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First time-dependent SOLPS-ITER simulations of detachment burn-through on MAST-U

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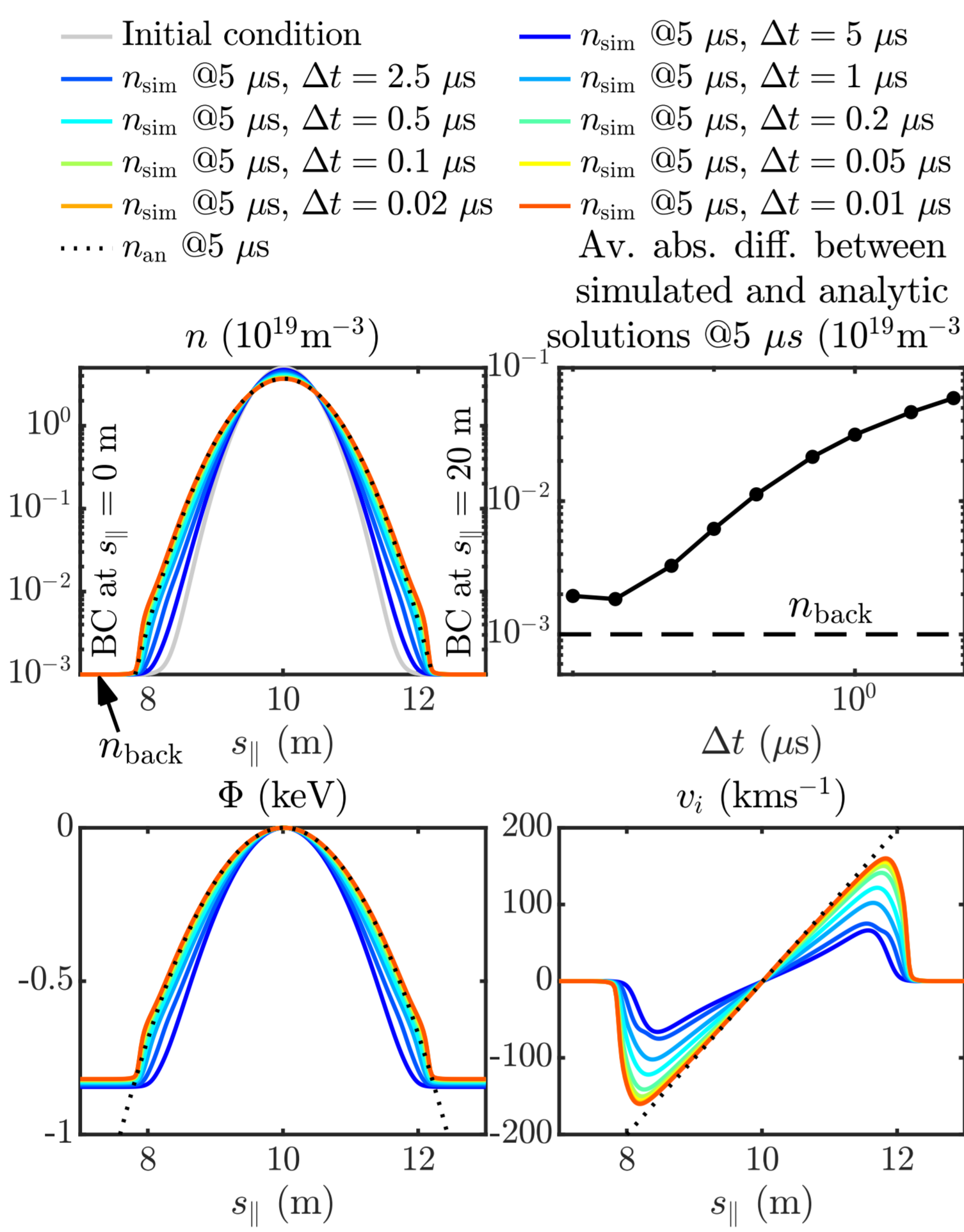
^bSee the author list of N. Vianello et al 2026 Nucl. Fusion in press (<https://doi.org/10.1088/1741-4326/ae71ec>)

SUMMARY

- We present the first interpretative simulations of transient burn-through on MAST-U in Super-X divertor (SXD) configuration, using fully time-dependent SOLPS-ITER.
- Simulations agree with measured Type-I ELM IR peak heat loads and Fulcher emission.
- Simulations do not align with a model whereby a single energy threshold for burn-through exists, set by the energy required to ionise the pre-existing neutral reservoir.
- Rather, a time threshold is observed in the simulations that corresponds to the parallel convection time, followed by a loading of the target that is strongly dependent on target recycling (no recycling leads to factor ~5 higher peak target heat loads compared to instantaneous recycling).
- In some cases, increased ion heating leads to significantly (more than double) higher peak loads. This could be a possible mechanism for 'high burn-through events'.

