Statistical properties of fluctuation driven flows in the outboard mid-plane SOL of Alcator C-Mod

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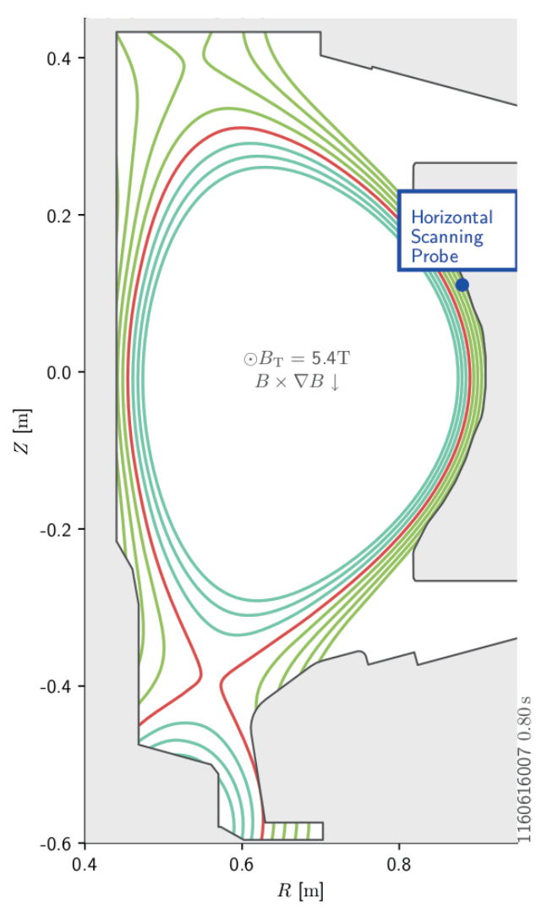
Introduction

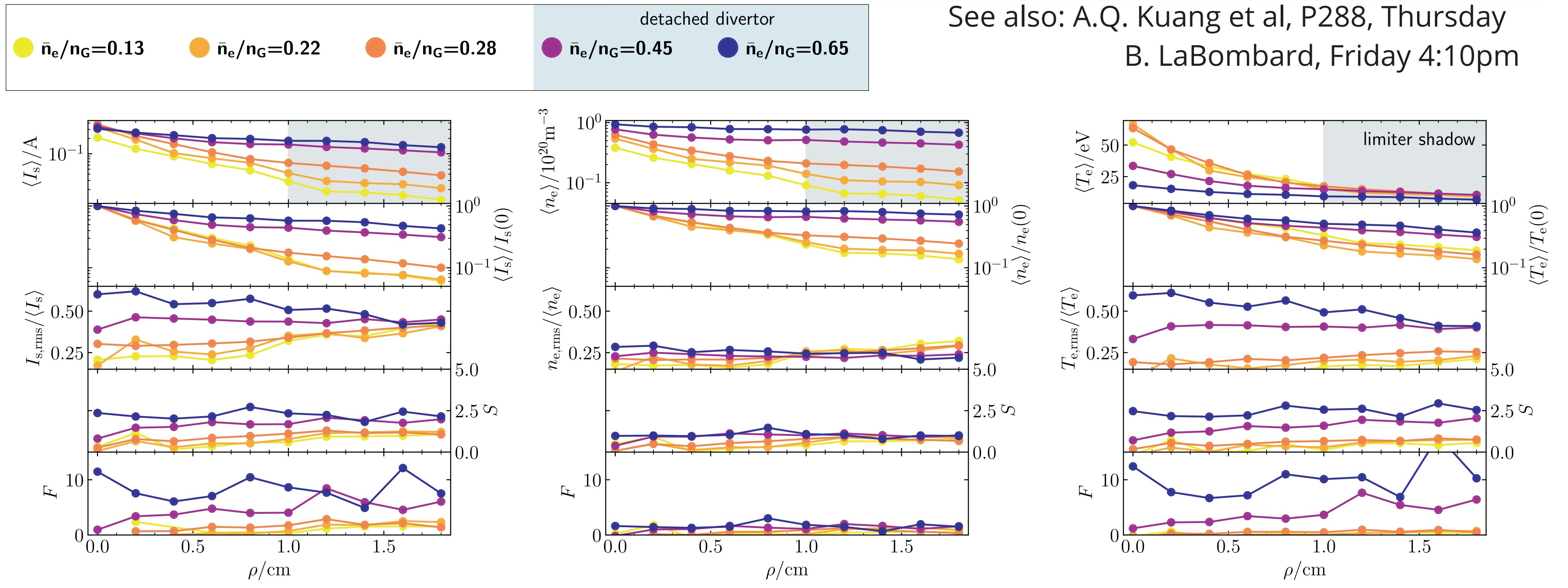
The scale length of the radial density profile in scrape-off layer plasmas has been shown to depend on on the line-averaged plasma density. While first reported on Alcator C-Mod [1], recent work [2, 3] verifies this phenomena in JET and ASDEX Upgrade. In low density plasmas with a sheath-limited SOL, the density profiles present a two-scale structure which allows the separation of the SOL into two distinct regions. While the near-SOL presents a small profile length scale, the far-SOL presents a flat density profile length scale. Transitioning into detached divertor conditions by increasing the line-averaged plasma density, the density profile features a shallow length scale. In this contribution, Alcator C-Mods Mirror Langmuir Probe system is used to investigate the radial profiles as well as the statistical properties of flucutations in the electron density, temperature, as well as the fluctuation driven fluxes.

