SOL transport characterization in WEST limiter configuration

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Introduction

- Understanding plasma transport in the edge and SOL regions is crucial for plasma performance optimization and heat loads predictiions on PFCs
- Every tokamak must initiate and terminate its discharge in a limiter configuration

Objectives

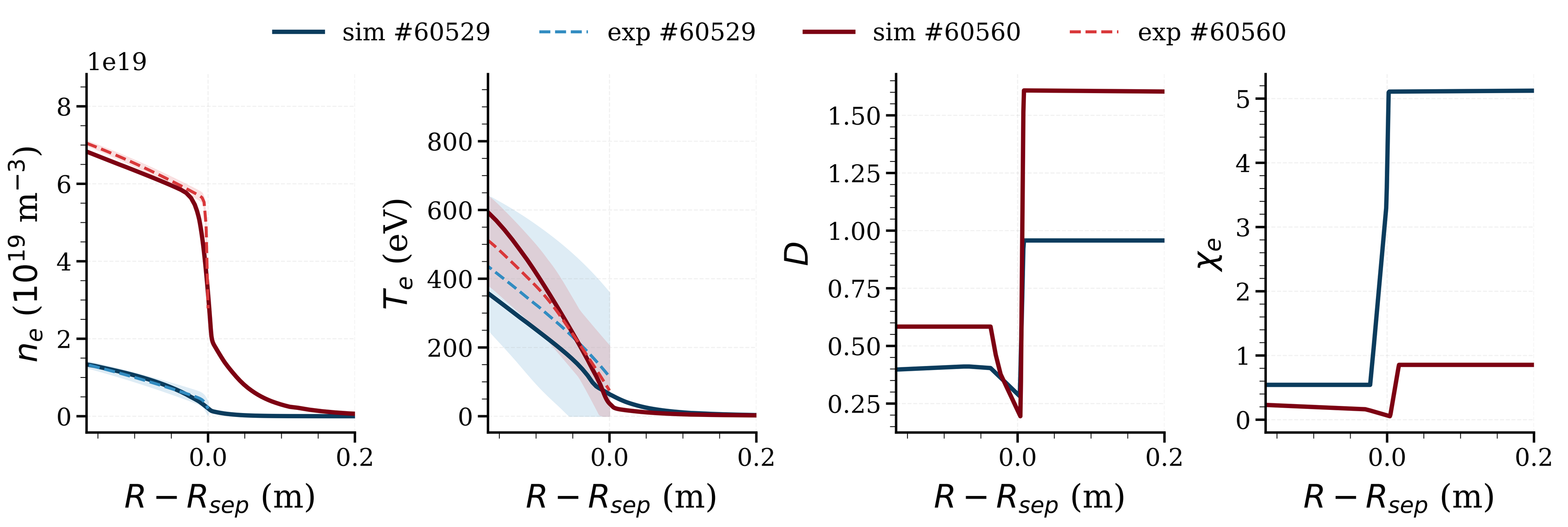
- Investigate transport across different WEST plasma regimes in limiter configuration
- Characterize relevant observables decay lengths for extrapolating to future devices