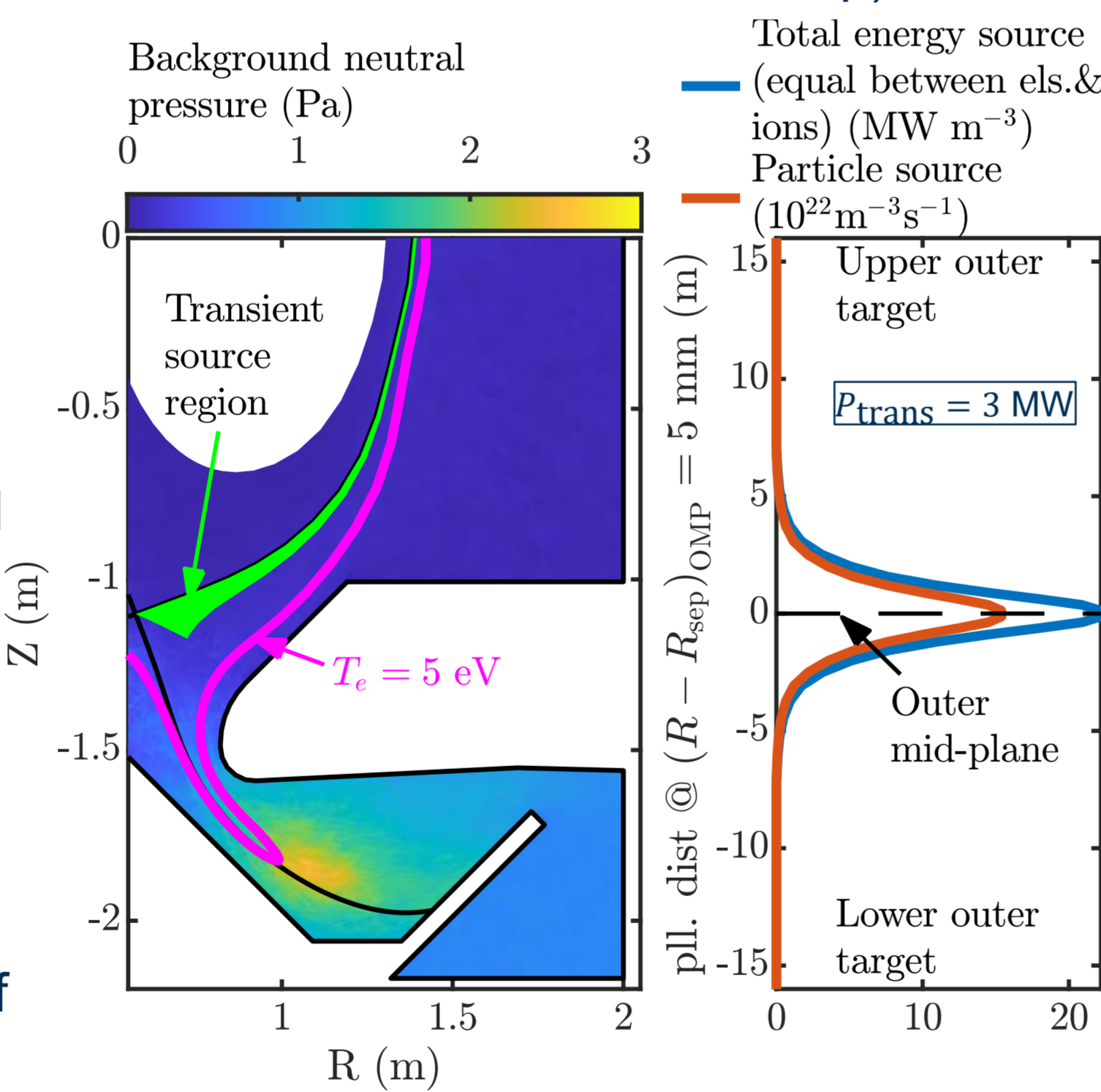
COMPARISON TO ANALYTIC SOLUTION FOR 1D ISOTHERMAL PLASMA EXPANSION INTO VACUUM

- The B2.5 time-dependent model has been verified against the analytic solution for a 1D isothermal expansion of a gaussian density perturbation into vacuum [Mora 2005].
- Good agreement is observed when sufficient spatial and time resolution is used.
- Critical to use the latest code version (since 20/3/2026) in order to get the correct behaviour (otherwise timescales can scale inversely with the number of internal iterations due to a bug introduced on 9/2/2023).
- Comparison to adiabatic expansion given in [Mora 2005] not possible since his energy equation assumes constant T_e .
- A less vigorous verification of time-dependent Eirene was also performed via comparison to an in-house neutral code and experimental dry runs (not shown).



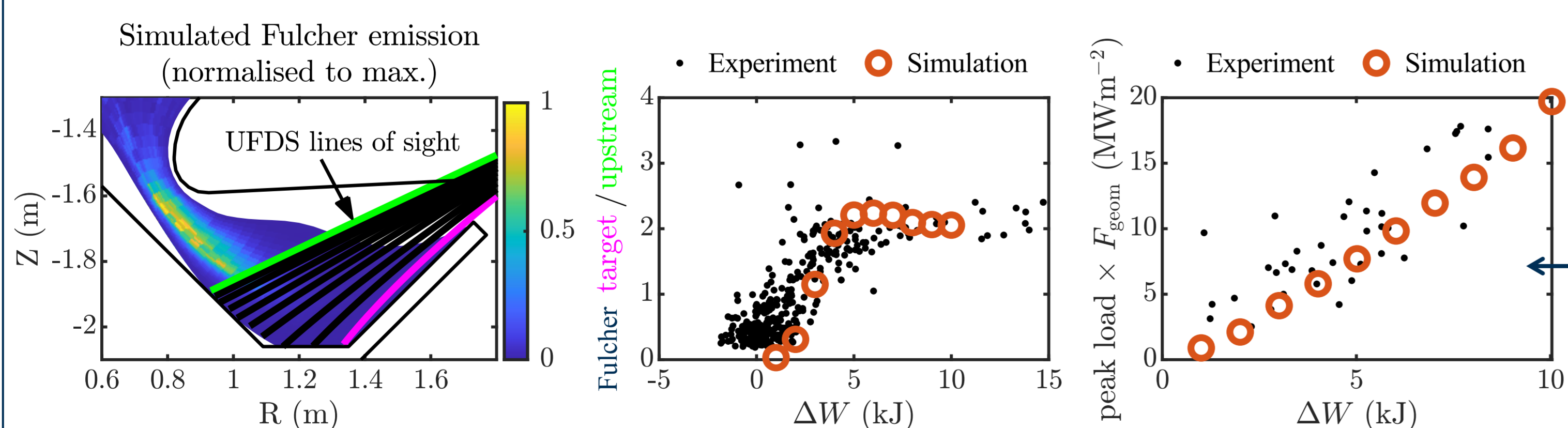
ELM SIMULATION SETUP

- Pure D Simulations reconverged in time-dependent mode (b2mndt_style=2, Eirene time census with time horizon equal to B2.5 time step, warm restart [NPTST=0] with 5×10^7 histories + 2000 new histories launched from each strata at each new step)
- Time-dependent SXD background simulation matches well to quasi-steady-state simulations shown previously [Verhaegh 2025]
- For initial study, we use this same $P_{sep} = 1$ MW beam heated L-mode background throughout and impose an instantaneous upstream source: 1 ms duration; $\lambda_{trans} = 1$ cm width; plasma energy (S_E) and particle (S_n) source upstream s.t. $S_E = 3kT_{ped}S_n$ [Havlickova 2012] ($T_{ped} = 300$ eV chosen here, electron and ion given equal energy in reference cases).
- Simplification to have an instantaneous source removes the additional timescale of the source from our analysis.
- Total transient power P_{trans} was scanned.



