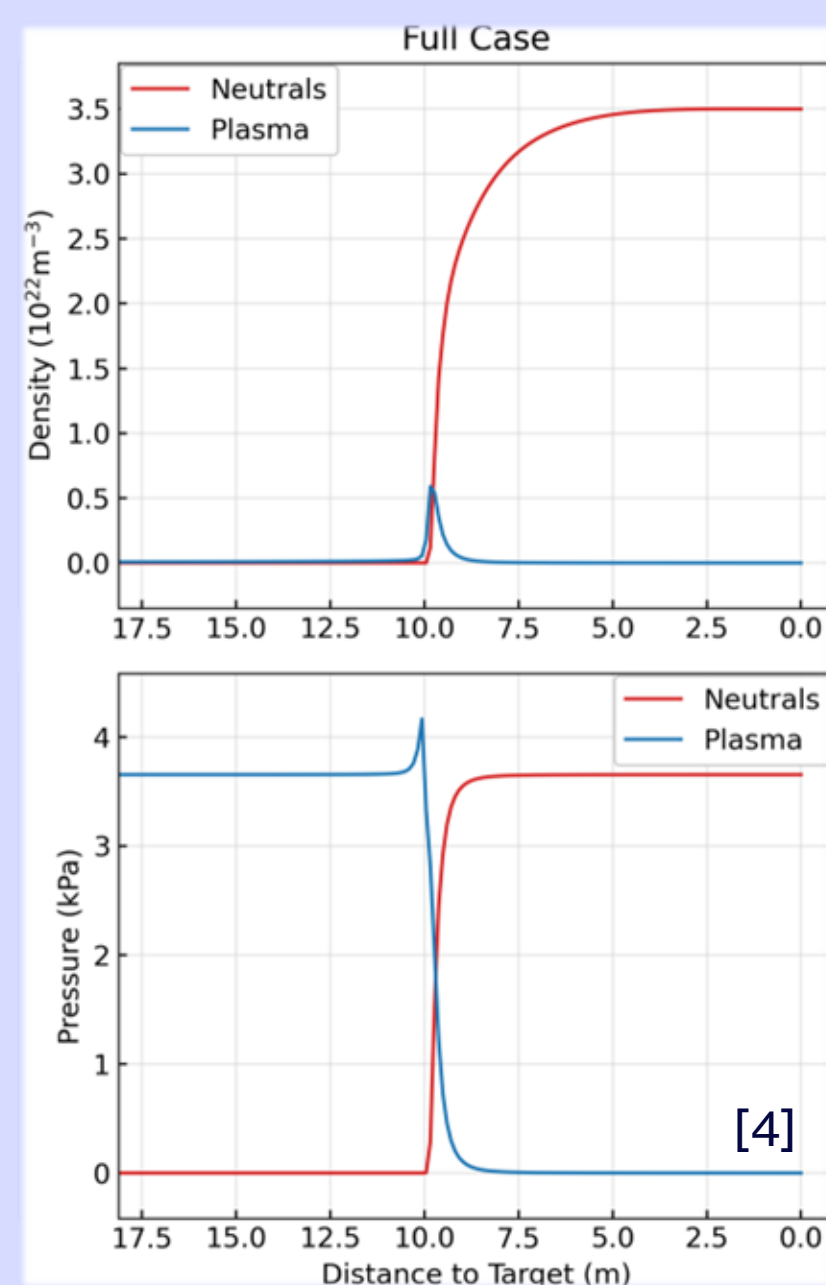
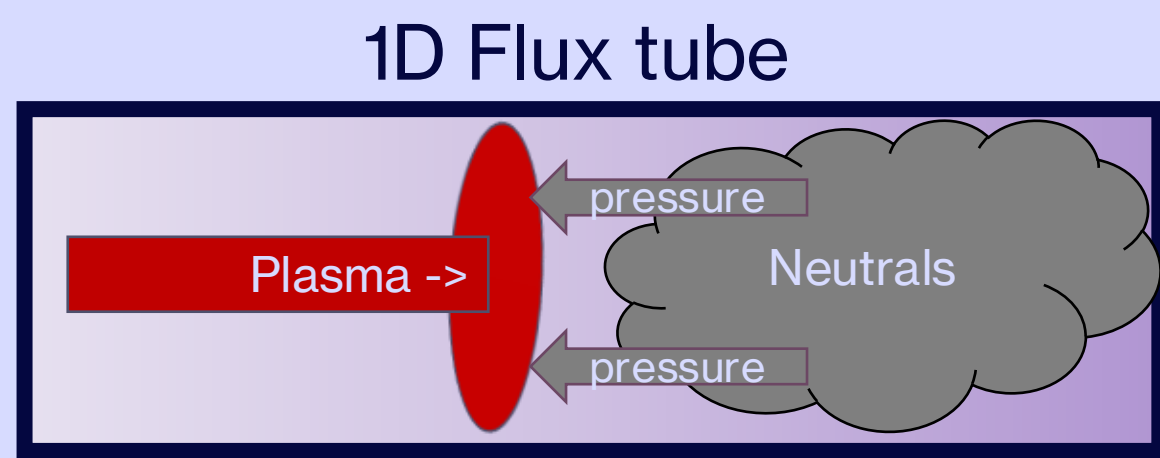