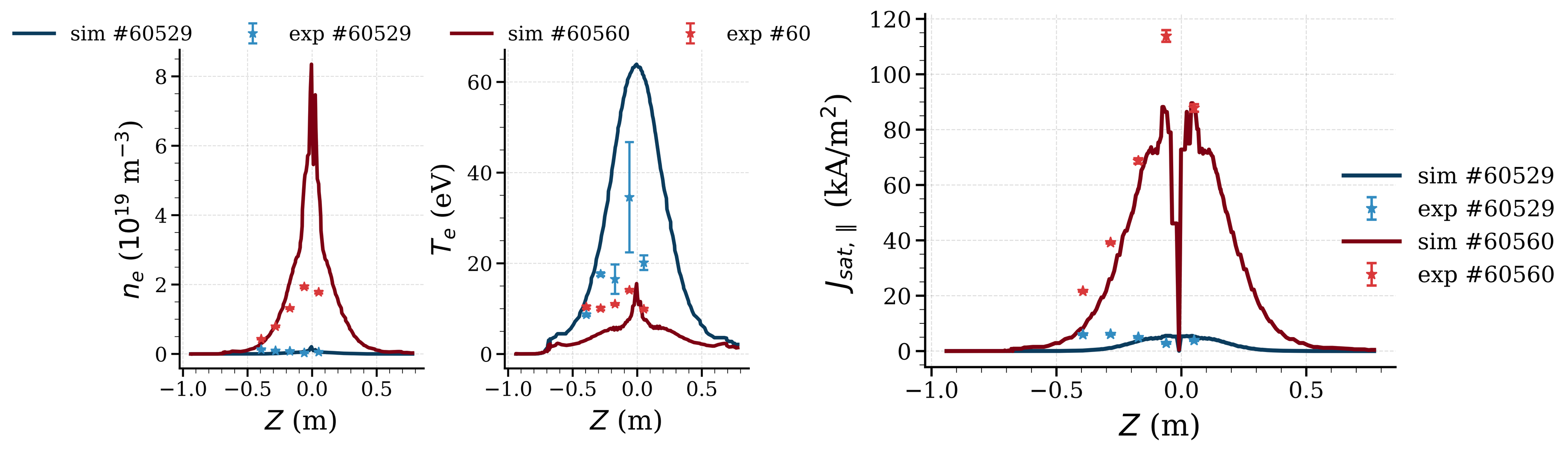
Simulations

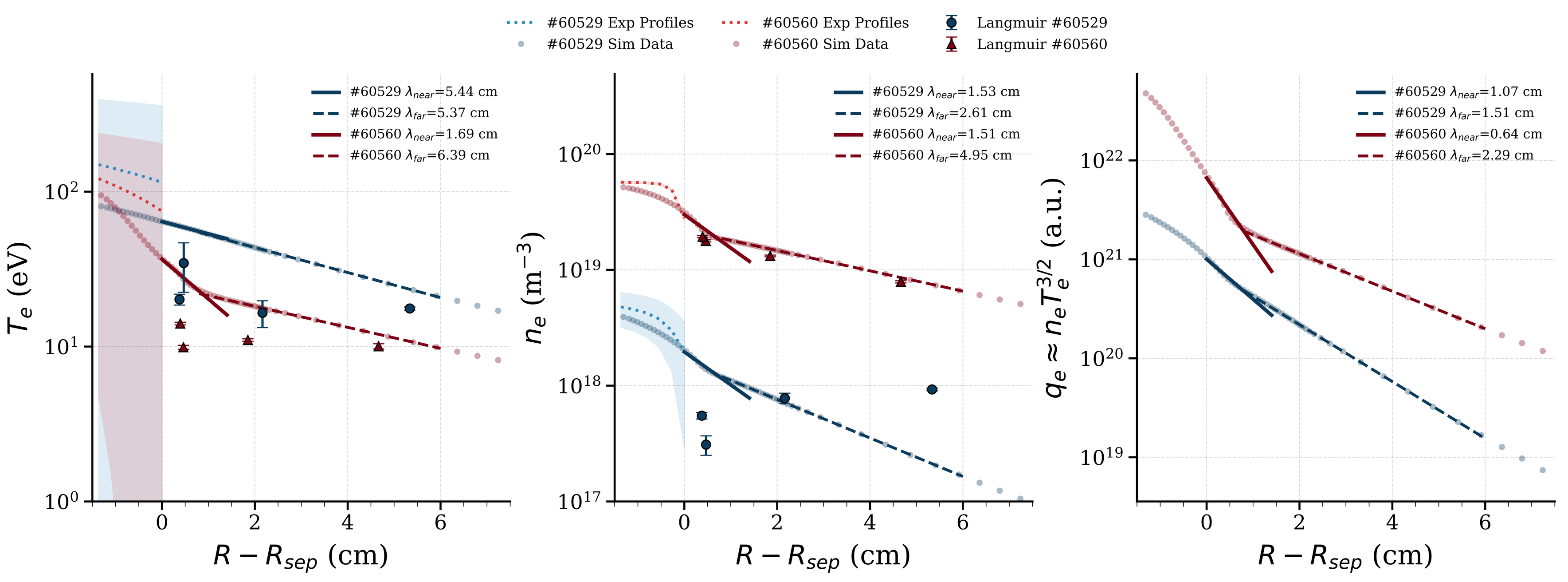
Dedicated WEST limiter discharges #60529 and #60560 ($B_T \approx 3.7\,\mathrm{T}$, $I_p = 300$ and $700\,\mathrm{kA}$, $P_{\mathrm{SOL}} \approx 160$ and $560\,\mathrm{kW}$, respectively), analyzed using Langmuir probes embedded in the PFCs, in ITER-like configuration.

