Recent SOLPS modelling of long-legged divertor configurations

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INTRODUCTION

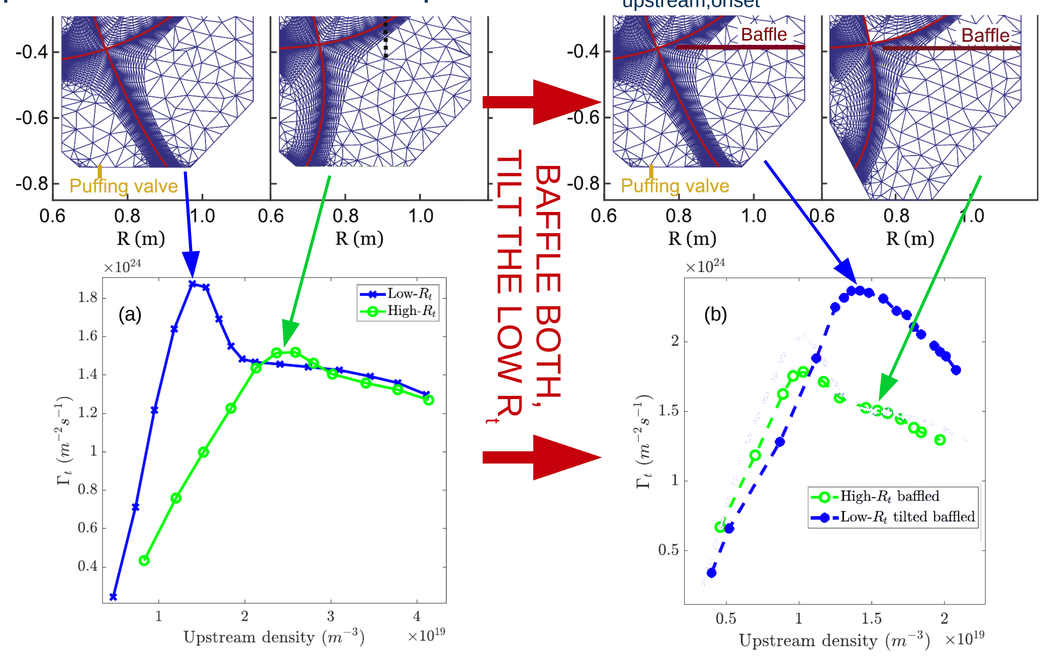
- Long-legged divertor configurations can expand a reactor's operational space, where core and exhaust requirements overlap.
- Increased parallel connection length, and/or decreased B field at the target (total flux expansion), and/or increased neutral compression in the divertor.
- **We present an overview of recent modelling of long-legged divertors, performed by UKAEA and the University of York.**

DETACHMENT ONSET

- Simple analytic models [1,2] predict that the required upstream density for detachment onset scales with the inverse of total flux expansion:

$$n_{\mathrm{upstream,onset}} \propto B_{\mathrm{target}} / B_{\mathrm{upstream}}$$

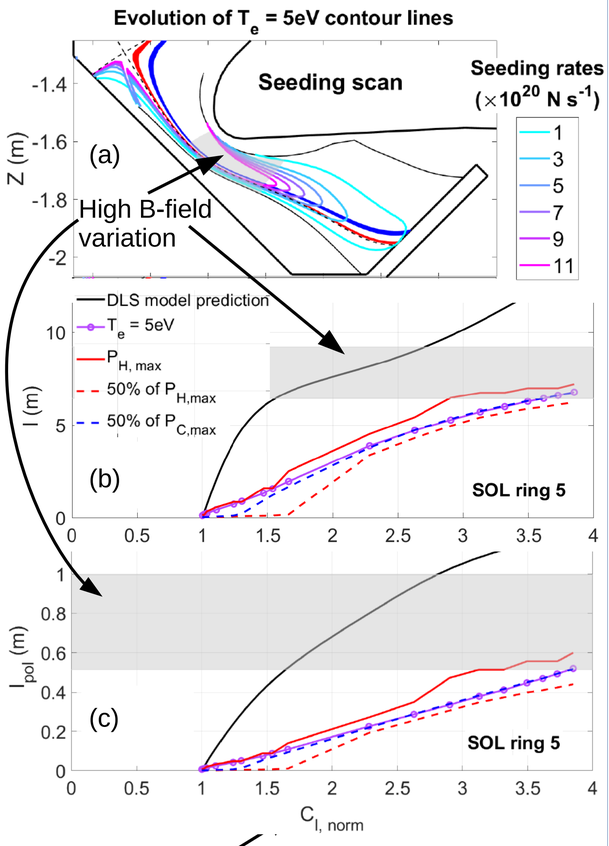
- In [3], this was reproduced in simple 'box divertor' SOLPS-5.0 simulations.
- But TCV experiments showed the opposite trend; decreasing $B_{target}/B_{upstream}$ (by increasing R_{target}) increased $n_{upstream,onset}$ (at target ion flux rollover) [4].
- In [5], full-geometry SOLPS-ITER simulations of those TCV experiments successfully reproduced this unexpected result.
- Furthermore, when differences in neutral trapping were eliminated (by baffling both high- and low-R_{target} cases and tilting the low R_{target} case), the expected effect of total flux expansion on $n_{upstream,onset}$ was restored.



