Taming the flame: Detachment access and control in MAST-U Super-X

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Introduction

- Divertor plasma detachment necessary to bring down target heat loads to acceptable levels in future devices ($10\ \mathrm{MWm^{-2}}$)
- Density and impurity driven detachment in MAST-U Super-X compared using SOLPS-ITER [1]

Detachment onset

- Detachment characterised by 'roll-over' of target plasma flux – a phenomenon not fully understood
- Role of energy and momentum loss in flux roll-over studied to better understand how the detached state can be accessed

Detachment control

- Controlling the detached state found to be difficult – thought to be due to narrow 'detachment window' [2]
- Effect of divertor magnetic geometry on ionisation/radiation peak location sensitivity studied

Simulation setup

- A puff scan (density scan) and a nitrogen seeding scan (divertor impurity concentration scan) carried out - see table for details
- Deuterium molecules are puffed from the inboard mid-plane and nitrogen atoms are seeded in the divertor, close to the baffle (Fig. 1)
- Currents, drifts and neutral-neutral collisions not included

Parameter	Density scan	Nitrogen seeding scan
Input power, P_{in}	2.5MW	2.5MW
Impurities	Sputtered carbon	Sputtered carbon Seeded nitrogen
Outboard mid-plane (OMP) density range, n_{eu}	$\sim(0.5-1.6)\times10^{19}\mathrm{m^{-3}}$	$\sim0.7\times10^{19}\mathrm{m^{-3}}$
OMP impurity concentration range	$f_{I,C}\sim0.08$	$f_{I,N}\sim0.05\ -0.11$ $f_{I,N+C}\sim0.08\ -0.12$

