MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Drift flows impact island divertor operation in Wendelstein 7-X

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EUROfusion

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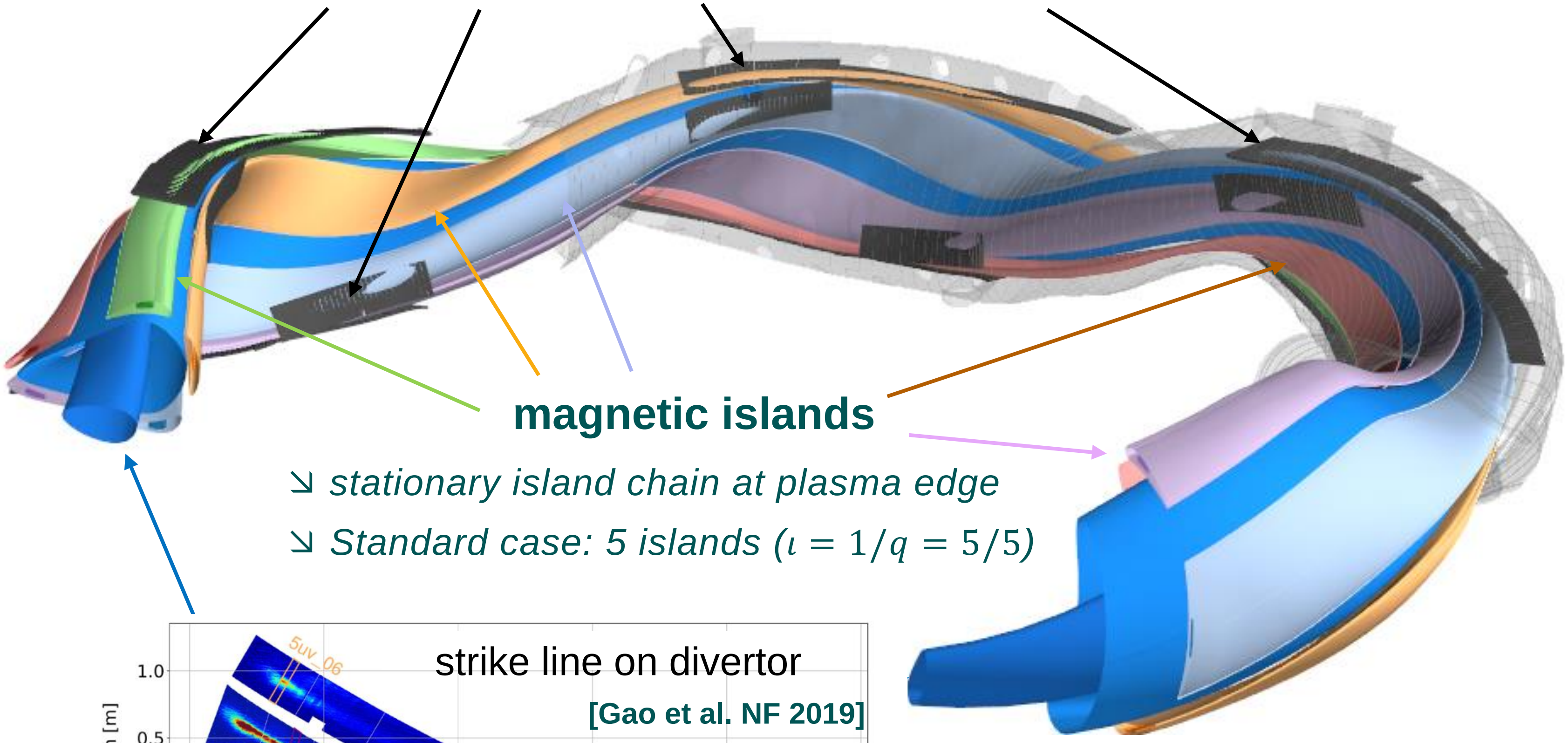
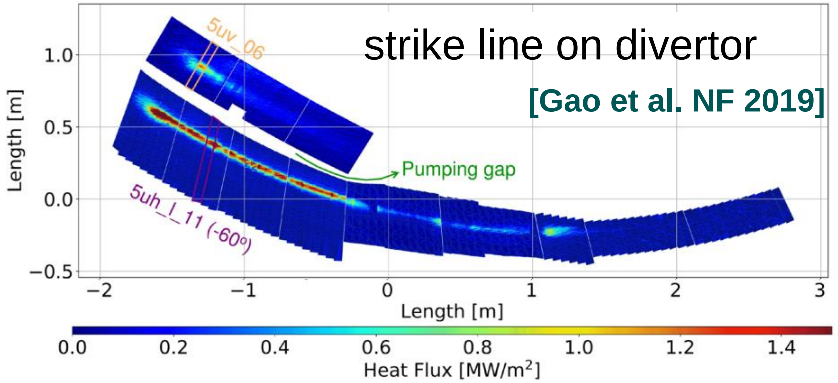
Island Divertor in W7-X

modular divertor plates intersect magnetic islands



magnetic islands

- ⦪ *stationary island chain at plasma edge*
- ⦪ *Standard case: 5 islands ($\iota = 1/q = 5/5$)*