RESULTS I

Comparison w.r.t. experimetal data to extrapolate *effective* transport coefficients D, χ_e.





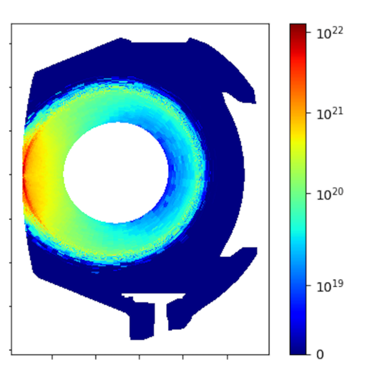


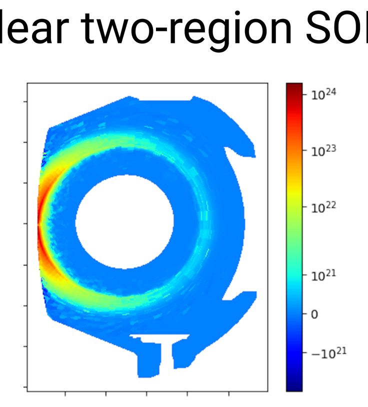
#60529 (low P, n):

- high χ_e in the SOL drives cross-field heat diffusion: broad, single temperature profile with no clear near/far-SOL separation;
- low radial density broadening compatible with an almost uniform D profile, weak spatial variations across the SOL ($\lambda_n \sim \sqrt{D_\perp \cdot L_\parallel / c_s}$);
- $\lambda_{q,\mathrm{near}}/\lambda_{T,\mathrm{near}} \approx 0.19 < 2/7$, compatible with a sheath-limited regime where parallel heat exhaust is mainly conserved ($T_u \approx T_t$) [1, 2, 3];
- low I_p (weak B_p) associated to longer and more uniform $L_\parallel$ across the SOL: weak radial variation of parallel losses and near/far-SOL behave as a single transport region [4].

#60560 (high P, n):