Methodology



- 4 MLPs installed on a Mach probe head
- Probe head either scanning (1-3 scans) or dwelled at limiter radius
- Each MLP records I_s, T_e, V_f with 1 MHz sampling frequency
- n_e and V_p are calculated with the same sampling frequency
- Timescale of SOL fluctuations (blobs) ≈ 10 μs
- Ohmically heated L-mode plasmas with constant line-averaged density are investigated

Radial profiles: I_s, n_e and T_e



See also: A.Q. Kuang et al, P288, Thursday
B. LaBombard, Friday 4:10pm

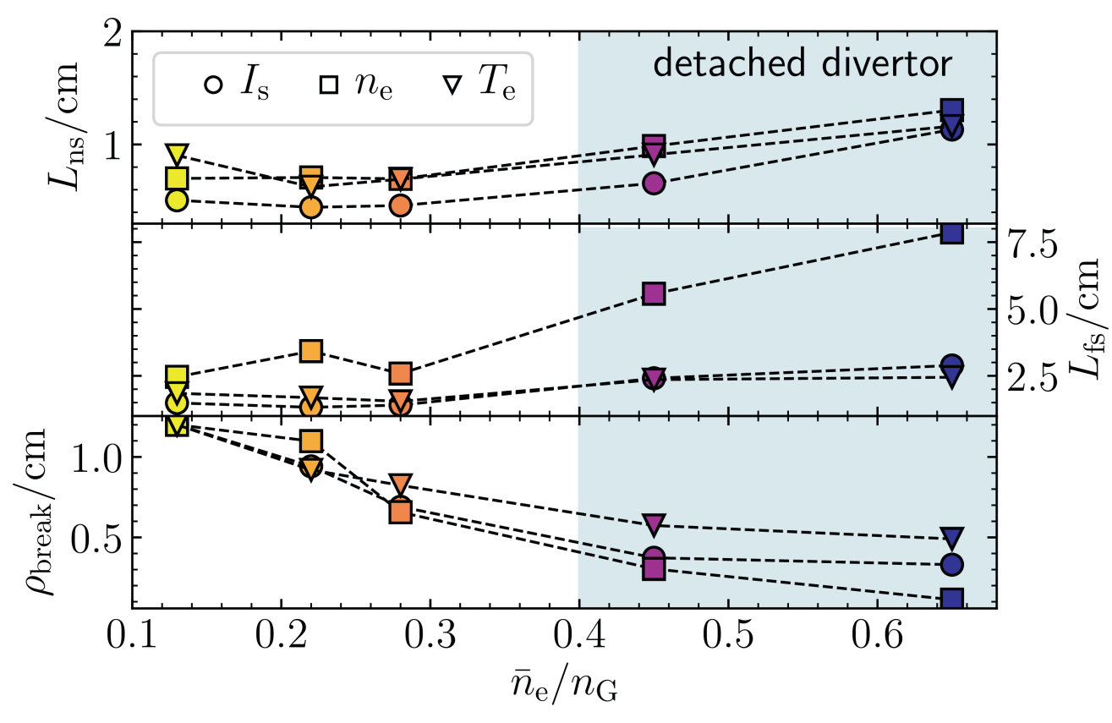
	Mean	Rel. fluctuation level	S, F
I_{sat}	Breakpoint moves inwards	Approx. constant with ρ, increases with n_e/n_G	Constant with ρ, increases n_e/n_G
n_e	Breakpoint moves inwards, shoulder develops	Constant with ρ and n_e/n_G	Constant with ρ and n_e/n_G
T_e	Breakpoint moves inwards	Constant with ρ, increases with n_e/n_G	Constant with ρ, increaseas with n_e/n_G