Island divertor experience so far

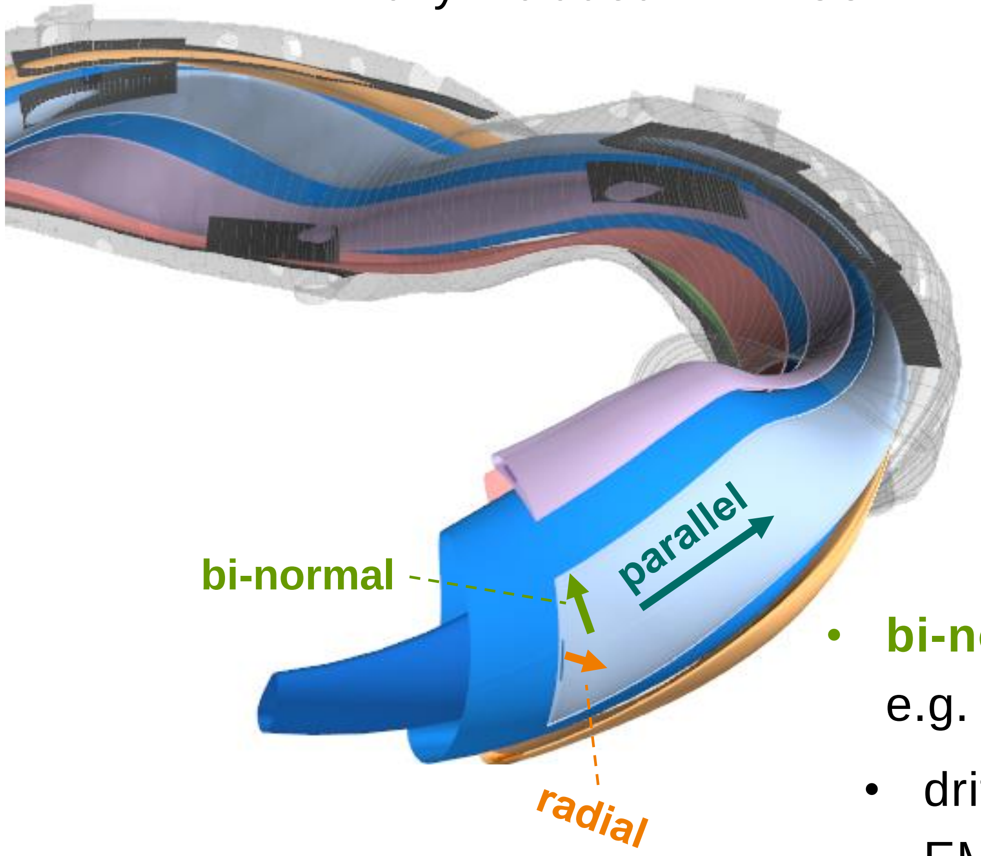
- performs well!
  - ⦪ *long pulse operation,*
  - ⦪ *detachment readily achievable*
  - ⦪ *good impurity retention*
- many fundamental features can be modeled with EMC3-EIRENE

However:

- heat and particle fluxes are not entirely predictable
- likely cause: no drift flow physics in EMC3-EIRENE

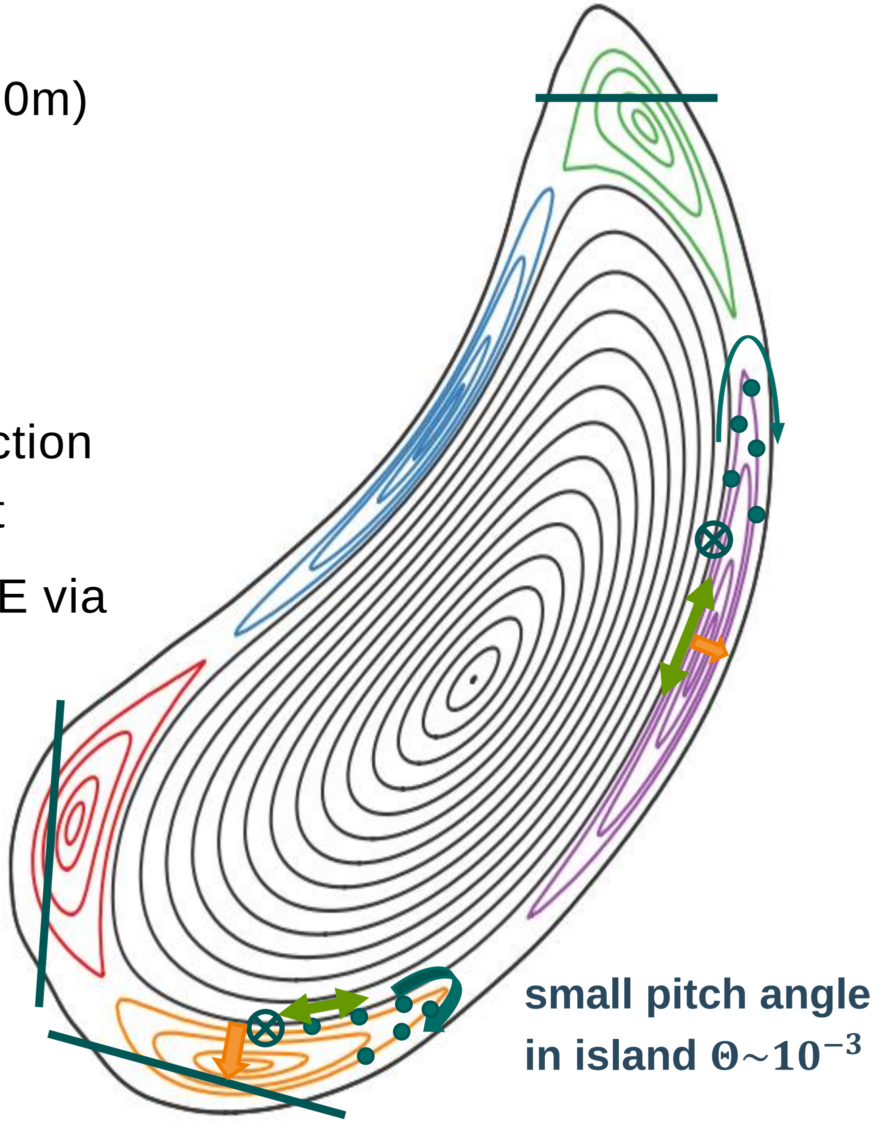
Fundamental transport directions in the island divertor