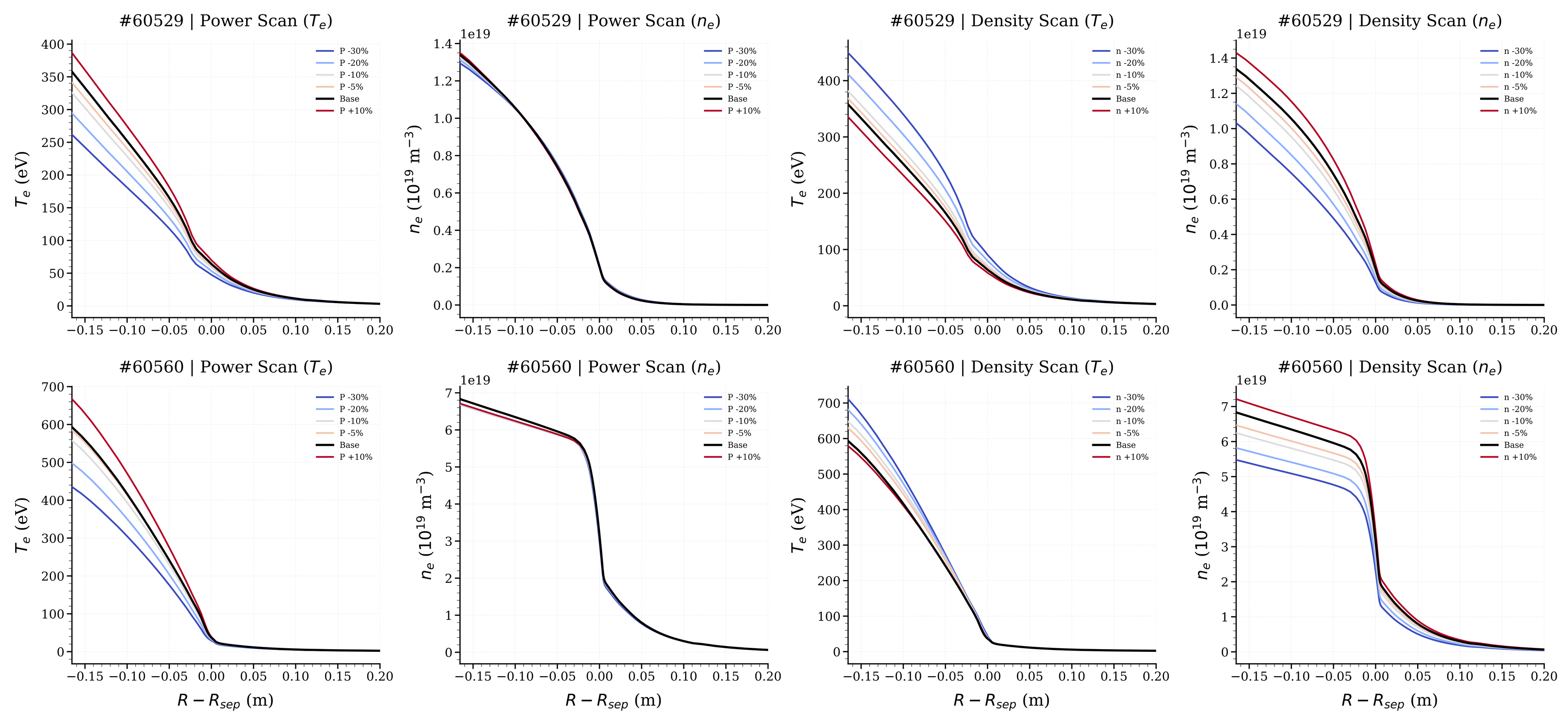
- sink χ_e near separatrix narrows the near-SOL T channel, produces a strong near/far thermal separation: signature of the localized turbulent suppression [5, 6];
- higher D in the far-SOL (w.r.t near-SOL) acts as a macroscopic proxy for convective transport driven by filamentary structures (blobs) [7, 8];
- $\lambda_{q,\mathrm{near}}/\lambda_{T,\mathrm{near}} \approx 0.38 > 2/7$, compatible with a conduction-limited regime with an opaque plasma and recycling neutrals stopped close to the LCFS [1];
- higher I_p ($\uparrow B_p$), consistent with $\downarrow L_\parallel$ and $\uparrow$ radial variation of parallel loss rates; more defined near-SOL while far-SOL more weakly constrained, clear two-region SOL structure.

