



Measurement of Edge Plasma Properties in the HSX Stellarator with Comparisons to EMC3-EIRENE



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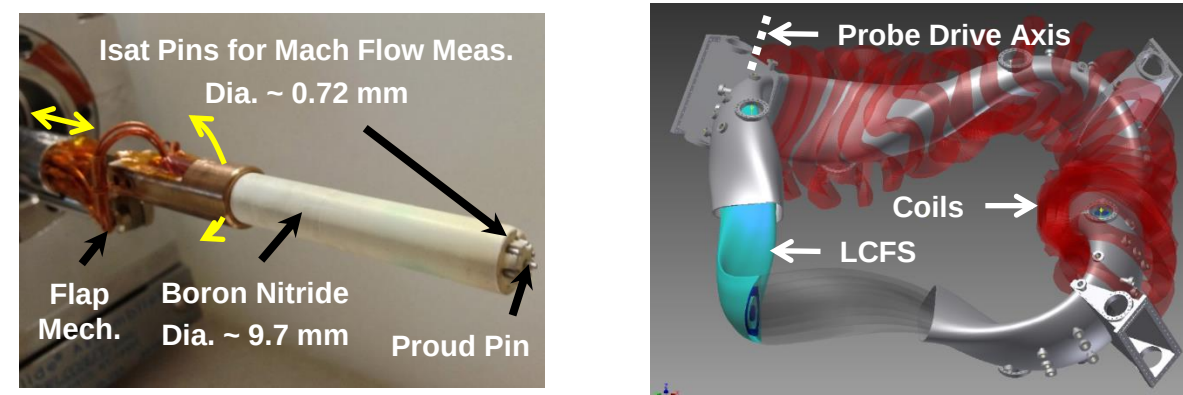
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Motivation

- The presence of edge magnetic islands is inherent to all stellarator configurations; these islands play a prominent role in edge physics.
- 2D profiles of plasma edge T_e , n_e , potential, and parallel flow have been obtained in the edge of the Helical Symmetric Experiment (HSX) using a multi-pin Langmuir probe.
- Simulations [2] from the coupled edge codes EMC3-EIRENE [1] are compared to edge measurements.
- Differences between simulation and measurements may be attributable to plasma potential structures, which are not included in EMC3-EIRENE.

Langmuir Probe

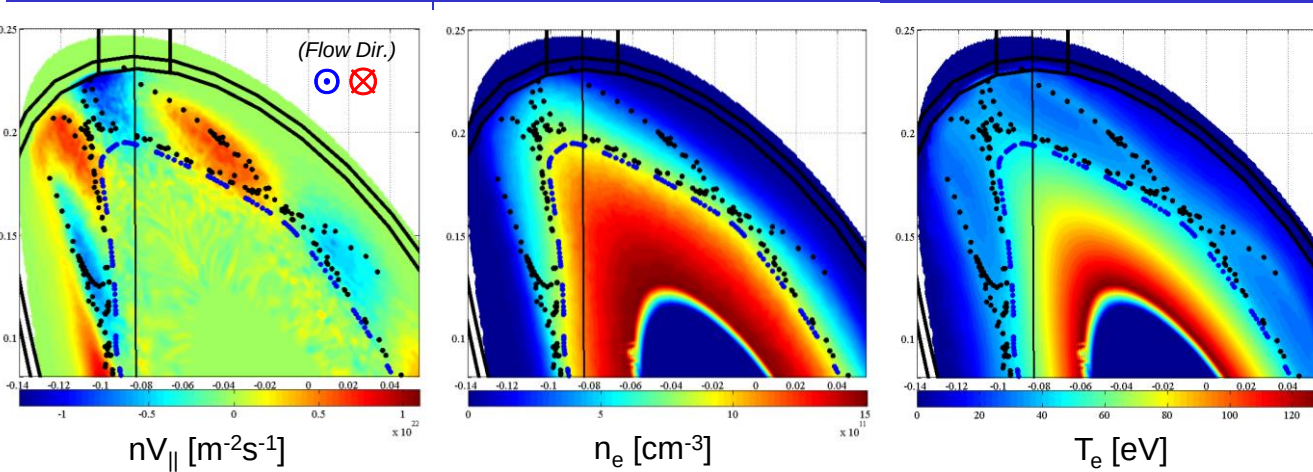
- A single Langmuir probe (proud pin) measures local n_e , T_e , and plasma potential.
- Directional ion Mach flows are inferred from six statically biased pins.