- **parallel**: long connection lengths to divertor targets (some 100m)
  - sheath physics, conductive / convective transport, …
  - fully included in EMC3-EIRENE



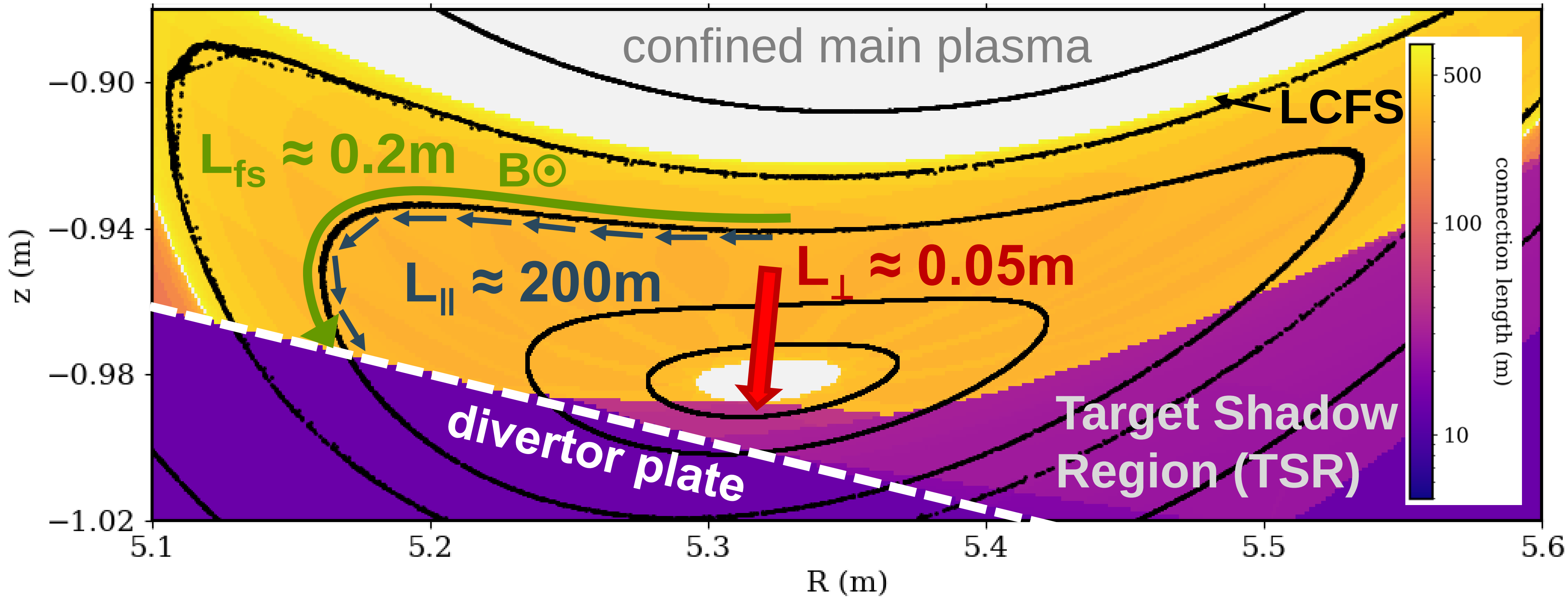
- **radial**: main gradients direction
  → turbulent radial transport
  - included in EMC3-EIRENE via prescribed diffusivities

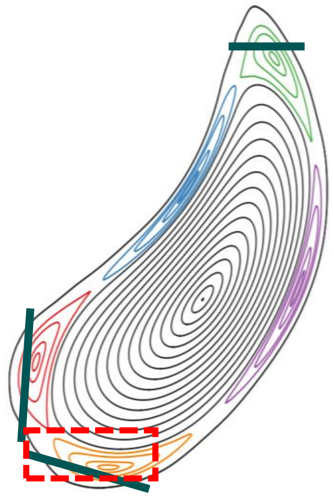
- **bi-normal**: on island flux surfaces, e.g. E_rxB drift from sheath E_r
  - drifts are **not** included in EMC3-EIRENE



