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Validation of time-dependent boundary plasma simulations with SOLPS-ITER against dynamic detachment experiments in the ASDEX Upgrade tokamak

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Introduction and motivation

- Power exhaust control is essential to keep the heat flux to the divertor surfaces within material limits
- Time-dependent plasma boundary simulations can be an important contributor to control design in future fusion reactors
- SOLPS-ITER [1,2] (Scrape-Off-Layer Plasma Simulator) is a mean-field plasma boundary code, historically used for the ITER divertor design
- However, the code has been mostly used in steady-state, and a fundamental validation in time-dependent mode is missing

SOLPS-ITER

- Advanced Fluid Neutral (AFN) models [3,4] can achieve an accurate description of hydrogenic neutrals in high collisionality regions
- The time-dependent algorithm of the fluid module B2.5 has recently been numerically verified and improved [5] in the 'Wide Grids' 3.2.1 code version [6]

B2.5
Braginskii plasma fluid equations
Finite Volume (FV) solver

+

EIRENE
Monte Carlo (MC) solver of kinetic Boltzmann equation

or

AFN
Fluid neutral equations solved within B2.5 (FV)

→ **This poster: validation of SOLPS-AFN dynamic detachment simulations**

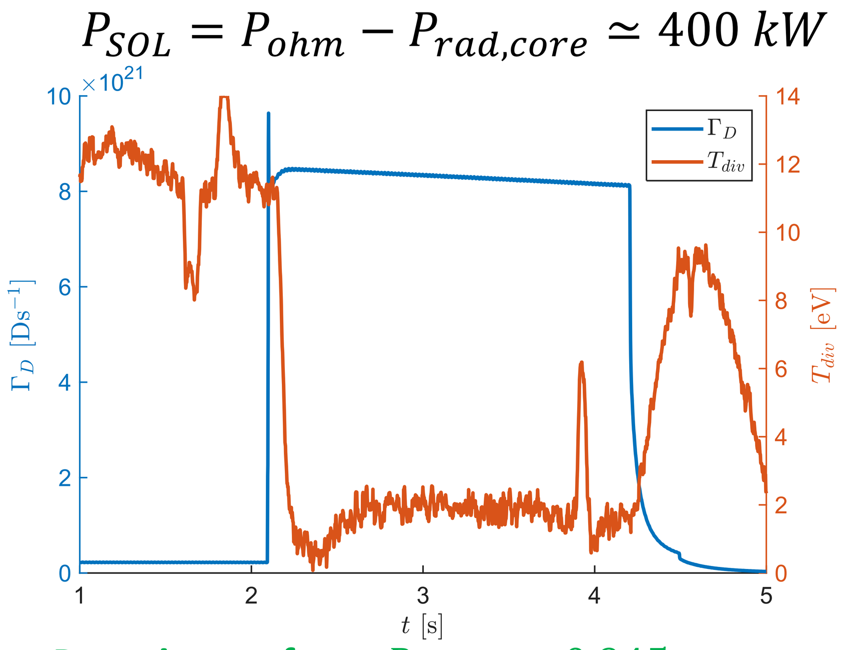
Experimental Validation

ASDEX-Upgrade #42650/1

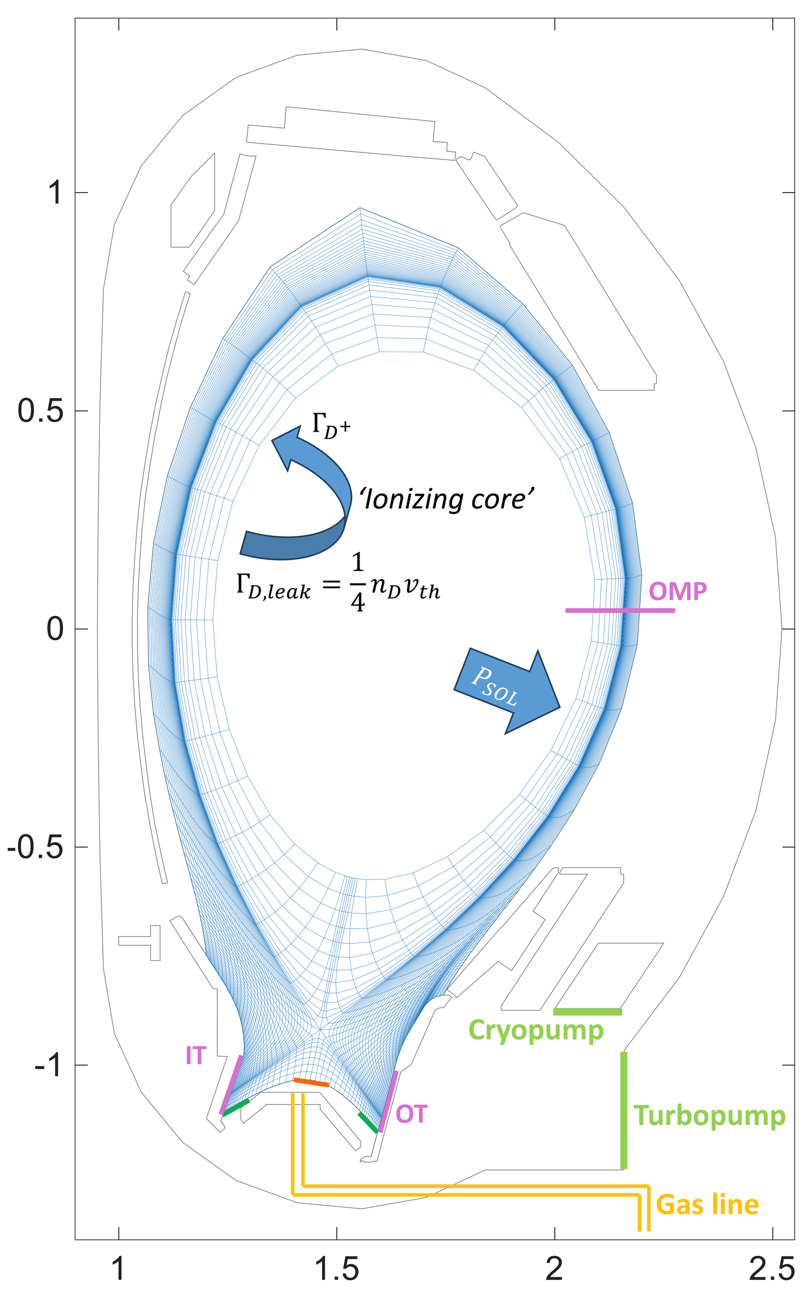
- Trigger detachment with a step in D fueling
- Low-power L-mode scenario to detach without impurities:

$$P_{ohm} \simeq 600\ kW$$

$$P_{SOL} = P_{ohm} - P_{rad,core} \simeq 400\ kW$$



SOLPS Simulation



Pumping surfaces $R_{pump} = 0{,}945$

Simulated puff

$\Gamma_{D,initial} = 2{,}8 \times 10^{20} D/s$ (+27% exp)