Introduction

- STEP's compact design poses severe exhaust challenges, requiring double null divertor configurations with impurity seeding to sustain viable detachment.
- Transient power loads from fusion/radiated power fluctuations or vertically displacement induced disconnected double null effects risk burning through detachment fronts and damaging the divertor
- High-fidelity SOLPS-ITER simulations of such transients are prohibitively expensive, motivating reduced 1D fluid models to scope the parameter space efficiently
- Neutral fluid models (especially in 1D) come at a price, requiring special consideration of fluid momentum, which plays a significant role in detachment front burn-through

Neutral piston effect

- Local charge exchange advects momentum to fluid bulk rapidly due to fluid momentum equation
- In 1D, this acts as compressive 'piston', establishing neutral-plasma pressure balance and driving extreme neutral density

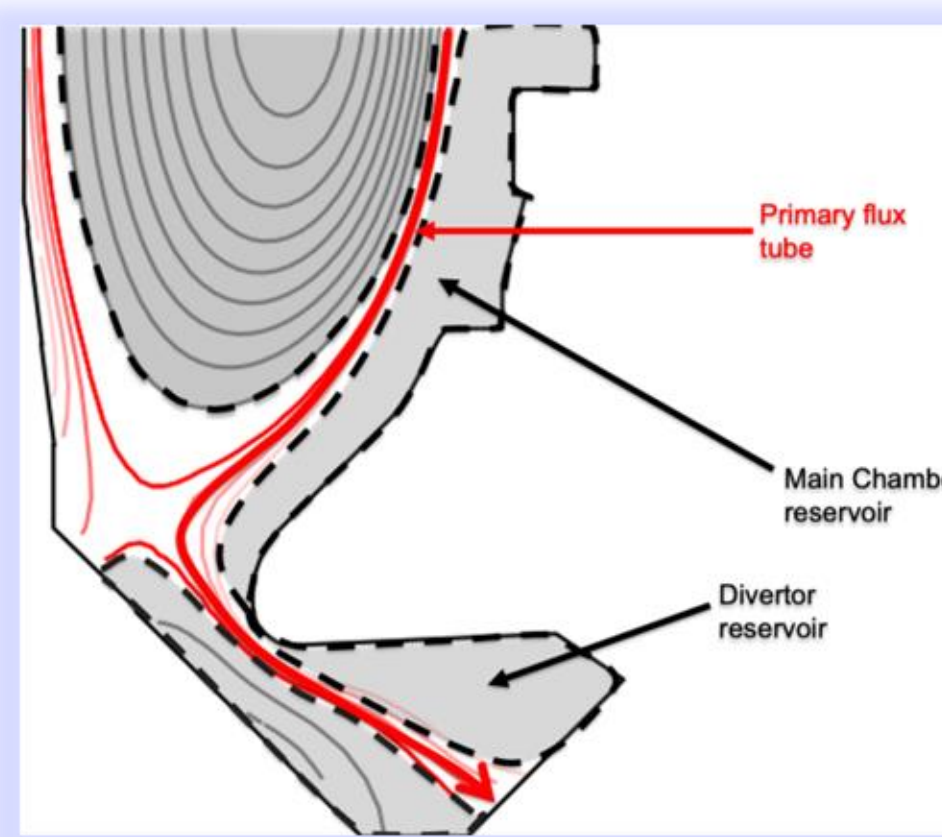


Hermes-3

- Hermes-3 [1] is an open source multi-fidelity exhaust fluid code built on the BOUT++ [2] framework, capable of 1/2/3-dimension simulations of both transient and steady state transport and turbulence
- Advanced fluid neutral model, similar to that of Horsten et al. 2017 [3], provides highly efficient computation allow for rapid exploration of transient parameter space, however, makes a key assumption – neutrals are collisional