Transport directions have different scale lengths

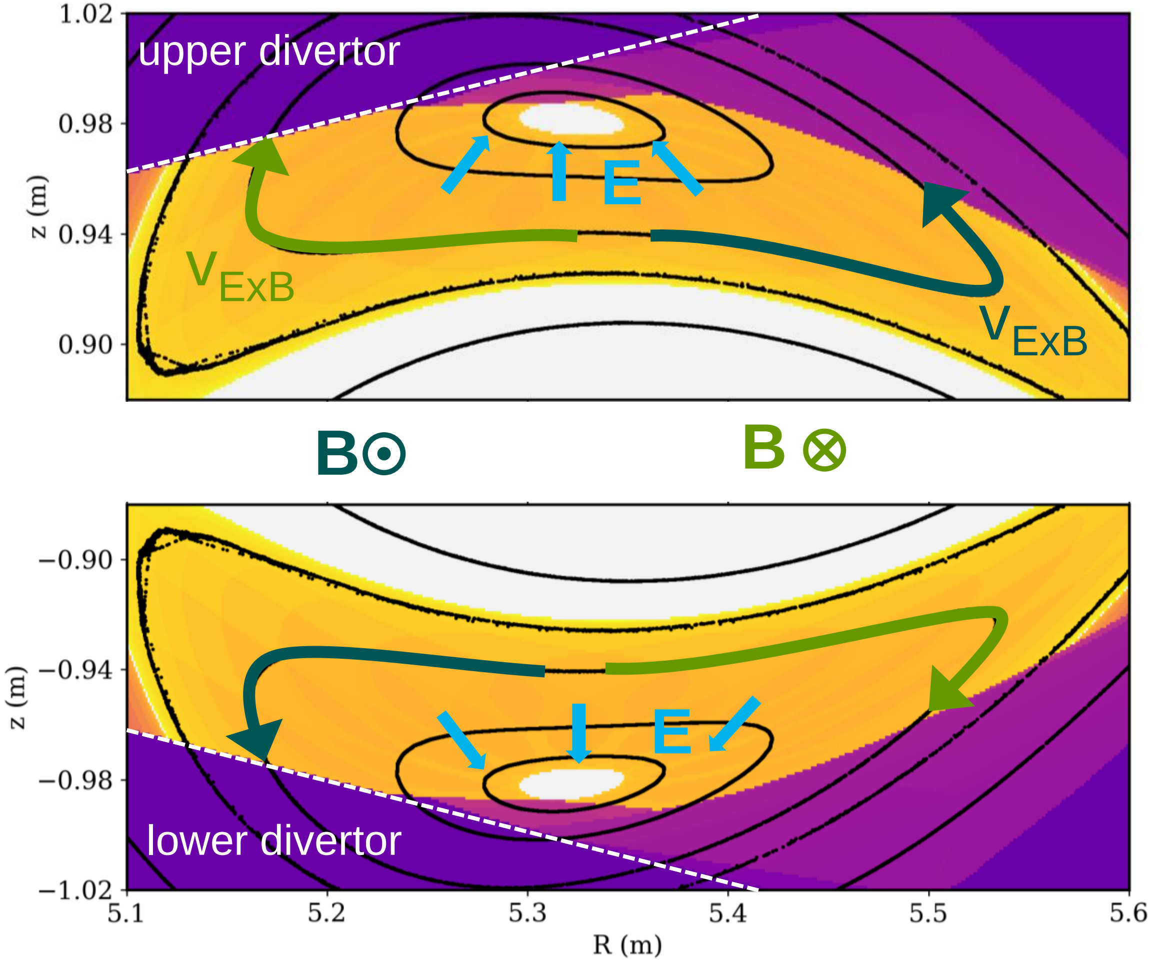
- perpendicular: short distance to target but turbulent particle fluxes are rather small in W7-X [Killer NF 21]
- bi-normal: $L_{fs} \sim 10^{-3} L_{\parallel}$ → effective transport channel even for moderate drift flows on flux surfaces