$\Gamma_{D,final} = 8{,}3 \times 10^{21} D/s$

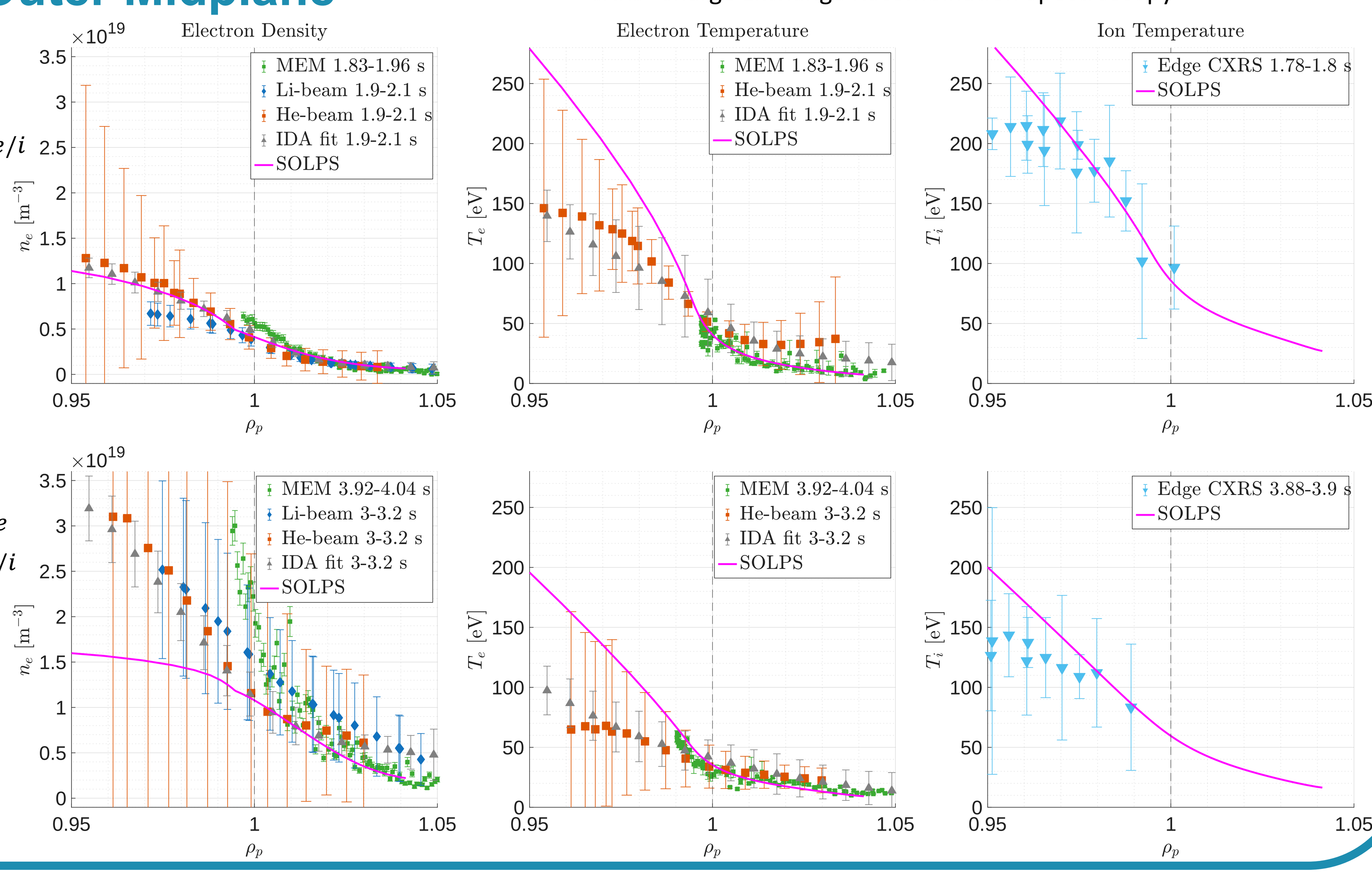
Anomalous Transport $D_{\perp,core} = 0{,}18\ m^2/s$; $D_{\perp,SOL} = 0{,}4\ m^2/s$; $\chi_{i/e} = 0{,}7\ m^2/s$

Outer Midplane

MEM: Midplane Manipulator Probe; IDA: Integrated Data Analysis; CXRS: Charge Exchange Recombination Spectroscopy