$$\begin{aligned}
 \text{Continuity} \quad \frac{\partial n_n}{\partial t} &= -\nabla \cdot (n_n v_{n,\parallel}) + \text{Source/Sink terms, ionisation, recombination, CX, ect} \\
 \text{Momentum} \quad m_n \frac{\partial v_{n,\parallel}}{\partial t} &= -\nabla \cdot (v_{n,\parallel} m_n \Gamma_{n,\parallel}) - \nabla_{\parallel} P_n + \nabla \cdot (\eta_n \nabla_{\parallel} v_{n,\parallel}) + \text{Viscosity} \\
 \text{Pressure} \quad \frac{\partial P_n}{\partial t} &= -\nabla \cdot (P_n v_{n,\parallel}) + v_{\parallel} \nabla P_n + \nabla \cdot (\kappa_n \nabla_{\parallel} T_n) - \frac{2}{3} v_n \nabla \cdot (\eta_n \nabla_{\parallel} v_n) + \text{Viscous heating}
 \end{aligned}$$

Reservoir models

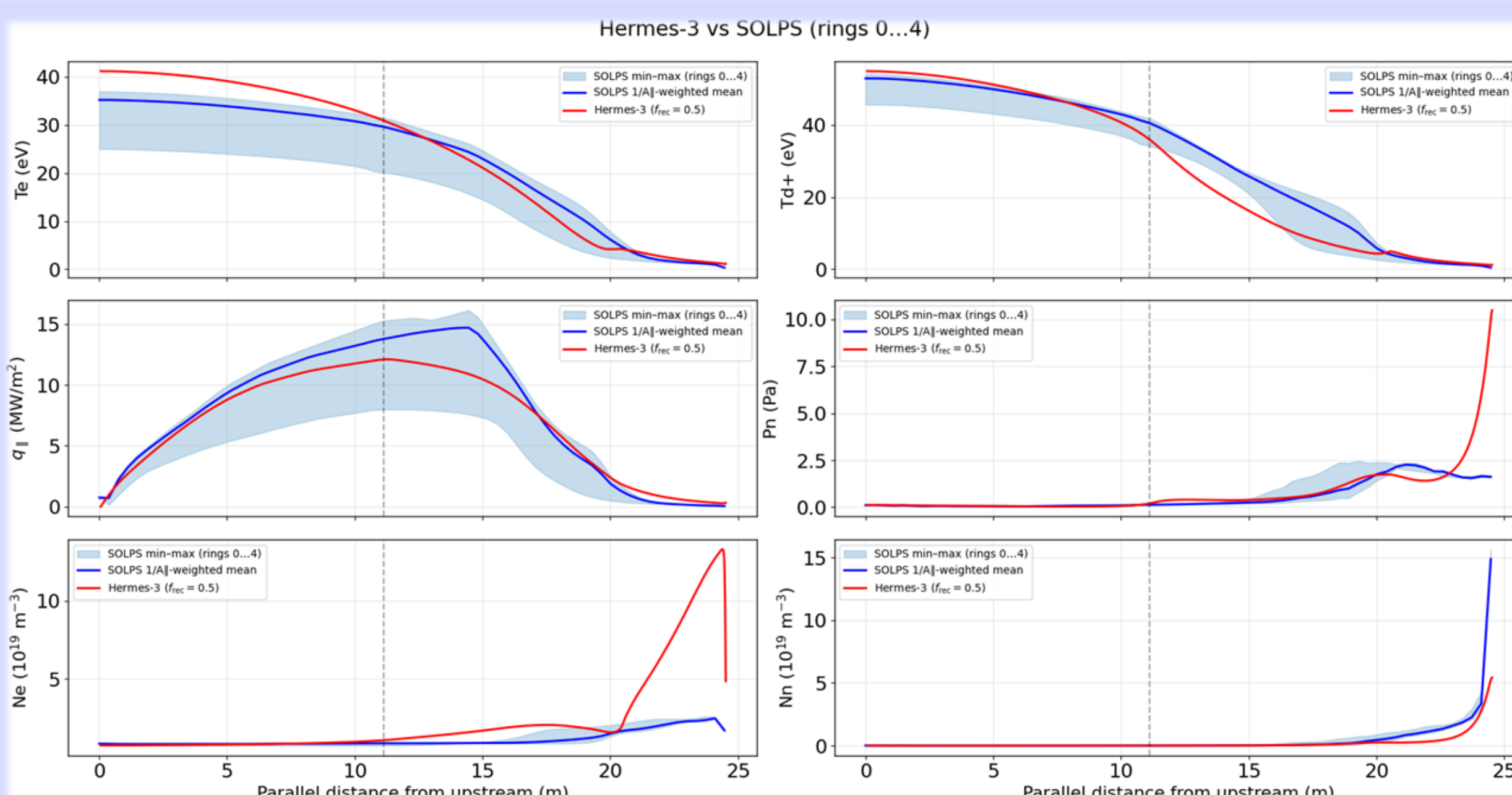


$$N_{\text{rate}} = (N_{\text{reservoir}} - N_{\text{sol}}) A_{\text{side}} v_{th} \alpha_{\text{res}} \quad v_{th} = \frac{\sqrt{8T_d/m}}{4}$$

- Alternative approach to capture neutral cross field transport, based on Derks et al. 2024 [5], applied to Power transients in MAST-U and STEP
- Reservoir exchange rate purely based on relative density between simulation and external reservoir, thermal velocity of the reservoir and a tuning factor

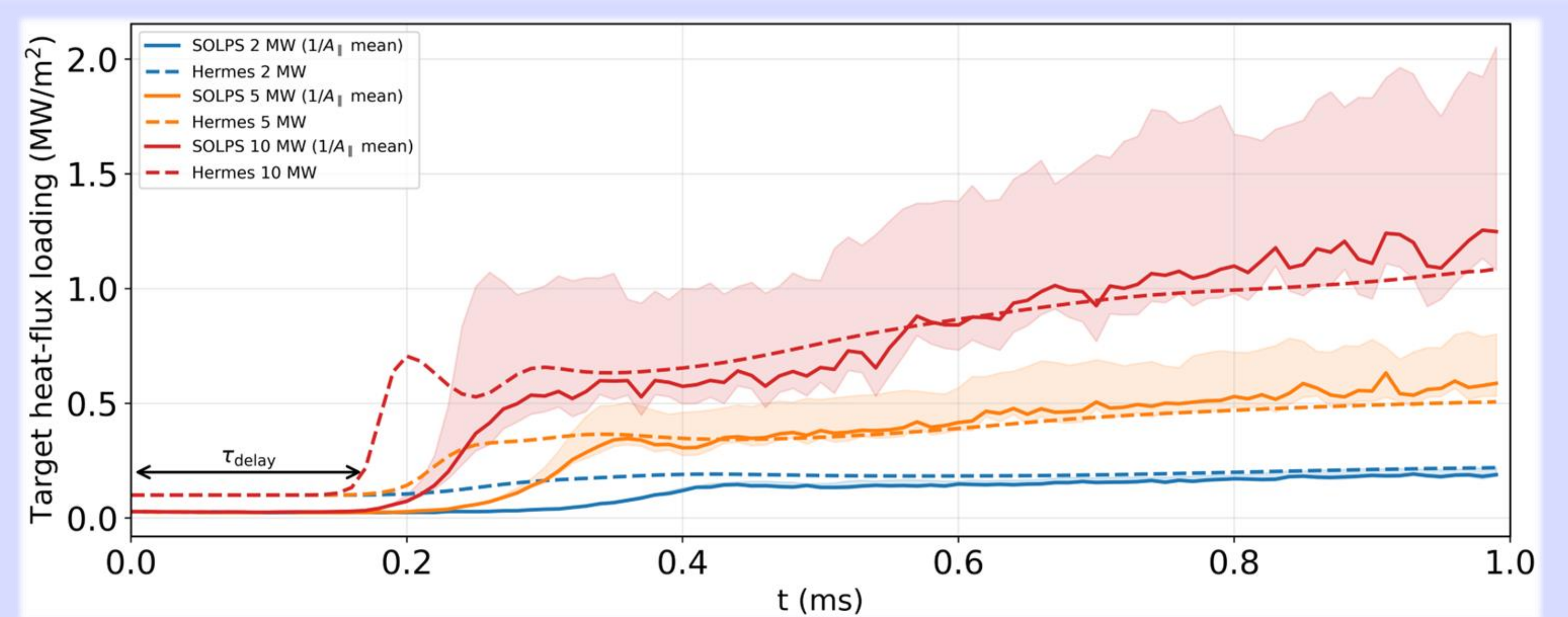
MAST-U:

Steady State



- Comparison of Hermes-3 1D to MAST-U SOLPS simulations of 46860 L-mode [6]
- Addition of molecules expected to improve match in future

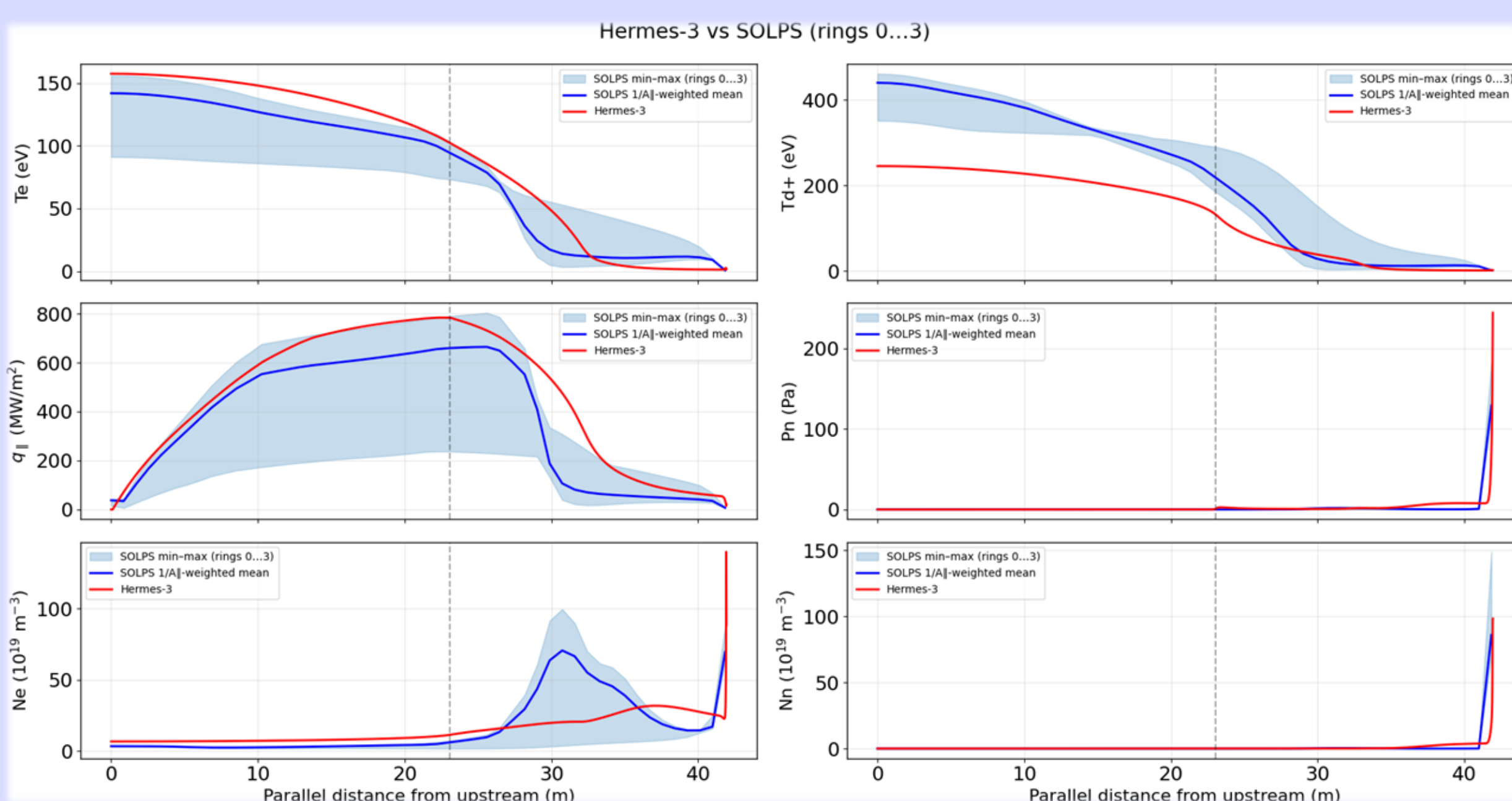
Transient



- MAST-U Type-I ELM fluences applied to steady state and compared to prior SOLPS-ITER simulations [7]
- Good agreement in target heat-flux loading magnitude, Hermes-3 higher T_{d+} and C_s mean convective heat flux arrives earlier