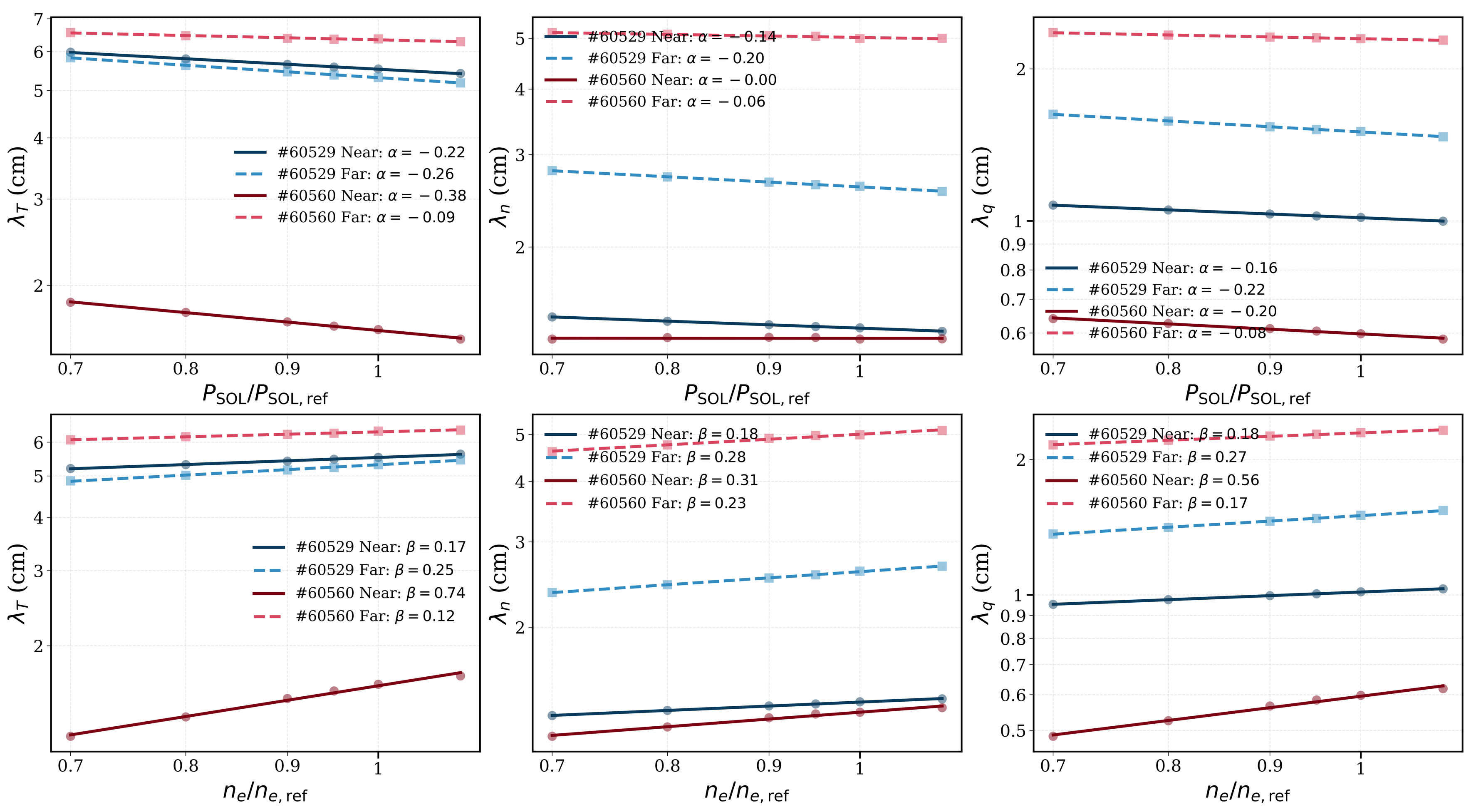




RESULTS II

Power and density scans with decay length scaling analysis ($\lambda \propto P^{\alpha}_{SOL} \cdot n_e^{\beta}$) of relevant SOL quantities for both cases #60529 and #60560 to evaluate their uncoupled impact on the SOL widths.





- #60529 – power scan: all decay lengths show slightly negative scaling with P_{SOL} ($|\alpha| \sim 0.14$–0.26); same response for near and far SOL, consistent with a sheath-limited, diffusion-dominated regime (weak power sensitivity)[1, 9, 10];
- #60529 – density scan: decay lenghts increase moderately with $n/n_{e,reference}$ ($\beta \sim 0.18$–0.28) accordingly to [9], near and far SOL showing comparable sensitivity, no pronounced two region structure;
- #60560 – power scan: stronger near/far bifurcation; near SOL with steep thermal scaling ($\alpha_T \approx -0.38$) but density seems power independent; no far SOL response for all quantities ($|\alpha| < 0.10$);
- #60560 – density scan: near SOL exhibits strongly enhanced sensitivity, while far SOL has weak response (opposite to shot 60529).

Conclusions & Outlooks

- Near-SOL heat flux width in high-P case narrower than in low-P, consistent with the narrowing of the heat channel in conduction-limited limiter plasmas reported on Tore Supra and JET [11, 9];
- localized sink in D and χ_e profile at the LCFS observed in both scenarios, consistent with transport barrier generated by $E \times B$ flow shear [6, 5];
- in #60529 far SOL responds slightly more than near SOL; in #60560 the near SOL dominates response, especially to density suggesting a regime change driven by higher I_p and collisionality [12, 8];
- shots differ in plasma current I_p, implying distinct $L_\parallel$, B_p structure and edge magnetic geometry, all of which modulate SOL width and the near/far transport balance [11, 3].

- extension to a wider shots dataset and parameters scan;
- activation of drift terms, known to affect poloidal asymmetries and particle flux directionality in SOL.

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