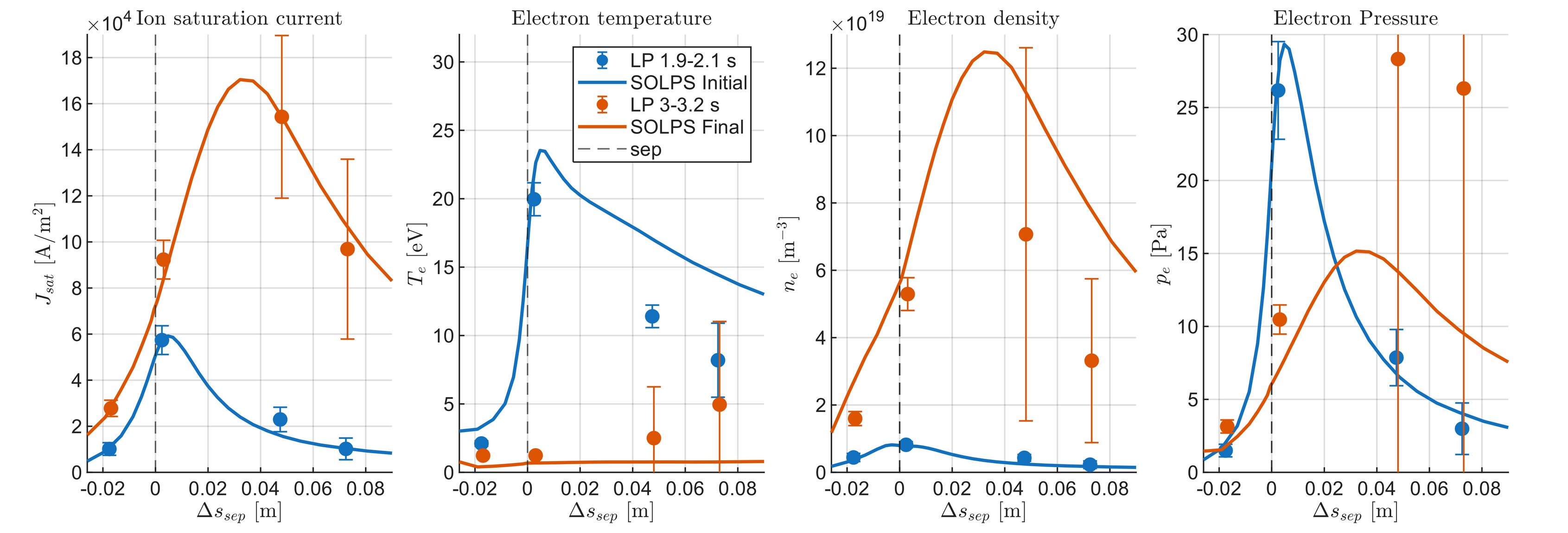
Initial: low n_e high $T_{e/i}$

Final: high n_e low $T_{e/i}$

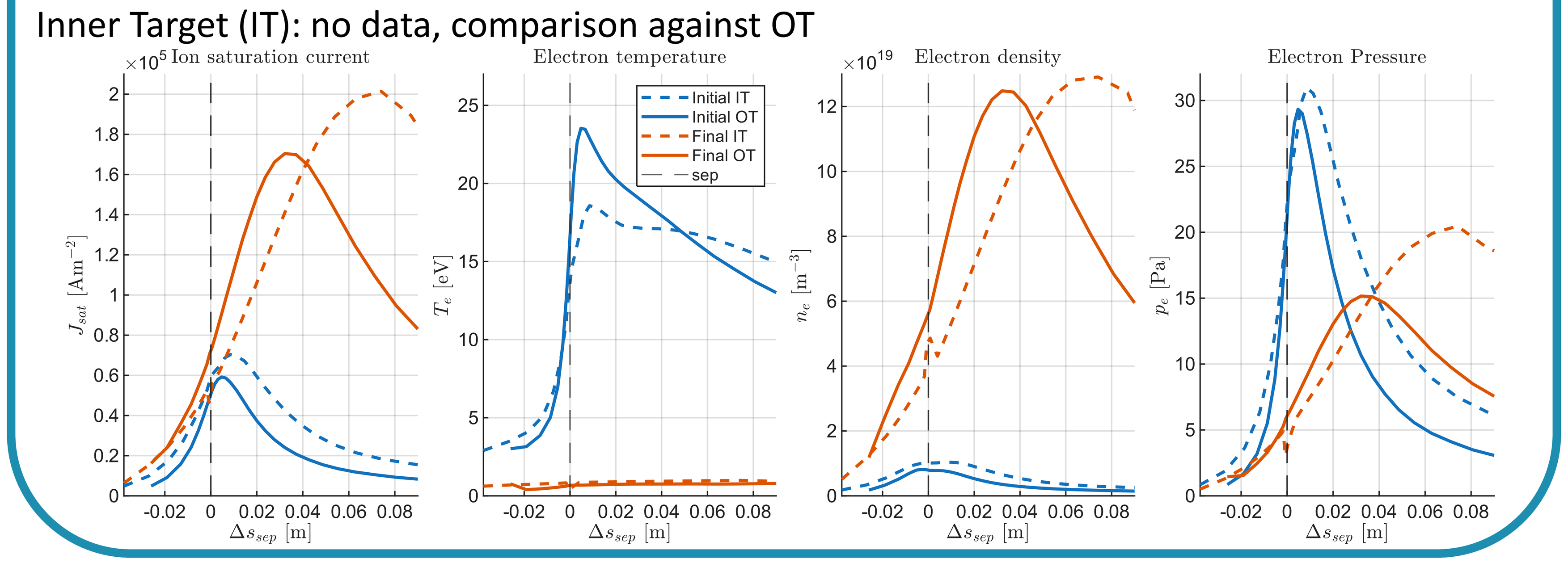


Targets

Outer Target (OT): comparison with Langmuir Probes (LP)

