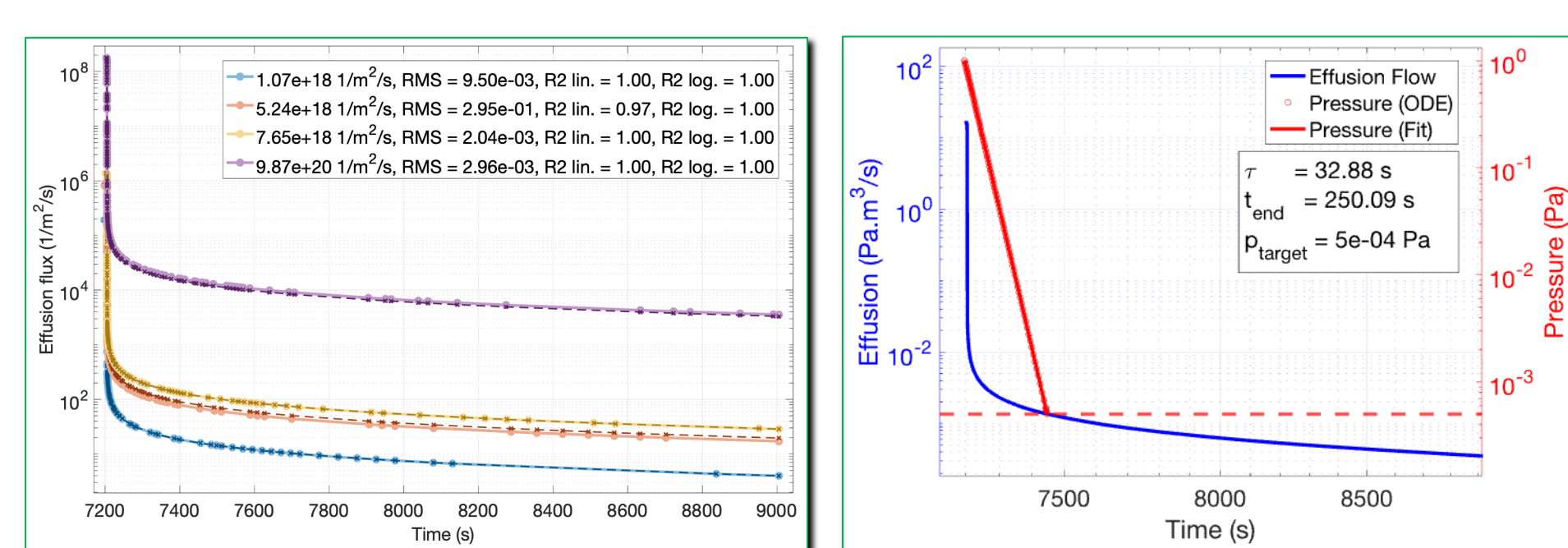
inherited MIRA: reactor config. & confined plasma



SOL transport: power balance & deposition channels



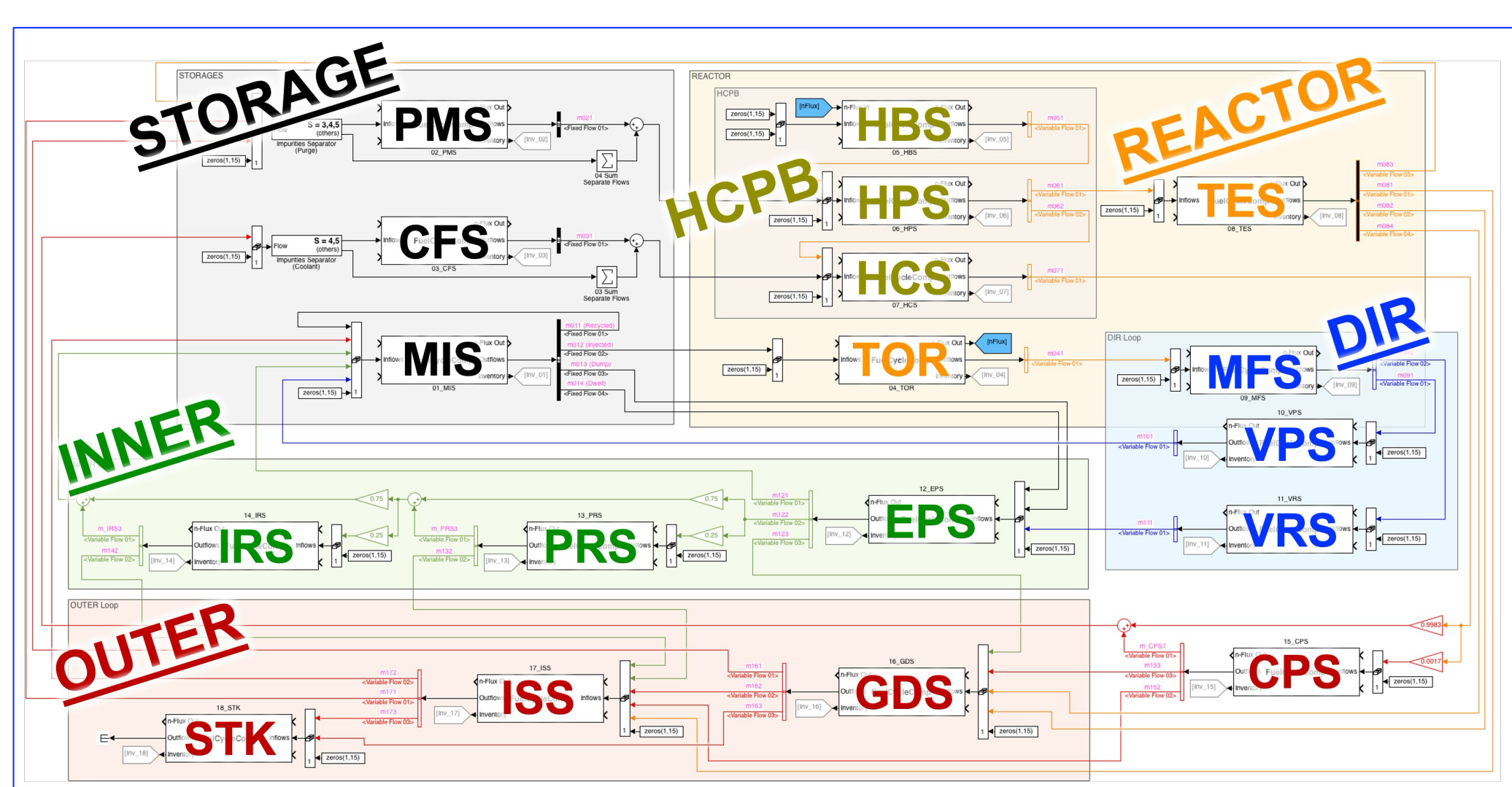
Superimposed NS + FS profiles due to charged particles