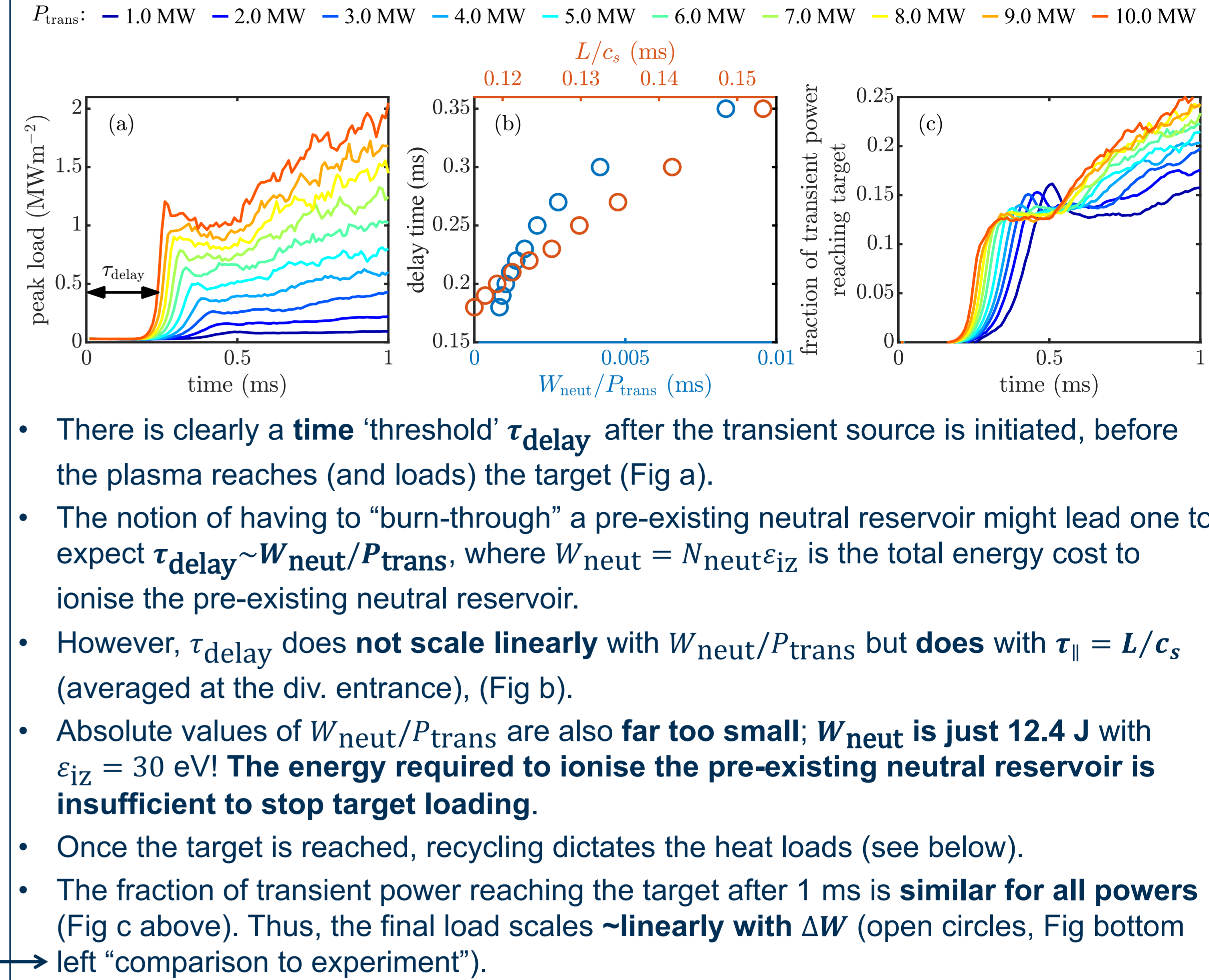
COMPARISON TO EXPERIMENT

- Compare simulations to Ultra Fast Divertor Spectroscopy (UFDS) Fulcher emission and Infra-red (IR) target heat loads of ELMs on MAST-U [Flanagan 2025, Flanagan 2026]:



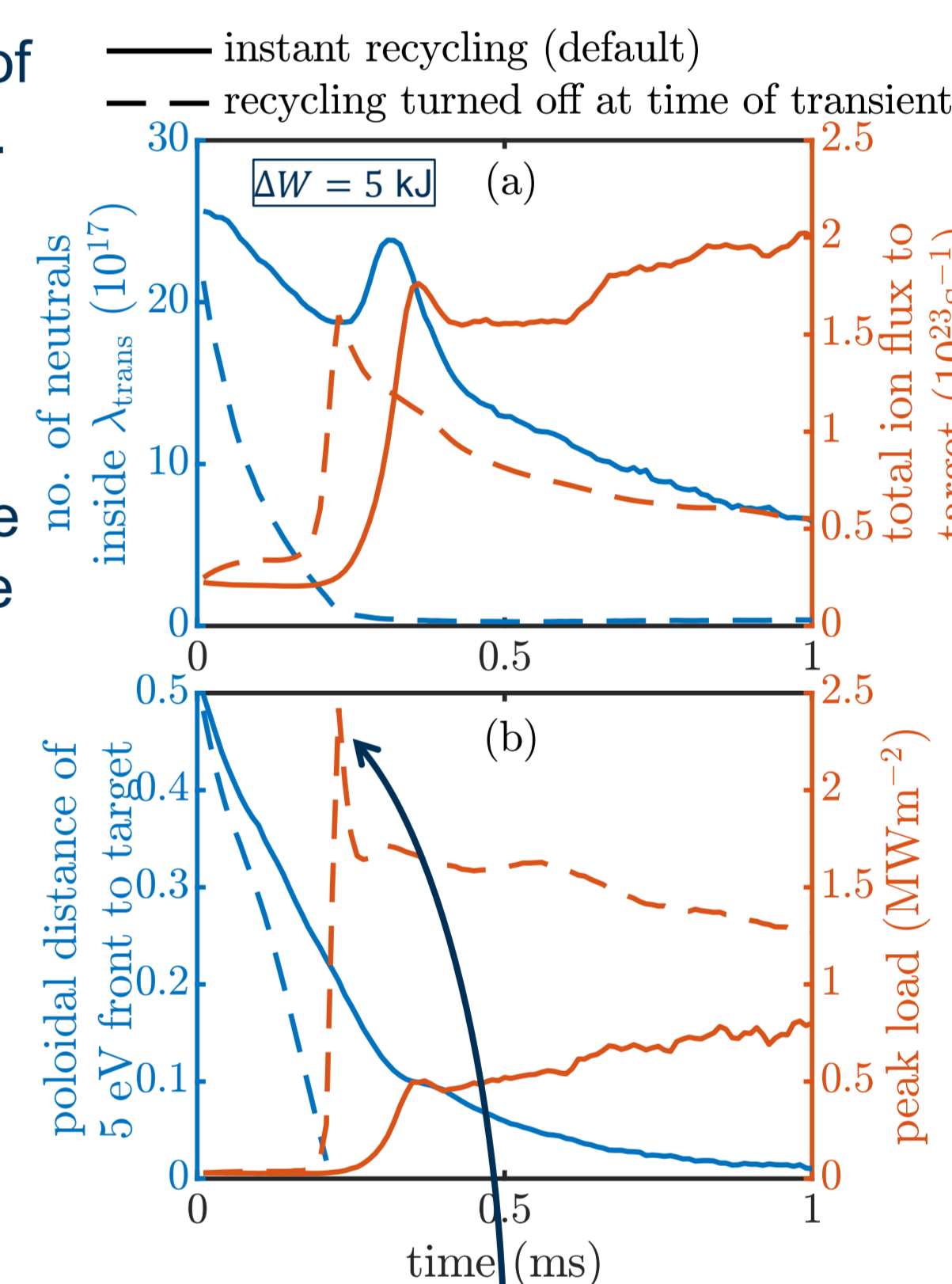
- Generally good agreement between simulation and experiment, considering that no effort was made to tune simulations.

THE CONCEPT OF A BURN-THROUGH 'THRESHOLD'