(Direction of motion indicated by yellow arrows)

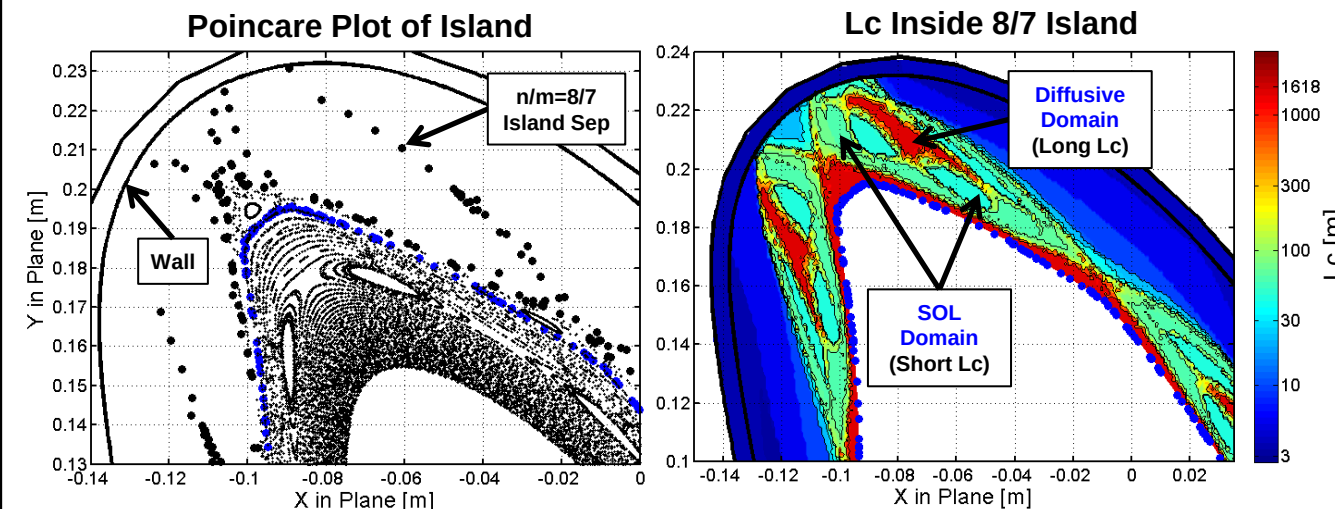
- Probe is inserted radially into above port with the flapping plane orthogonal to the magnetic axis.

EMC3-EIRENE Predictions



- EMC3-EIRENE modeling of standard QHS configuration [2] with LCFS and edge 8/7 islands boundaries highlighted.
- Physical features of interest include radial decay of n_e profile, T_e peaking at the island periphery, and the presence of counter-streaming flows.