- **Differences in neutral trapping between configurations can outweigh differences in total flux expansion in setting $n_{upstream,onset}$.**

DETACHMENT LOCATION SENSITIVITY (DLS)

- In [6], nitrogen-seeding and deuterium-fueling scans were simulated in MAST-U Super-X geometry using SOLPS-ITER.
- The sensitivities of variously-defined detachment front positions to control parameters were compared to the generalised DLS model (as in [2] but generalised for an arbitrary magnetic field profile).
- The DLS model and SOLPS-ITER both predicted that **the parallel movement of the thermal front becomes less sensitive to control parameters in regions of high B field variation.**
- Neither model predicted much slow down in the poloidal movement of the front with control parameters
- The observed poloidal slow down with increased seeding rate was due to that seeding rate having a reduced impact on the control parameter C_l.



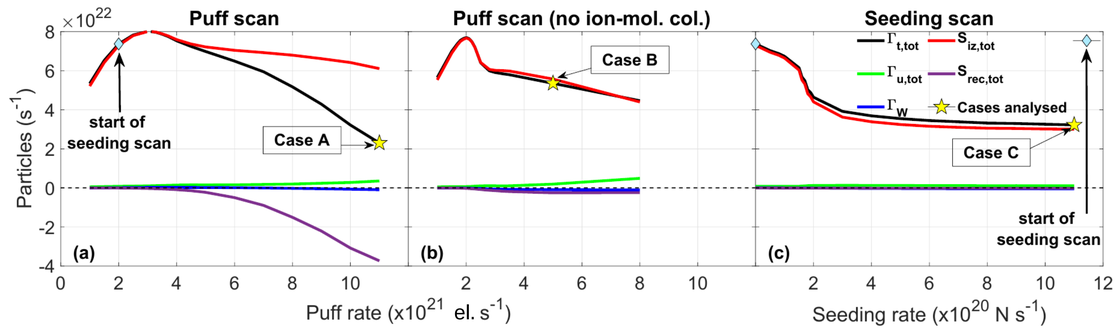
$$C_l = \frac{n_{\mathrm{upstream}} \sqrt{f_{\mathrm{eff}}}}{q_{\parallel,\mathrm{upstream}}^{5/7}}$$

Effective radiating species fraction (includes nitrogen, carbon and deuterium)

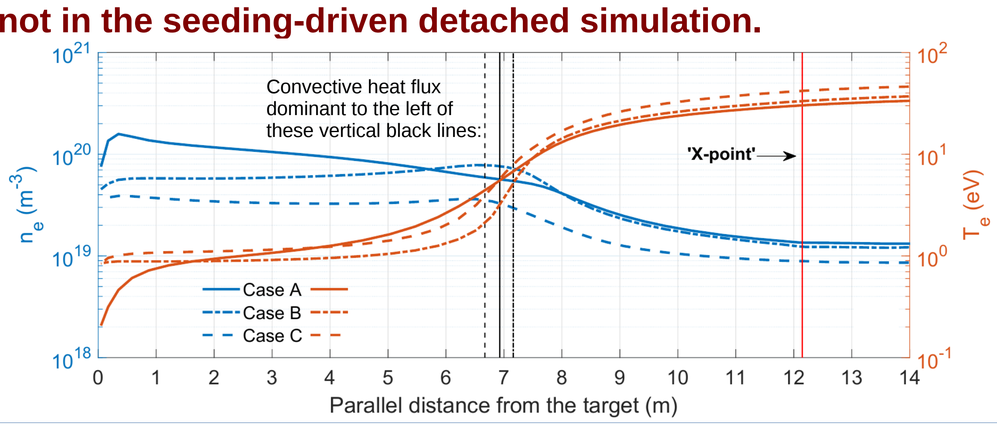
$C_{l,\mathrm{norm}}$: normalised C_l to its value just when the front pulls off the target