Skewness $S = \mathbf{E}\left[\left(\frac{X-\mu}{\sigma}\right)^3\right]$

Excess kurtosis $F = \mathbf{E}\left[\left(\frac{X-\mu}{\sigma}\right)^4\right] - 3$

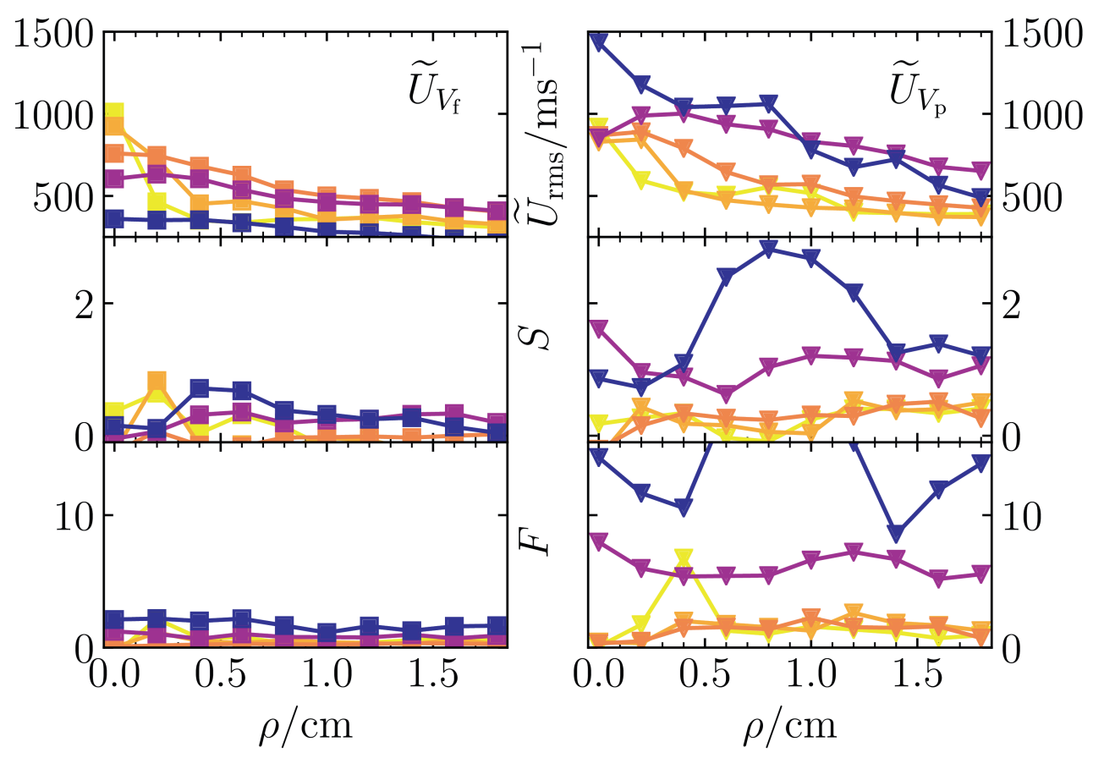
SOL profiles are fitted on

$$\langle \Phi \rangle (\rho) = \begin{cases} \sim \exp\left(-\frac{\rho}{L_{ns}}\right) & \text{if } \rho \leq \rho_{\text{break}} \\ \sim \exp\left(-\frac{\rho}{L_{fs}}\right) & \text{if } \rho > \rho_{\text{break}} \end{cases}$$