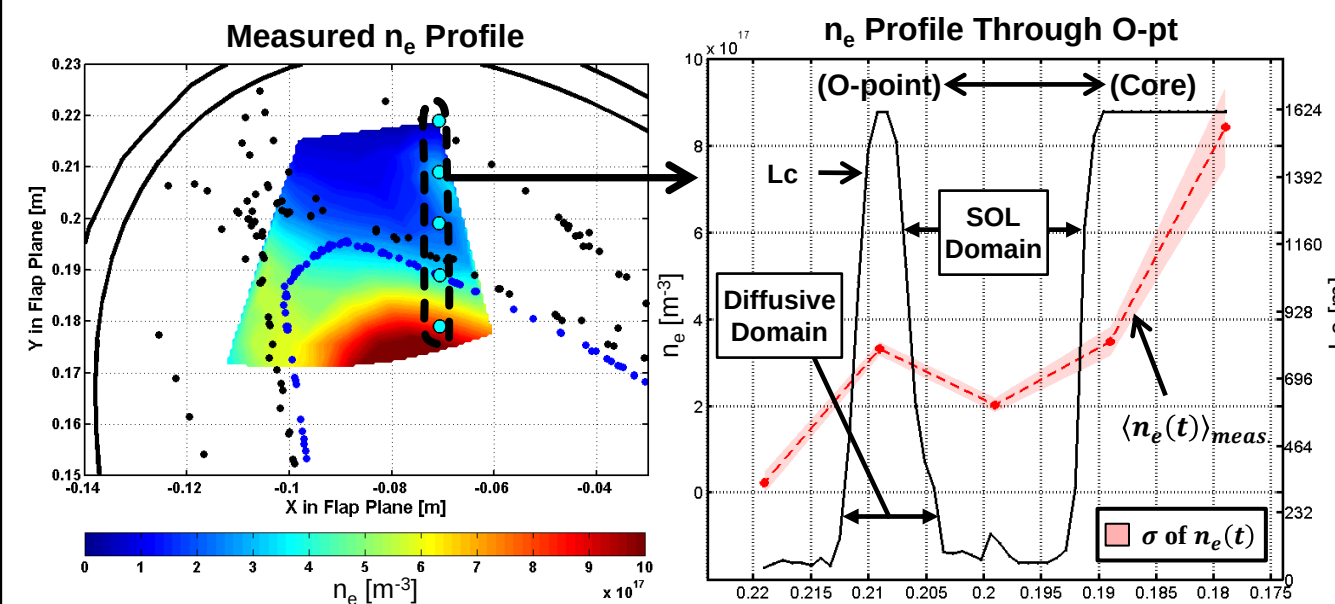
Diversity in Connection Length (Lc) Suggests Coexistence of Multiple Transport Channels



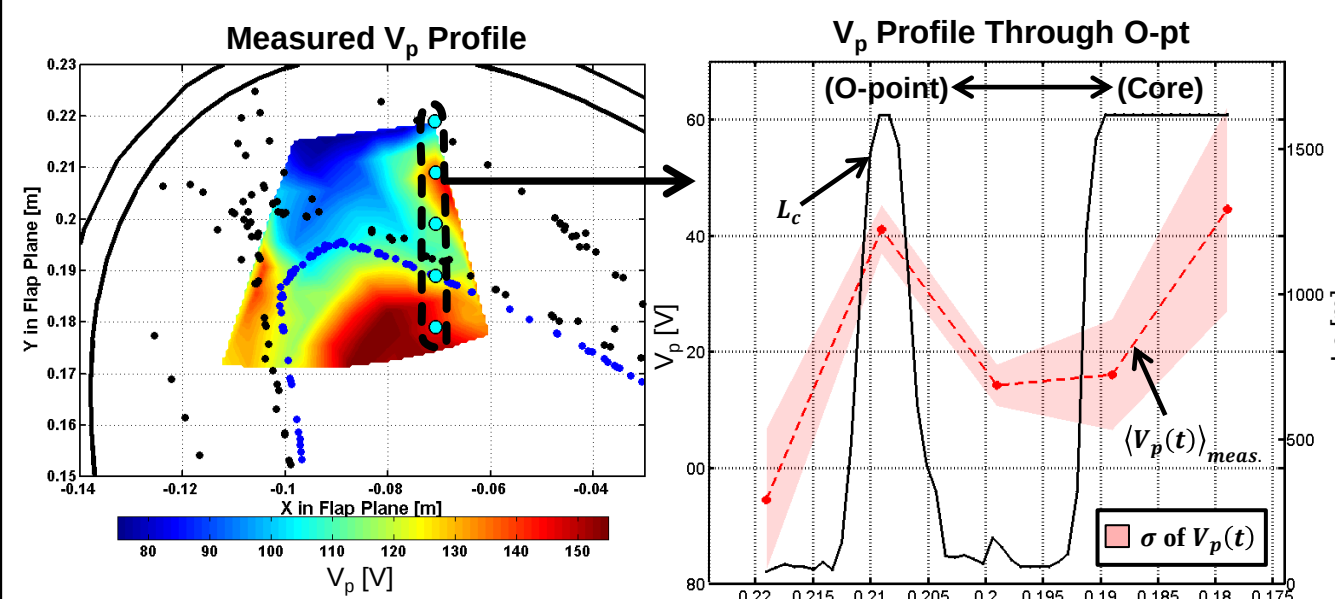
Heterogeneous SOL:

- SOL Domain:** Characterized by parallel and perpendicular transport competing along open field lines
- Diffusive Domain:** Characterized by diffusive plasma transport across closed field lines

Observations Indicate Features Useful for Characterizing Edge Transport



- Decaying n_e profile characteristic of SOL transport visible
- Change in density gradient about O-point highlights diffusive transport domain



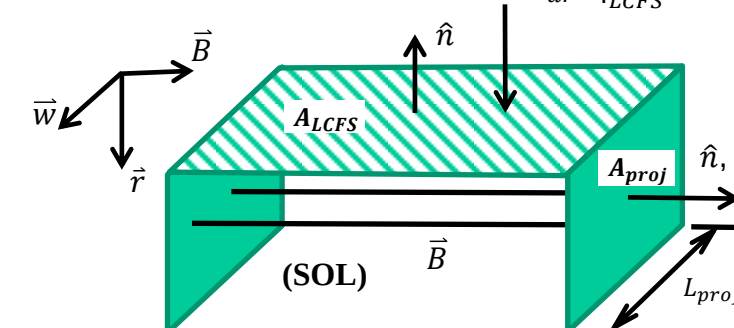
Measurements suggest transport within heterogeneous SOL may contribute to observed potential feature

Estimating $D_{\perp}$ Using Simple SOL model

Assumptions:

- T_e is isothermal along $\vec{B}$
- No edge ionizations
- $D_{\perp}$ = constant
- $\eta_{\parallel} \rightarrow C_s$ at sheath entrance
- No cross-field drifts
- Steady-state
- $n_e(r) = n_{e,LDFS} e^{-r/\lambda_n}$

Simple Model:



Particle Continuity:

$$\vec{\nabla} \cdot \vec{r} = 0 \rightarrow \int \vec{r}_{\perp} \cdot d\vec{a}_{LDFS} + \int \vec{r}_{\parallel} \cdot d\vec{a}_{proj} = 0 \rightarrow -\frac{D_{\perp} A_{LDFS}}{\lambda_n} + 2C_s L_{proj} \lambda_n = 0$$

$$D_{\perp} = \frac{2C_s L_{proj} \lambda_n^2}{A_{LDFS}} = \frac{C_s \theta \lambda_n^2}{\pi a}$$

where: θ = Field line pitch
 a = Plasma minor radius
 C_s = Sound speed
 λ_n = Density scale length

Small $D_{\perp}$ Estimated from Simple SOL Model

$D_{\perp}$ derived from profiles

Measured:

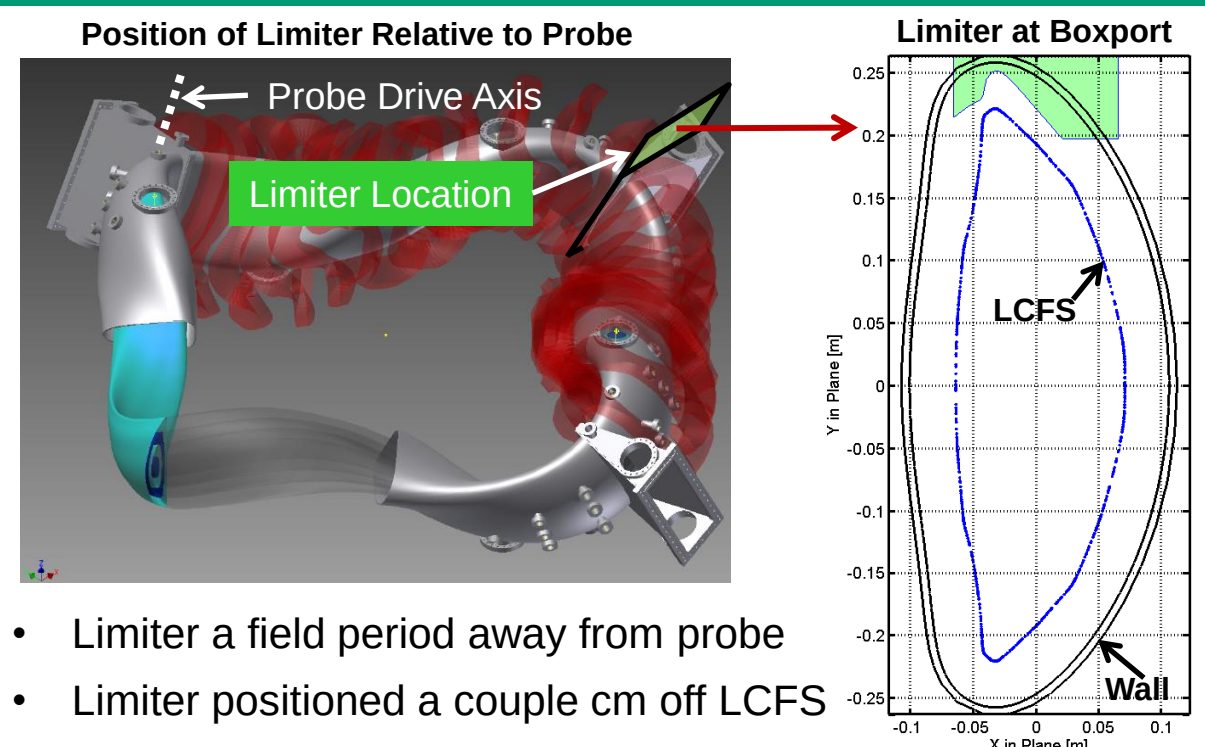
$$D_{\perp} \approx (0.034 \pm 0.003) \text{ m}^2/\text{s}$$