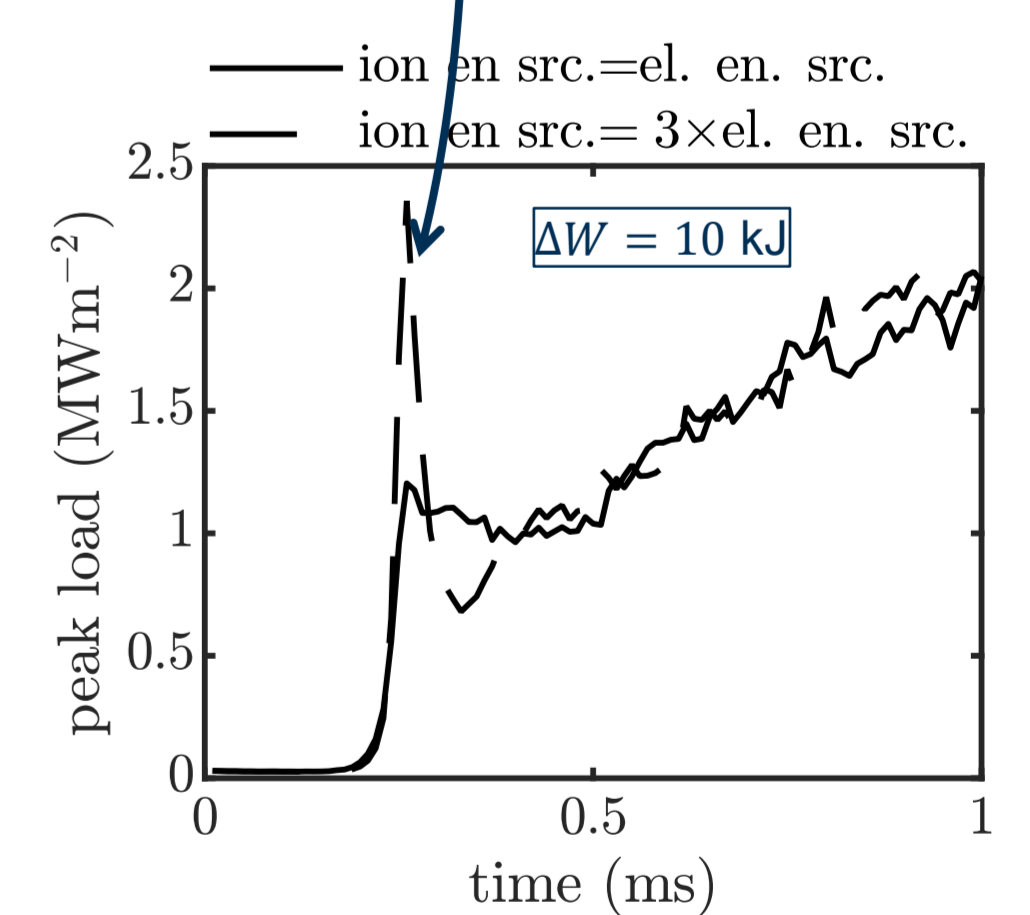
THE NEUTRAL RESERVOIR AND THE IMPORTANCE OF RECYCLING

- By default, we assume instantaneous recycling of the incoming target ion flux (solid lines in Fig right).
- In that case, for a $\Delta W = 5$ kJ transient whose 5 eV front just reaches the target after 1 ms, the neutral reservoir inside λ_{trans} is only depleted by $\lesssim 30\%$ before being boosted again by recycling.
- By contrast, when the target is fully pumped at the instant the transient is initialised (dashed lines), the neutral reservoir is completely depleted and the peak load to the target is ~5 times higher.
- Implies that neutrals do play an important role in reducing peak heat loads, but neutrals born from recycling more than the pre-existing reservoir.
- In the default case, the 5 eV front also slows once the incoming ion flux starts to recycle from the target, which is not observed in the absence of recycling.



INCREASED ION HEATING SHARE LEADS TO INCREASED LOADS

- There is uncertainty in our choice of how the transient energy source is shared between electrons and ions.
- In high powered simulations ($\Delta W = 10$ kJ), a bias towards the ions lead to significantly higher (factor ≥ 2) peak target loads when the transient first reaches the target.
- Loading is reminiscent of the case without recycling shown above.
- Suggests recycled neutrals are less able to dissipate incoming ion heat compared to electron heat.
- Possible mechanism for 'high burn-through events', where increased peak target heat loads occur for the same ΔW for some sawtooth transients [Scannell 2026]?



FUTURE WORK

- Comparison of loading in Super-X vs Conventional configurations; do simulations recover recent experimental findings [Scannell 2026]?
- Repeat the presented transient scan for a range of different divertor neutral pressures.
- Assess timescales for detachment once the transient source is removed and compare to experiment.
- Include impurities (both intrinsic carbon and seeded nitrogen). Memory intensive for time-dependent Eirene cases.

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