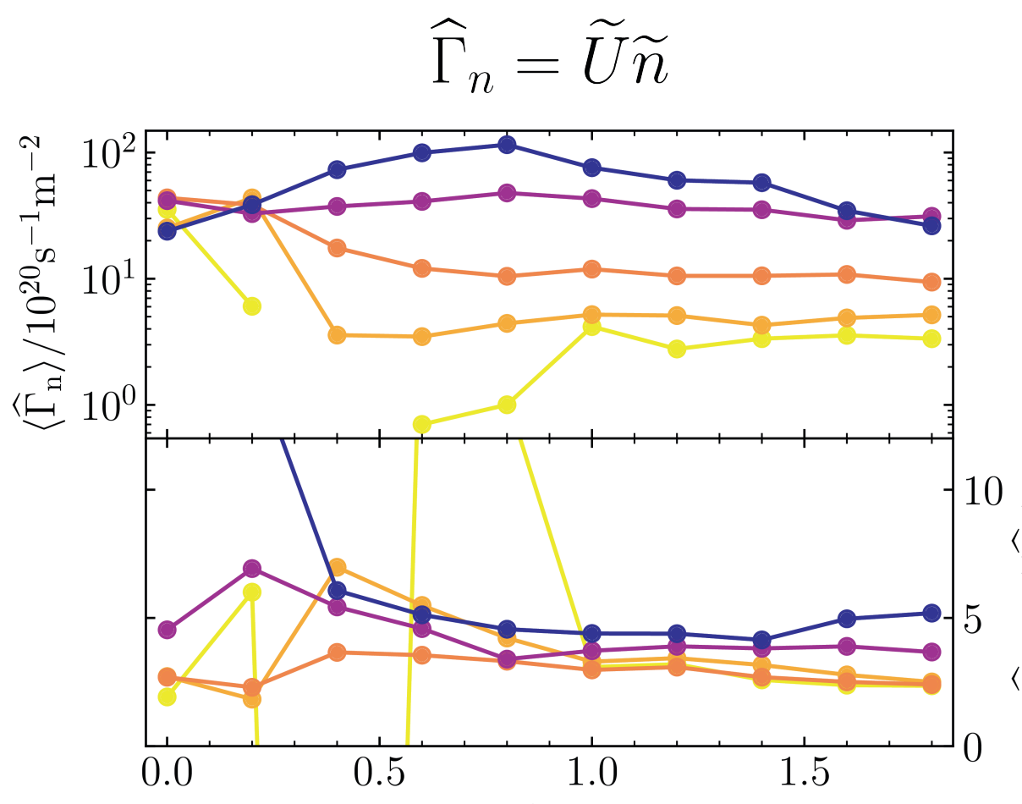


Radial profiles: ExB velocity and fluctuation driven fluxes

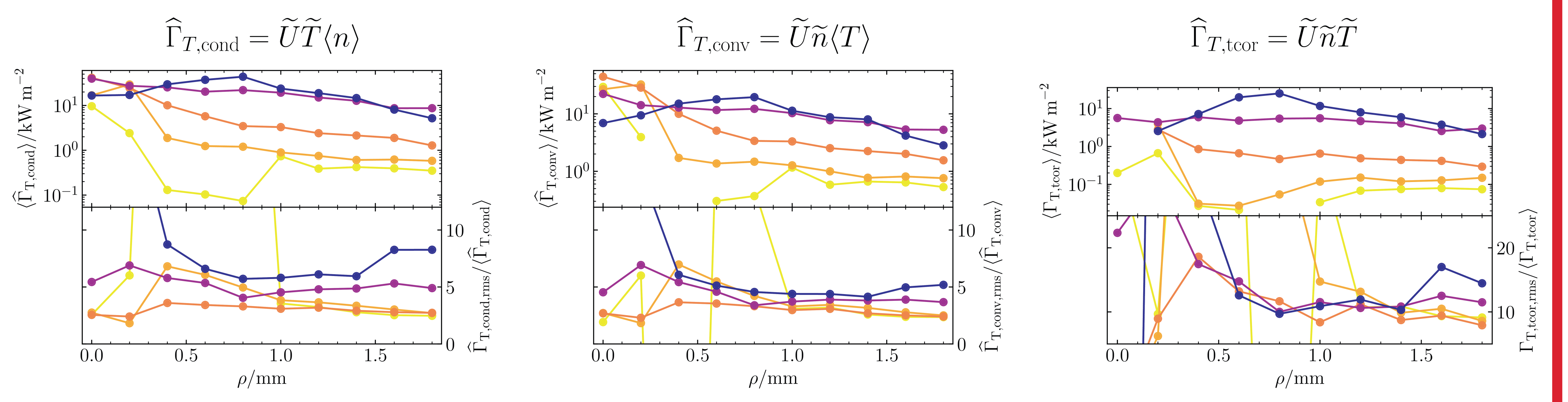
Langmuir Probes: Estimate ExB velocity U using V_f
Mirror Langmuir Probe: Estimate U using $V_p = V_f + \alpha_{sh}(T_e)\, T_e$