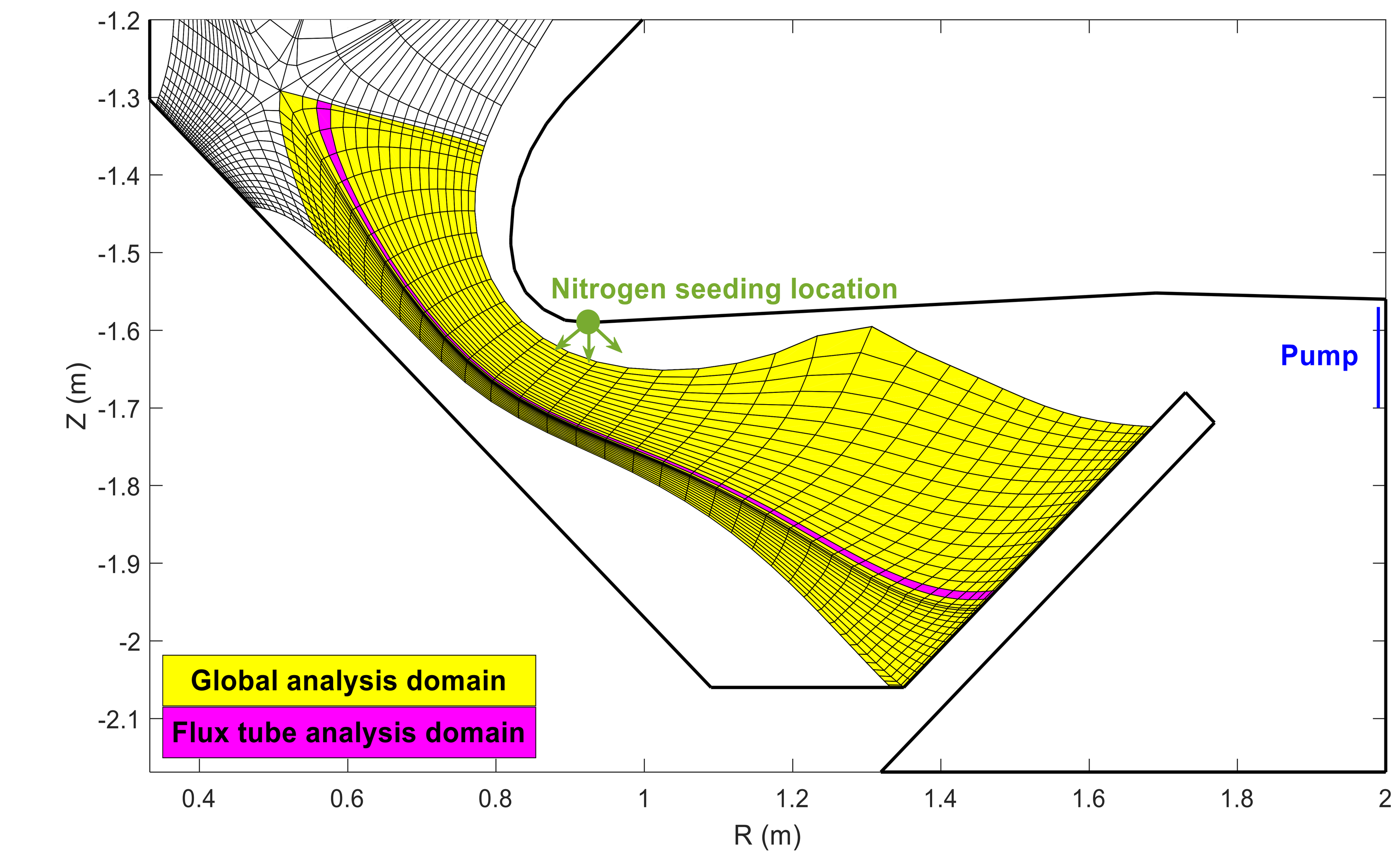

Fig 1: ***Yellow:*** Analysis domain for global particle and power balance. ***Purple:*** flux tube chosen to study parallel profiles and peak movement

Comparison of density and impurity driven detachment

Detachment evolution

- **Power** available for D ionisation **limited** mainly by power lost in $\mathbf{D_2/D_2^+}$ **ionisation** and **impurity radiation** in both cases
- When about half the power available for D ionisation is used for D ionisation **($f_{ion}\sim0.5$), Γ_t (target flux) deviates strongly from linear** in puff scan – consistent with theory [3] and experiment [4] (Fig. 2(a)-(b))
- **Recombination negligible at flux rollover** in density scan and negligible throughout the seeding scan