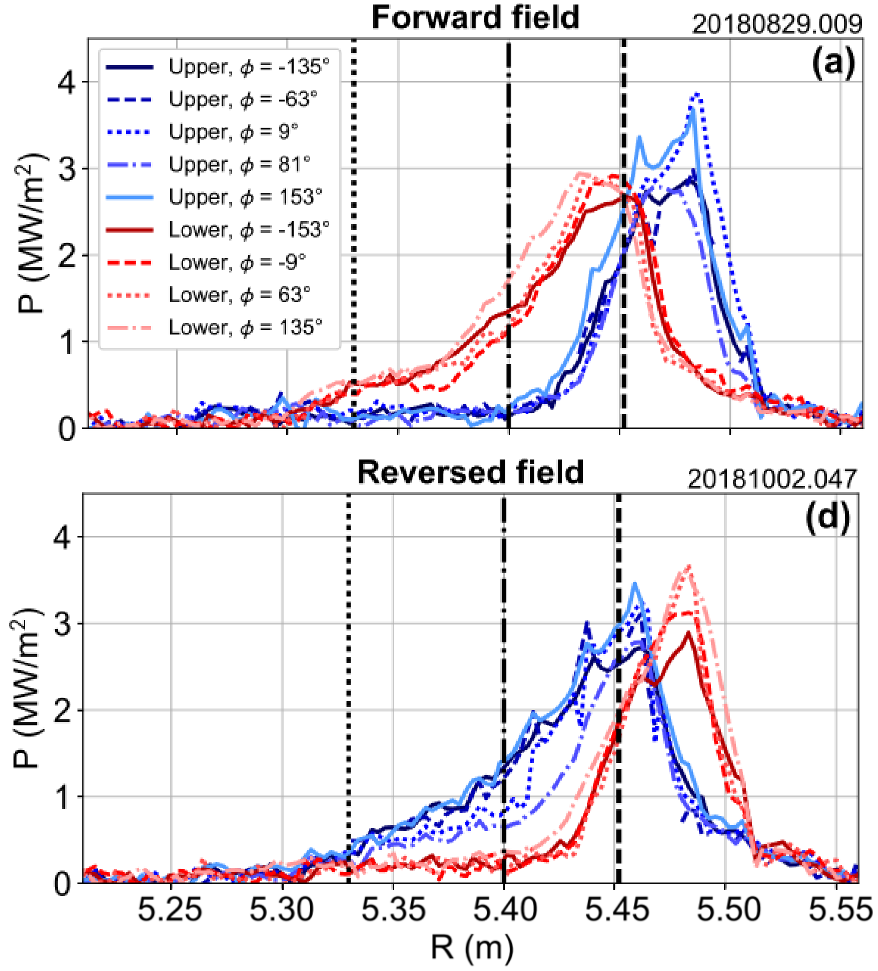


Up-Down asymmetric divertor loads indicate role of drift flows

bi-normal drift flows point into / out of the TSR
(depending on B direction and divertor location)



**low iota* configuration - different island geometry but same physics process



[Hammond et al PPCF 61 (2019) 125001]

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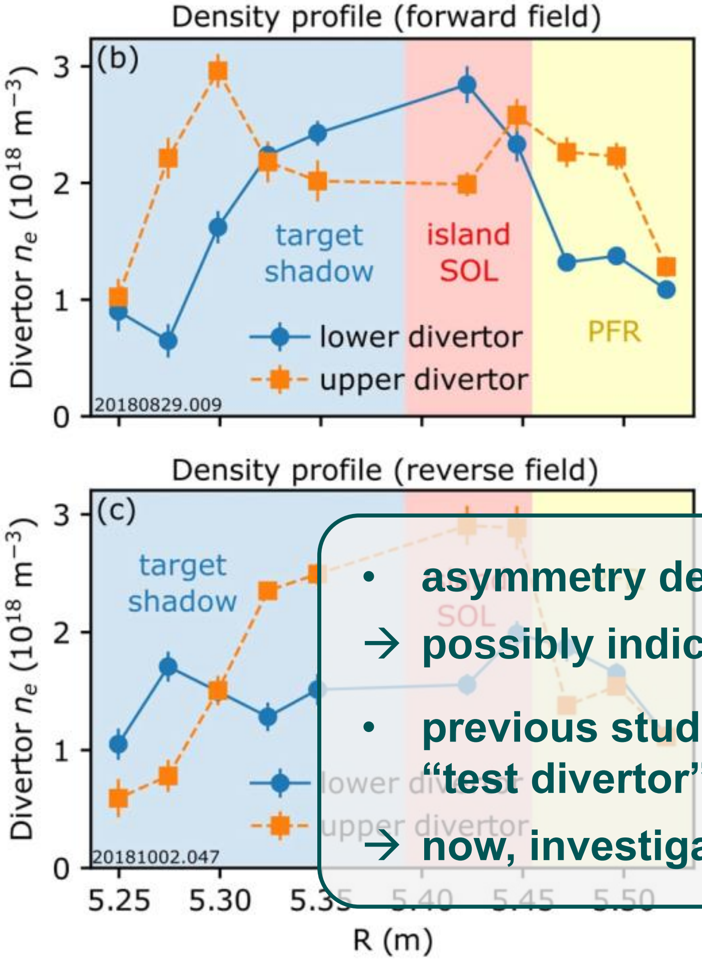

[Kriete et al NF 63 (2023) 026022]

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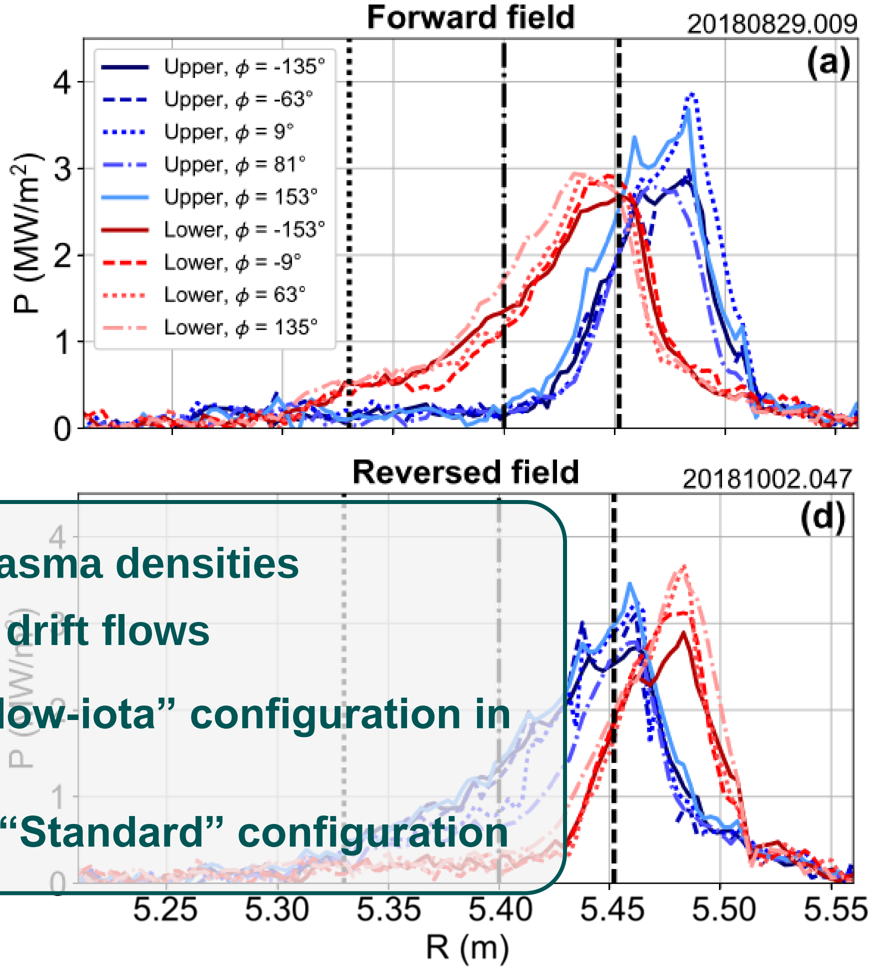