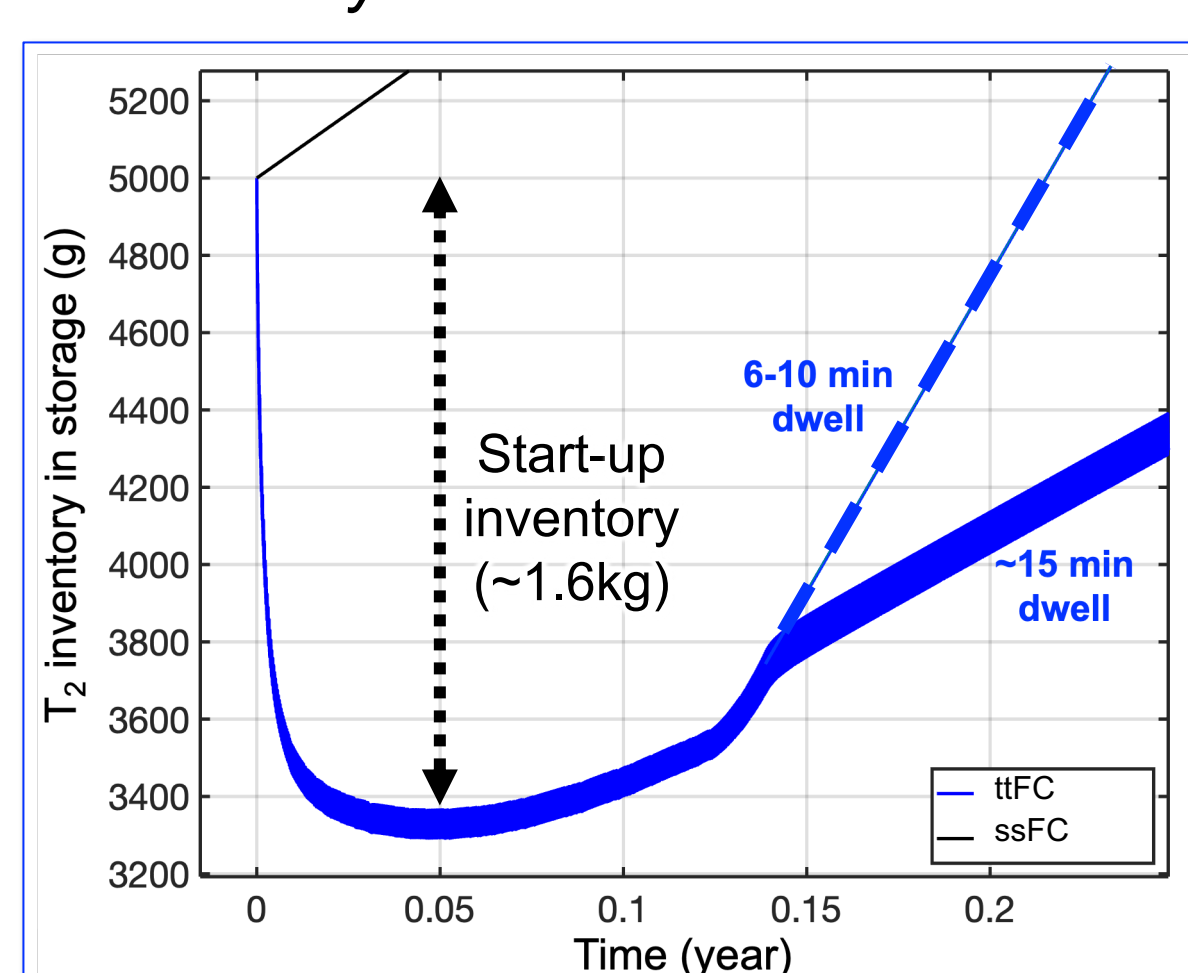
Cross-validation of log-interpolation model

Pump-down: effusion flow & pressure decrease in time

- goal: compute pump-down dynamics
- Loading:** Cumulative Distribution Function (CDF) sampling from SOL
- Unloading:** diffusion & trapping from TESSIM-X [3] + log-interp model
- verify: ~1/4 of runs for cross-validation



Fuel Cycle: ttFC with residence-times parameters from ssFC



Preliminary coupled results

- steady-state Fuel Cycle (ssFC)**
 - goal: characterize technologies
 - verify: against KIT Fuel Cycle
- transient Fuel Cycle (ttFC)**
 - goal: time-dependent net fuel
 - verify: against BLUEPRINT