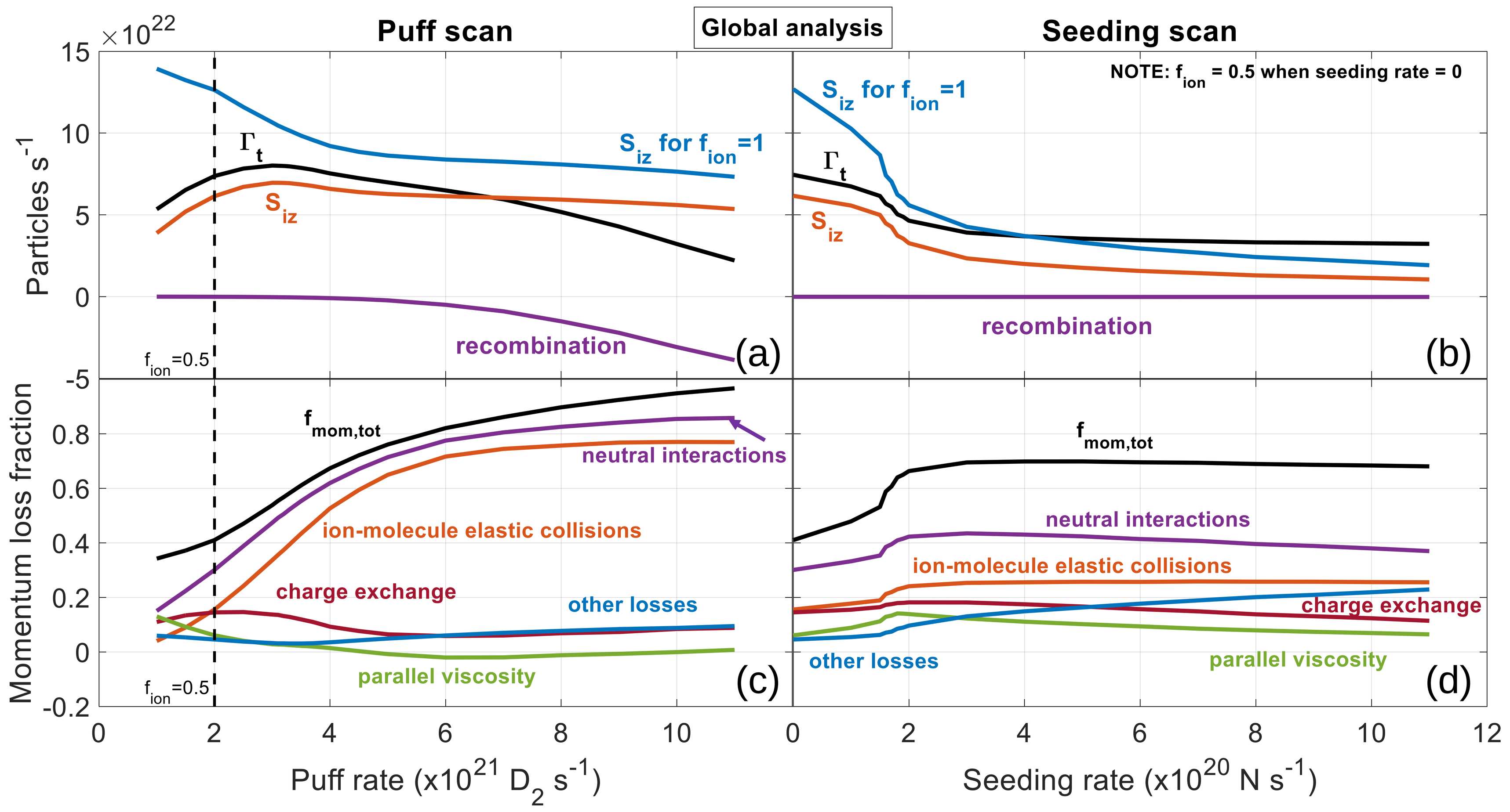

Fig 2: ***(a)-(b)*** Contribution of D ionisation and recombination to Γ_t and possible ionisation source for $f_{ion}=1$ in the puff and seeding scan respectively ***(c)-(d)*** Plasma momentum sink decomposition

- **Neutral interactions dominant momentum sink** in both cases, high divertor plasma/neutral densities in puff scan lead to more momentum loss, fig. 2(c)-(d)
- **Momentum loss to molecules** result in **qualitative differences in parallel density profile**, fig. 3(a)-(b)
- **Ion-molecule collisions** dominant energy sink when $T_e\leq1\mathrm{eV}$ – high divertor neutral density results in **lower $T_{e,t}$ in puff scan** (Fig. 3(c)-(d))