[Hammond et al PPCF 61 (2019) 125001]

- **asymmetry decreases for higher plasma densities**

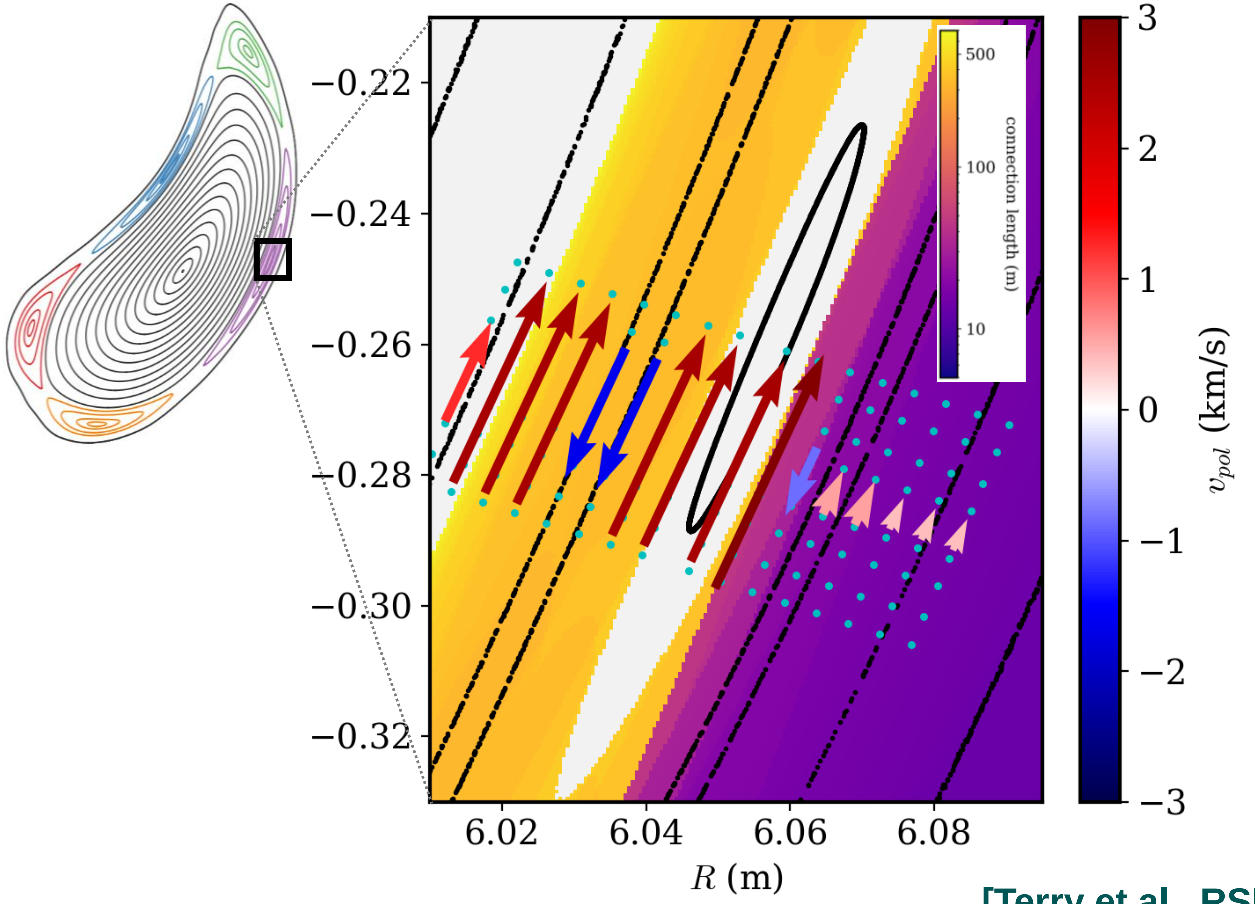
→ possibly indicating reduced role of drift flows

- **previous studies are restricted to "low-iota" configuration in "test divertor" (2017-2018)**