Simulated:

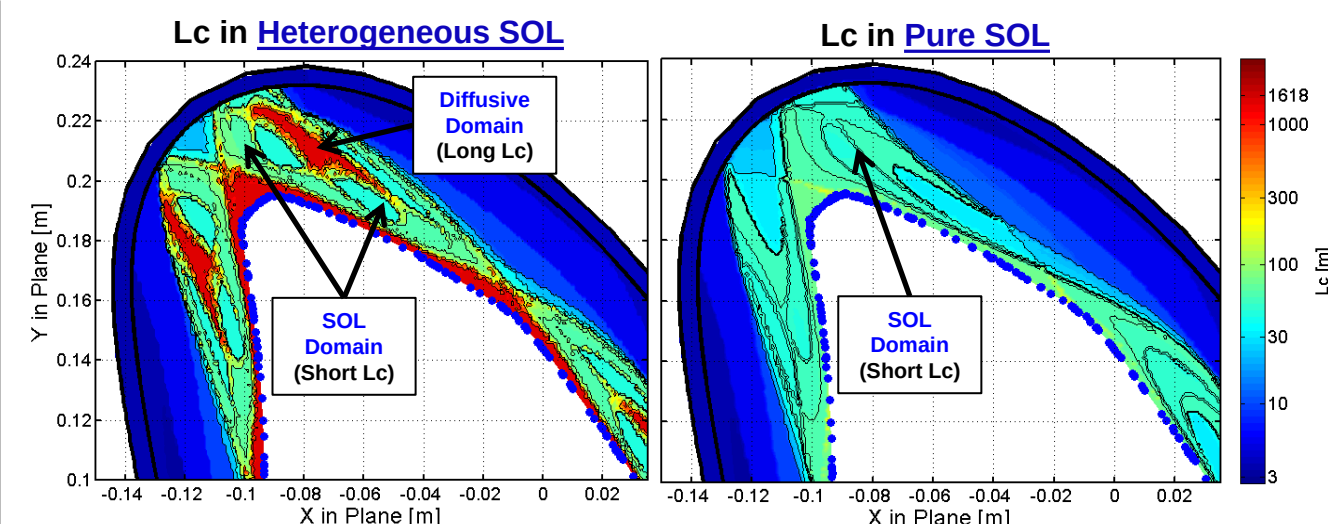
$$D_{\perp} \approx (0.51 \pm 0.01) \text{ m}^2/\text{s}$$

- Linear trend in $\log(n_e)$ validates decaying n_e profile in SOL region
- Simple SOL estimate of $D_{\perp}$ from synthetic profile consistent with $D_{\perp} = 0.5 \text{ m}^2/\text{s}$ code input