DEEP DETACHMENT

- In [7], deeply-detached simulations obtained via deuterium fueling (puff scan) and nitrogen seeding (seeding scan) were compared, using the same seeding and fueling scans in MAST-U as in the DLS sensitivity study.
- For similar detachment front locations (5 eV points), **significant recombination is only observed in the fuelling-driven detached simulation and is negligible in the seeding-driven detached simulation.**

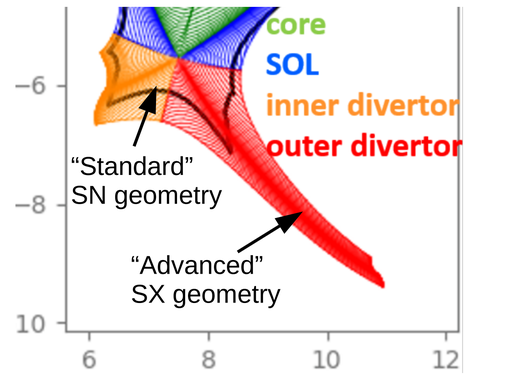


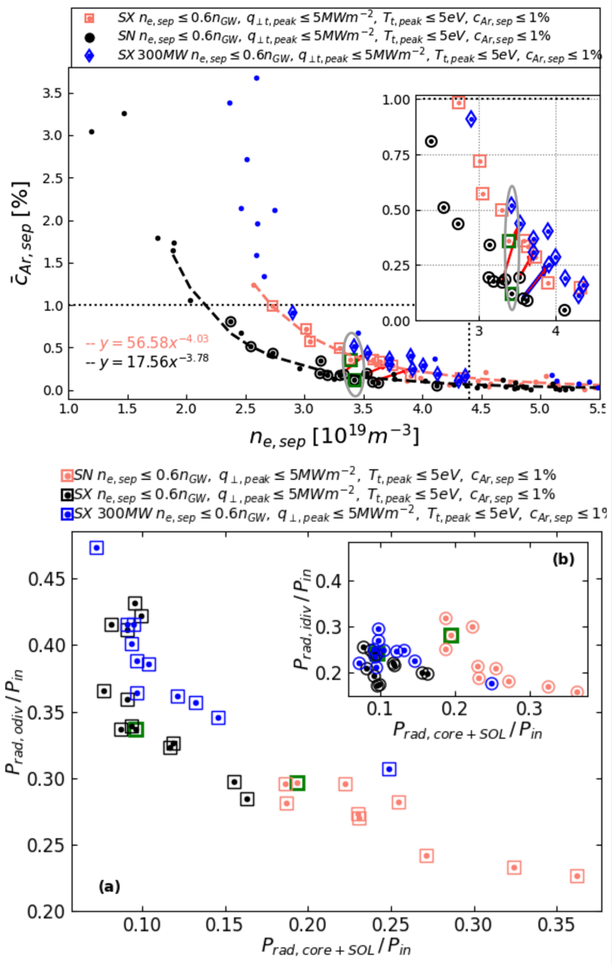
- Deuterium ion-molecule elastic collisions play an important role in this qualitative difference. In their absence, the puff scan no longer achieves significant recombination for the same detachment front location.
- They remove not only momentum, but are the dominant near-target heat loss mechanism, allowing recombining temperatures to be obtained.
- They also reduce the parallel ion velocity in the detached region, so that the **n_e is peaked near the target in the fuelling-driven detached simulation, but not in the seeding-driven detached simulation.**



REACTOR RELEVANCE

- In [8], the utility of an engineeringly-plausible long-legged divertor was assessed for DEMO within the Eurofusion work package WP-DTT1/ADC.
- The outer divertor connection length was increased by 75% and the total flux expansion by 30%.
- **For the same $n_{e,sep,OMP}$ ($\bar{c}_{Ar,sep}$), the ~0.5 lower $\bar{c}_{Ar,sep}$ (~0.8 lower SX (black circles) required a factor $n_{e,sep,OMP}$) to achieve operationally-tolerable exhaust conditions, compared to the SN (pink squares)**
- **The SX with 300 MW input power required only slightly higher $n_{e,sep,OMP}$ and $\bar{c}_{Ar,sep}$ compared to the SN with 150 MW input power.**
- This improvement was attributed primarily to the increased connection length of the SX, rather than the marginally increased total flux expansion.
- In SX, a significantly larger fraction of the radiated power was located in the divertor, while the SN radiated more from the core.





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[7] O Myatra et al. (2021) to be submitted
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