→ now, investigate the more relevant "Standard" configuration

Direct observation of drift flows

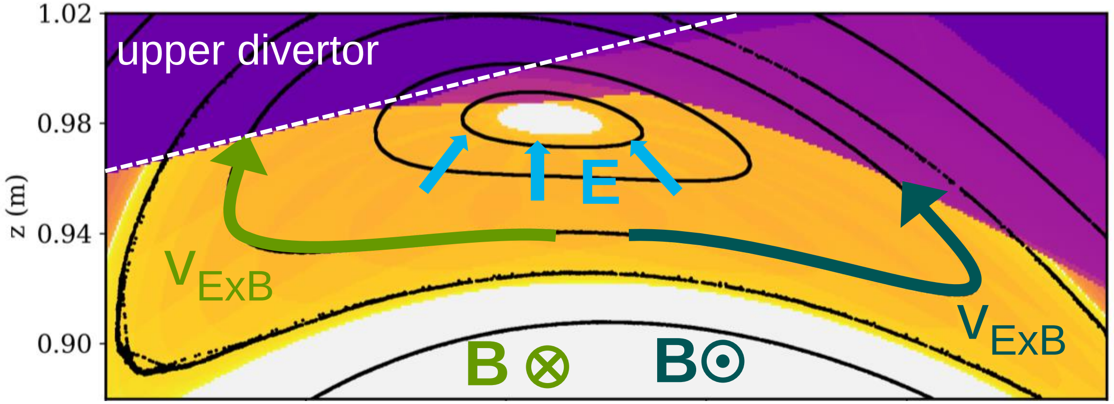
flow pattern in island divertor SOL observed with Gas Puff Imaging (GPI)

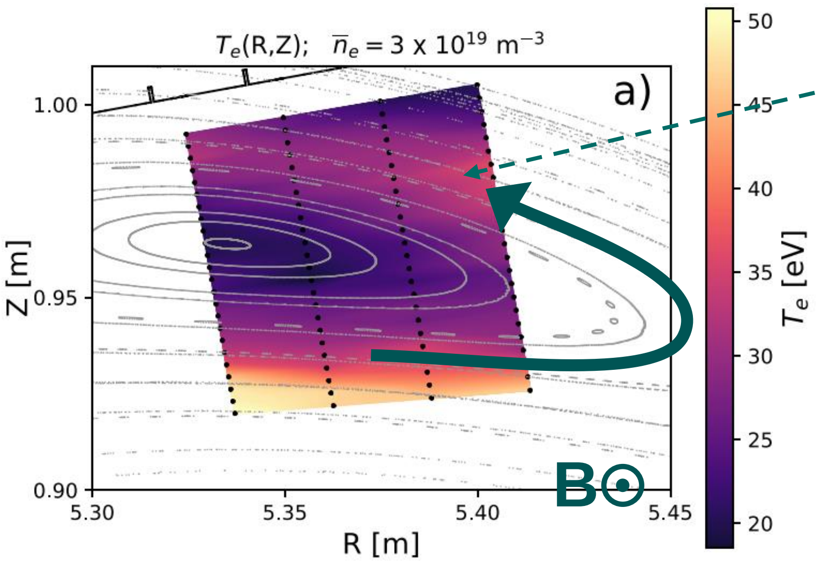


- bi-normal flows with velocity of km/s are observed in the island SOL
- flow direction changes across the radial range of the island
- detailed flow pattern is highly sensitive to magnetic island size / position
- flow direction flips with field reversal
  → drift flow

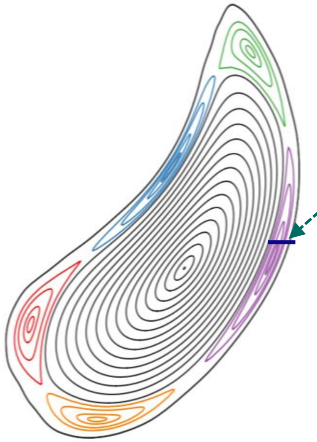
[Terry et al., RSI 95 093517 (2024)]

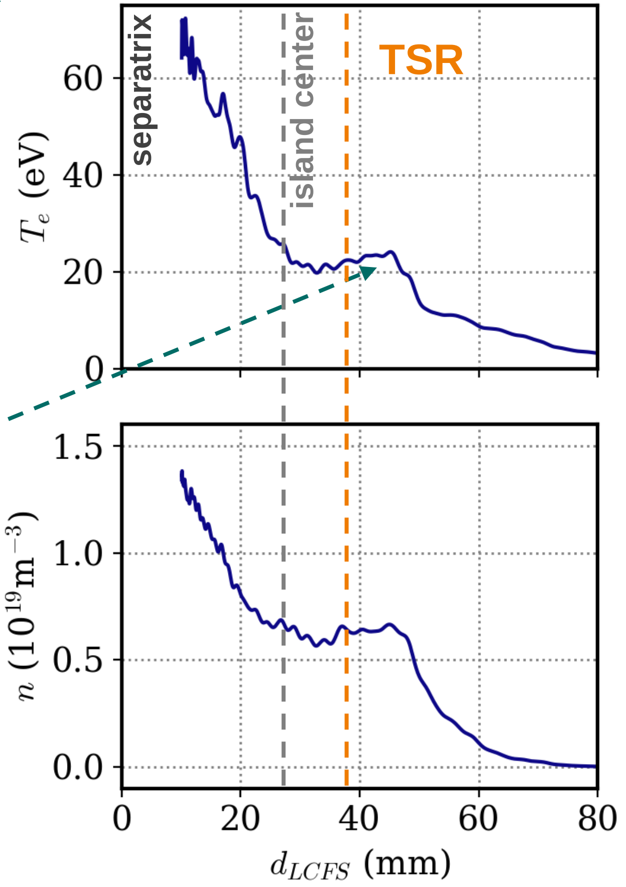
Non-monotonic T_e profiles in island divertor indicate electric fields that can drive drift flows