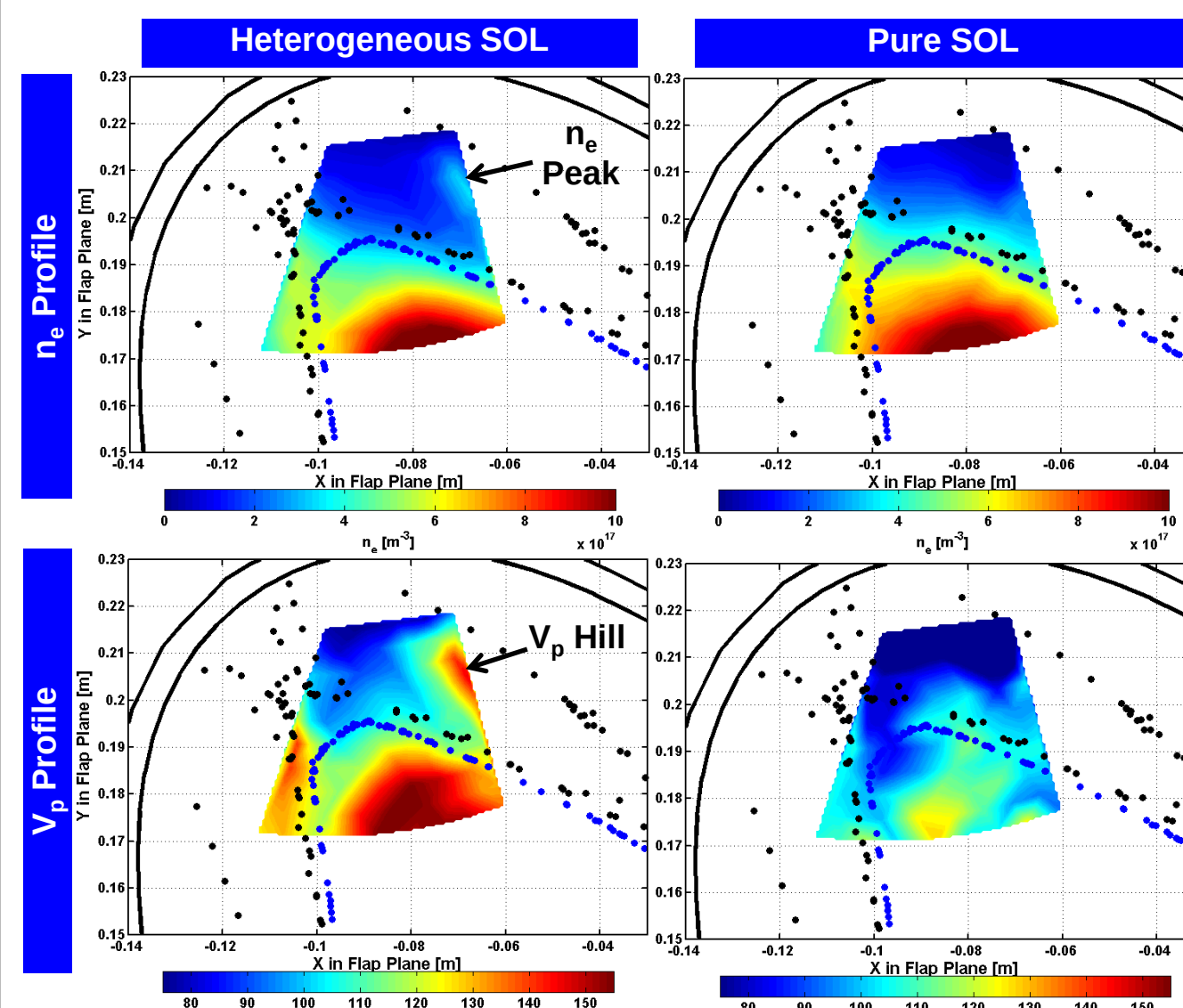
Transition to a Pure SOL can be Achieved with a Limiter



- Limiter a field period away from probe
- Limiter positioned a couple cm off LCFS



Peaked n_e and V_p Hill Absent in Pure SOL Configuration



Removal of Edge Potential Leads to a Factor of 2 Increase in $D_{\perp}$ Estimate