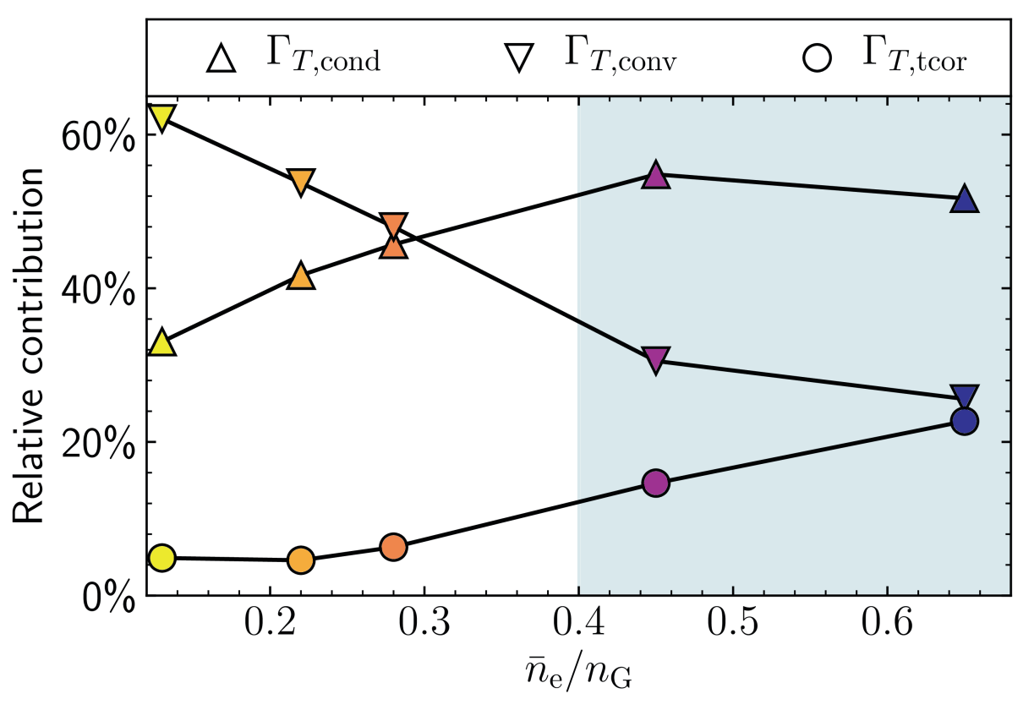
- U_{rms} increases with n_e/n_G
- n_e/n_G <0.3: $U_{rms}(V_f) \approx U_{rms}(V_p)$
- n_e/n_G > 0.3: $U_{rms}(V_p) >> U_{rms}(V_f)$
- $U(V_f)$: S, F small and approximately constant
- $U(V_p)$: S, F large, increase with n_e/n_G



- Γ_n increases with n_e/n_G
- Flat profiles, little dependence on ρ
- Constant fluctuation level in far-SOL
- Consistent with profiles determined from particle balance [1]



- Γ_T profiles are flat in far SOL
- Average Γ_T increases with n_e/n_G
- Relative fluctuation levels increase with n_e/n_G
- Convective flux dominant for low n_e/n_G
- Conductive flux dominant for high n_e/n_G due to large fluctuations in T_e and U
- Contributions from triple correlations are non-negligible for high n_e/n_G



Correlation of density, temperature, and radial velocity fluctuations

MLP was dwelled at the limiter radius, ρ ≈ 1.5 cm.
Time series data normalized to running mean, rms: $\widetilde{\Phi} = \frac{\Phi - \langle \Phi \rangle_{mv}}{\Phi_{mrms}}$