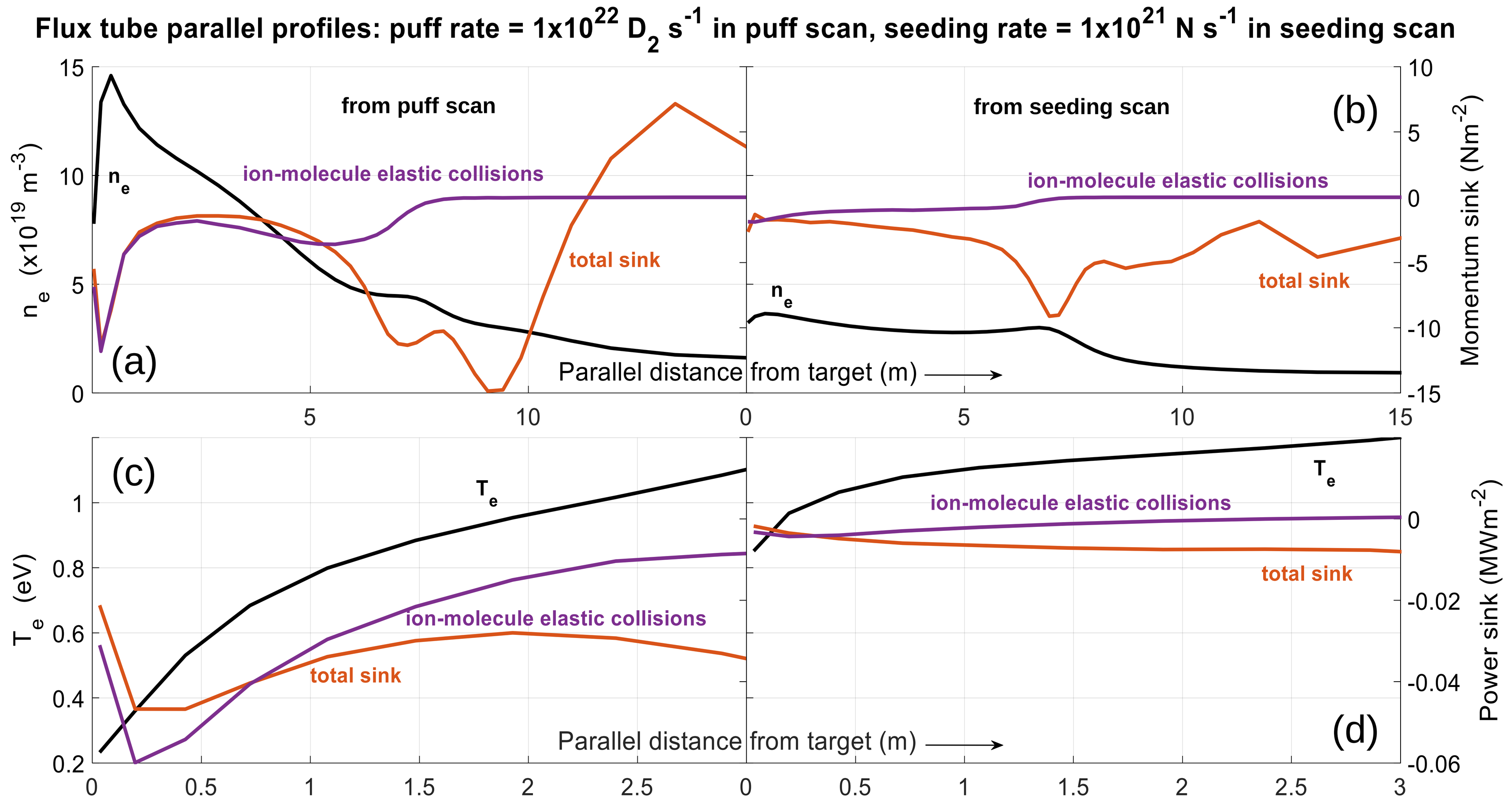

Fig 3: ***(a), (b)*** Parallel n_e profile, momentum lost to ion-molecule interactions and total momentum sink ***(c), (d)*** Parallel T_e profile, energy lost to ion-molecule interactions and total energy sink

Detachment control

- **Peak movement slows down** significantly in region of **high gradient in $\mathbf{B_{tot}}$** – consistent with theoretical predictions [2] (Fig. 4(b)).
- This is also a region of high poloidal flux expansion (Fig. 4(a)) and is very close to the baffle (Fig. 4(c)-(d)).