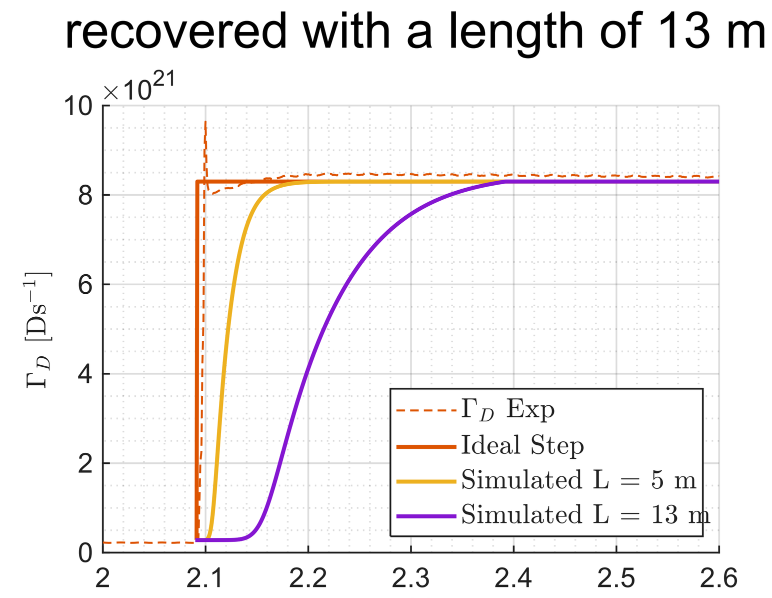


Inner Target (IT): no data, comparison against OT

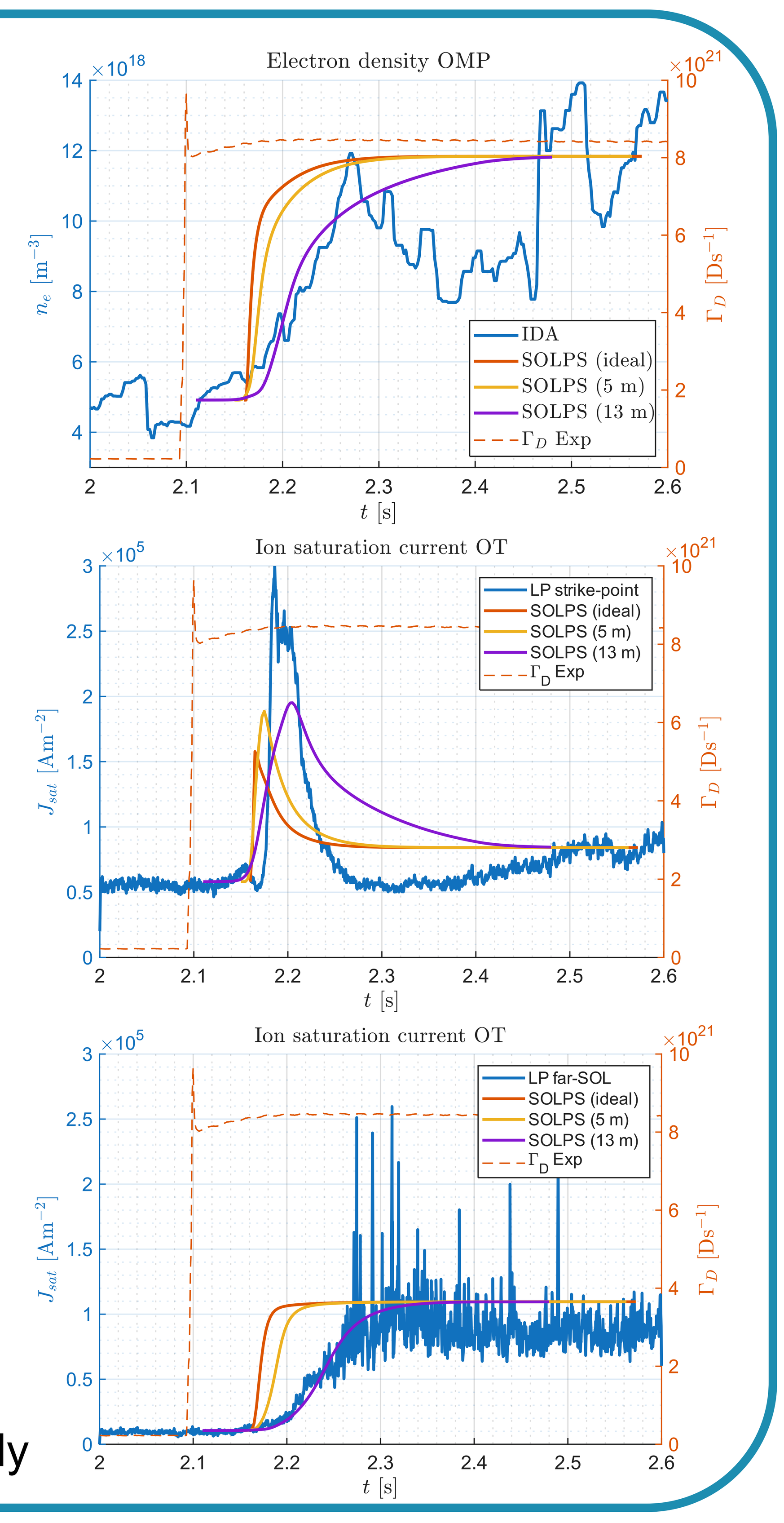


Time-dependent

- Simulation: 2nd order backward differentiation scheme with $\Delta t = 10^{-6}$s
- Gas flow through pipe (L = 5 m, D = 4 mm) modeled with 1D fluid model from [7]
- 5 m model underpredicts experimental delay, which can be recovered with a length of 13 m



- Matching experiments requires assuming a longer pipe
  → indicates either pipe model limitations or missing slow dynamics
  → assess pipe delay experimentally



Conclusions and perspectives

- SOLPS-AFN reproduces qualitative trends, but quantitative agreement can be improved.
- Key uncertainties remain and are part of on-going work: core dynamics, kinetic neutrals, missing molecular physics, pipe model, first wall recycling, …
- Experimental scenario proved not optimal to isolate SOL dynamics
  →New experiments in H-mode to decouple upstream from divertor, but impurity seeding will be required

References
[1] X. Bonnin *et al 2016 Plasma Fusion Res.* [2] S. Wiesen *et al 2015 J. Nucl. Mater.*
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[5] F. Cursi *et al 2025* PET Workshop [6] W. Dekeyser *et al* 2021 *Nucl. Mater. Energy*
[7] S. J.W. van Laarhoven, 2024, Master Thesis TUe

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