- Correlation of density and temperature increases with n_e/n_G

Low density n_e/n_G=0.12

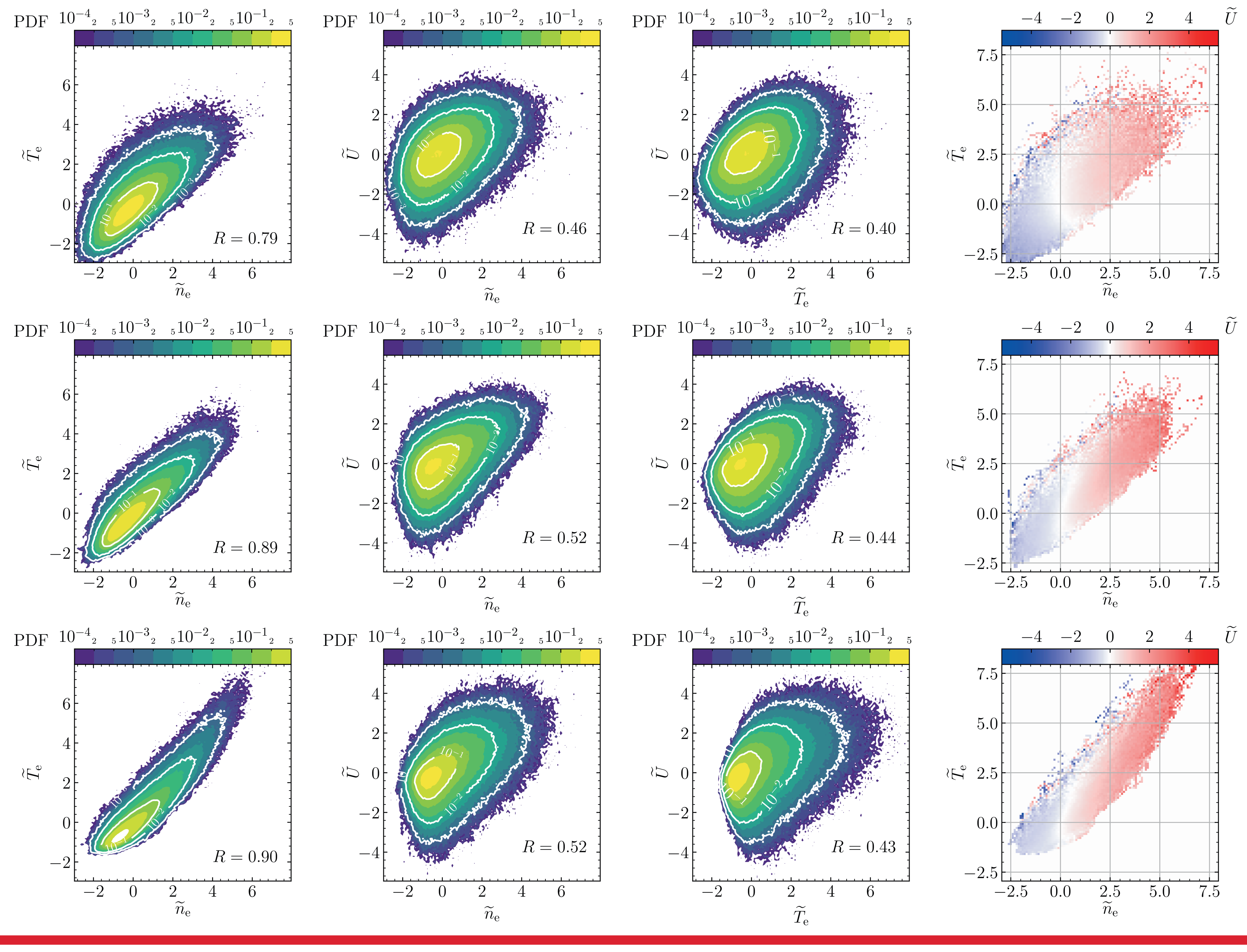
	mean	std
$n_e/10^{18}$ m^{-3}	8.46	1.68
Te/eV	16.7	2.22
U/ms-1	0	367

Medium density n_e/n_G=0.28

	mean	std
$n_e/10^{18}$ m^{-3}	18.7	4.49
T_e/eV	15.0	3.17
U/ms^{-1}	0	476

High density n_e/n_G=0.46

	mean	std
$n_e/10^{18}$ m^{-3}	48.0	10.3
T_e/eV	13.4	5.21
U/ms^{-1}	0	453



Conclusions

- Density shoulder formation is observed using novel diagnostic which samples the plasma parameters in real time
- Relative fluctuation level of the n_e fluctuation is independent of n_e/n_G
- Relative fluctuation level of the T_e fluctuations increases with n_e/n_G, especially when the divertor region detaches
- Particle transport increases with n_e/n_G and presents flat profiles, consistent with previous results
- Convection governs the radial heat flux in low density plasmas
- Conduction governs the radial heat flux in high density plasmas
- Triple correlations contribute significantly to the heat flux in high density plasmas
- Strong correlation of n_e and T_e fluctuations in high density plasmas

References

[1] B. LaBombard et al., Phys. Plasmas 8, 2107 (2001)
[2] D. Carralero et al., Nucl. Fusion 54 123005 (2014); Nucl. Fusion 57 056044 (2017)
[3] A. Wynn et al., Nucl. Fusion 58 056001 (2018)
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