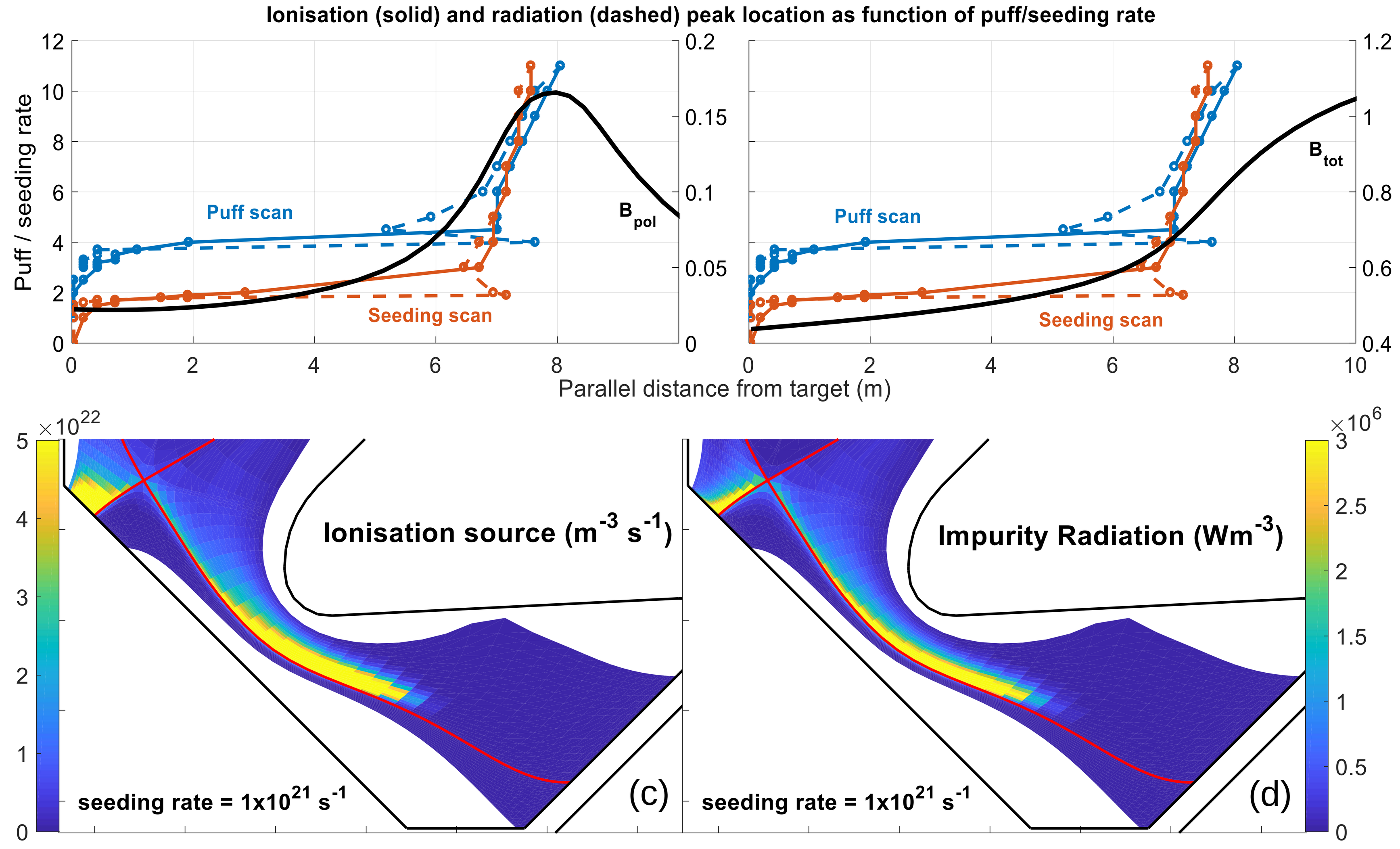

Fig 4: (a), (b) Ionisation/radiation peak movement for increasing puff/seeding rate in relation to B_{pol} and B_{tot}. **(c), (d)** 2D ionisation/radiation profiles when peak movement slows down.

Conclusions

Density driven vs. Impurity driven detachment

1) Ion-molecule collisions dominant energy sink when $T_e\leq1\mathrm{eV}$
2) Divertor plasma/molecule density significantly higher in puff scan
3) Because of (1) and (2)., target T_e saturates after rollover in the seeding scan and continues to drop in puff scan
4) The combined result of (1), (2) and (3) is negligible recombination throughout the seeding scan, significant recombination (after rollover) in puff scan
5) Ion-molecule collisions also dominant momentum sink – this coupled with (2) leads to qualitative differences in density profile

Detachment control

- Ionisation/radiation peak location sensitivity to control parameters reduced significantly in region of high gradient in B_{tot}
- This corresponds to a widening of the detachment window, suggesting that total flux expansion may lead to improved control

References

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This work has been funded by EPSRC (grant number EP/L01663X/1).

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