$D_{\perp}$ derived from profiles

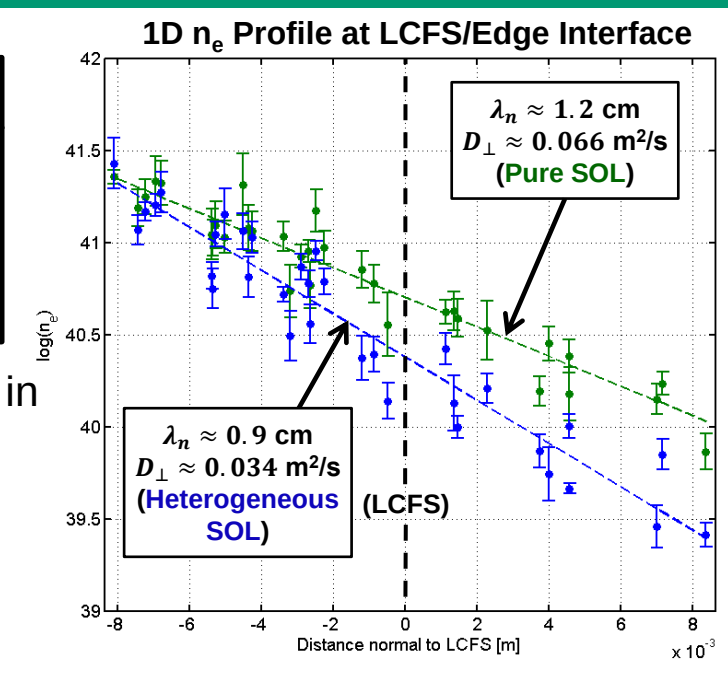
Heterogeneous SOL:

$$D_{\perp} \approx (0.034 \pm 0.003) \text{ m}^2/\text{s}$$

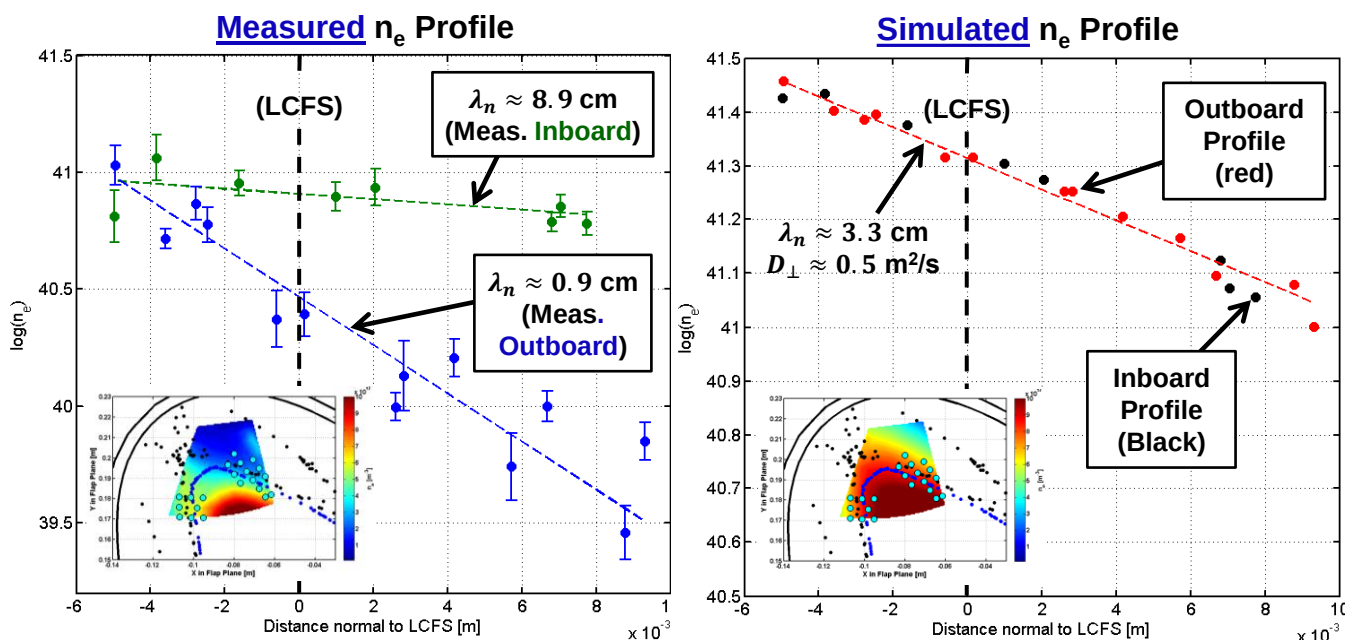
Pure SOL:

$$D_{\perp} \approx (0.066 \pm 0.008) \text{ m}^2/\text{s}$$

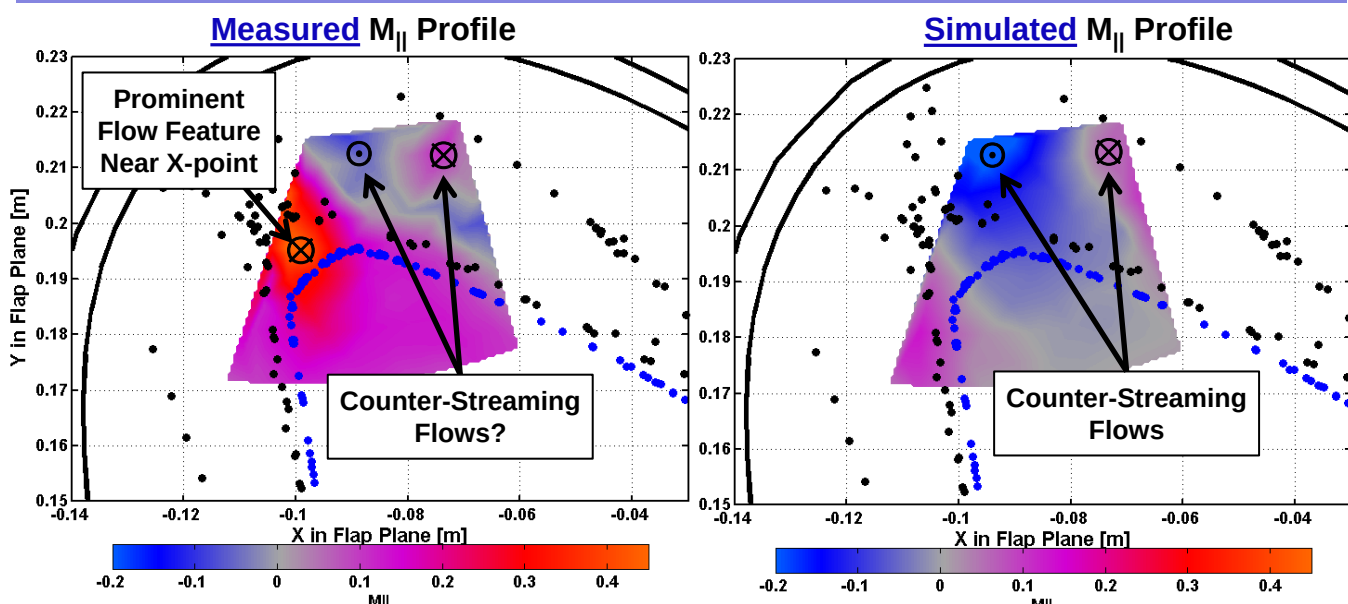
- Mechanism for increase in transport unclear
- Can speculate that edge potential structures are a candidate for affecting transport



Poloidal Asymmetry in Measured λ_n Suggests Presence of Local Source



Differences in $M_{\parallel}$ Profiles Points Towards Uncertainty in Topology or Additional $M_{\parallel}$ Source



Summary

- Observations indicate the presence of both convective + diffusive transport channels in edge of HSX
- Limiter experiments provide evidence for long Lc domain acting as a diffusive plasma transport channel with locally increased potential
- Interpretation of the measured n_e gradients with a simple SOL model yields values of $D_{\perp}$ of $0.03 \text{ m}^2/\text{s}$
- Removal of edge potential structure is observed to lead to a x2 increase in $D_{\perp}$ when transitioning to a pure SOL edge
- A prominent flow feature at X-point suggests a deviation from the ideal source/sink relation, possibly caused by uncertainties in the local magnetic topology
- Edge field-line mapping is in progress

References

- Y. Feng et al. "3D edge modeling and island divertor physics." Contrib. Plasma Physics. 44 (2004).
- A. Bader et al. "Simulations of edge configurations in quasi-helically symmetric geometry using EMC3-EIRENE." Nucl. Fusion 53 (2013)

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