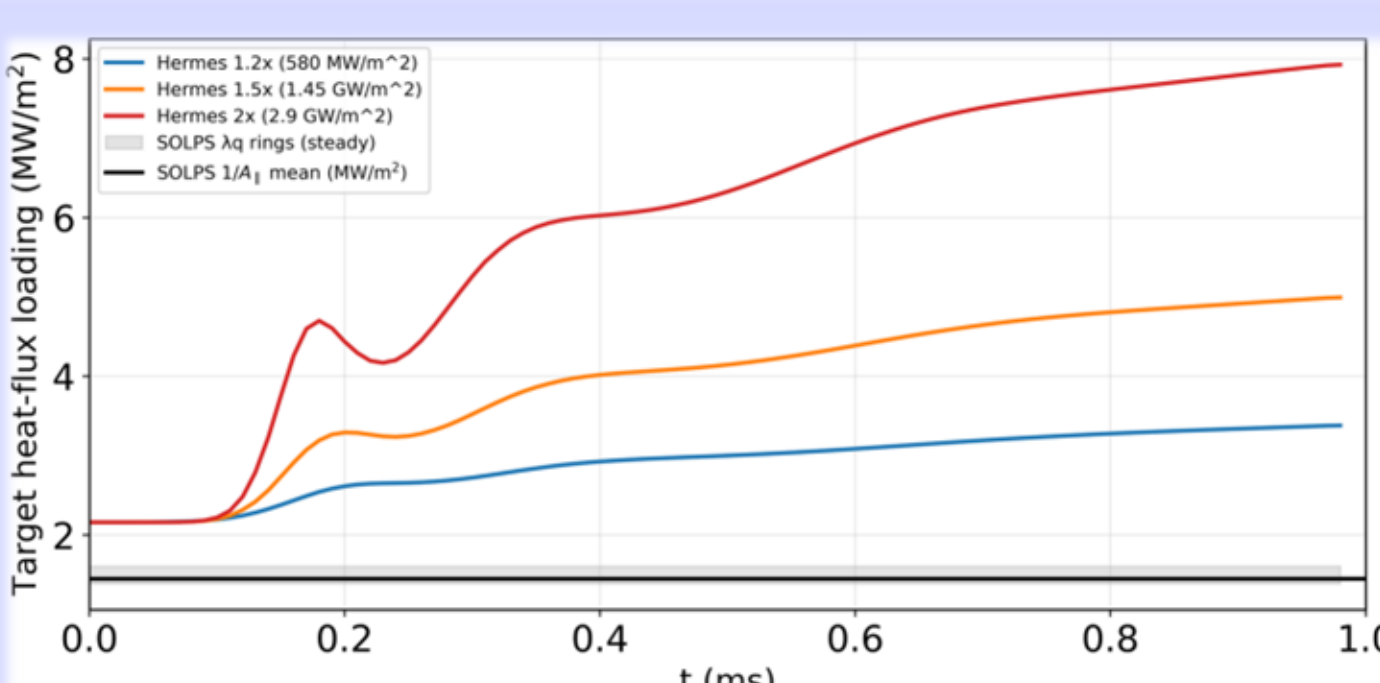
STEP:

Steady state



- Comparison of Hermes-3 1D to MAST-U SOLPS simulations of STEP SPR V10 [8]
- Lower T_{d+} upstream currently under investigation

Transient



- Transients applied on order of disconnected double null imbalance
- Target loading ($\leq 10 \text{ MW/m}^2$) entirely convective, with little movement of detachment front
- Fixed fraction argon culprit, buffers majority of transient

Conclusions

- Applications of reservoir models improve 1D match significantly to MAST-U and STEP
- Transiently, reservoirs appear to perform far better than expected, however significant improvements can be made
 - Time dependent inventory
 - Response delay between reservoir and main simulation
- Improvements to fixed fraction radiation scheme required for STEP (fixed density? impurity transport?)