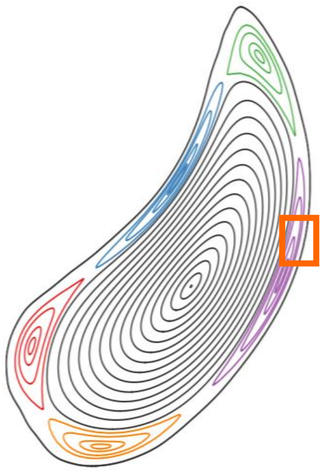
[Flom et al., https://arxiv.org/abs/2312.01240]

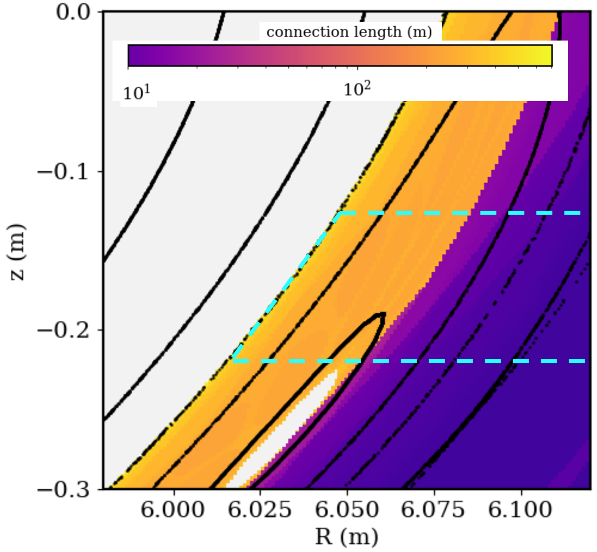


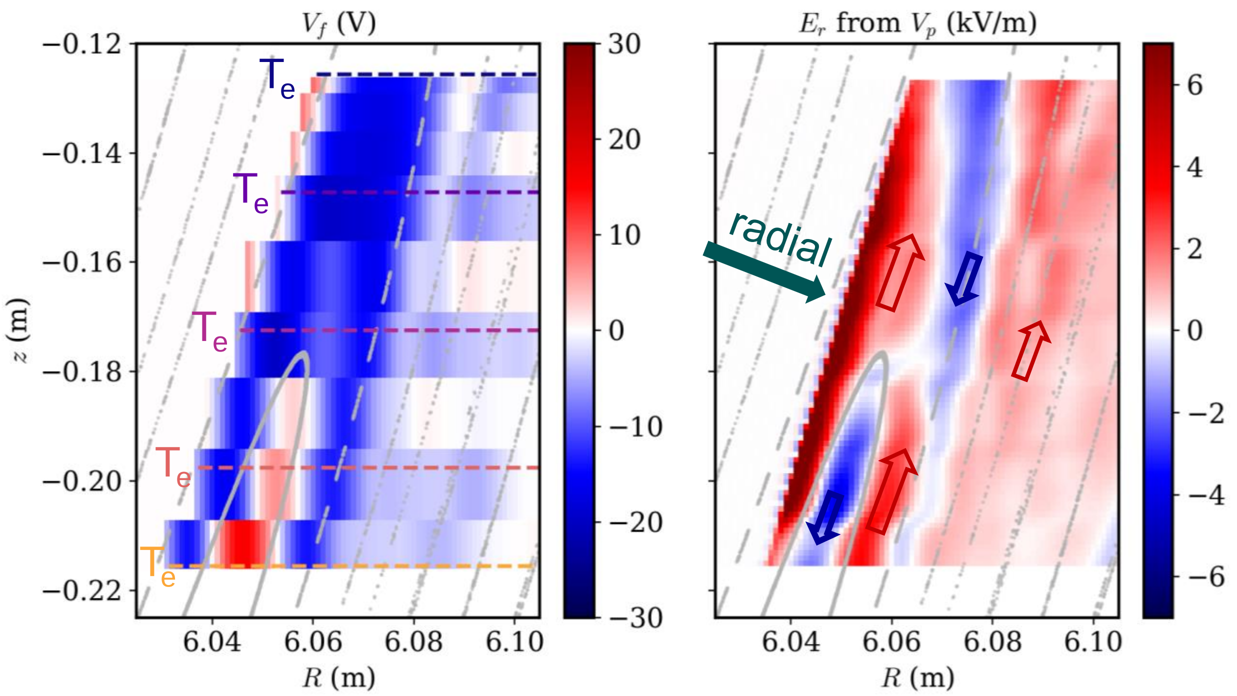


- **T_e maximum at TSR boundary**
- not consistently reproducible with EMC3-EIRENE

Reciprocating probe array provides electric field map from 2D measurement of T_e, V_{float}







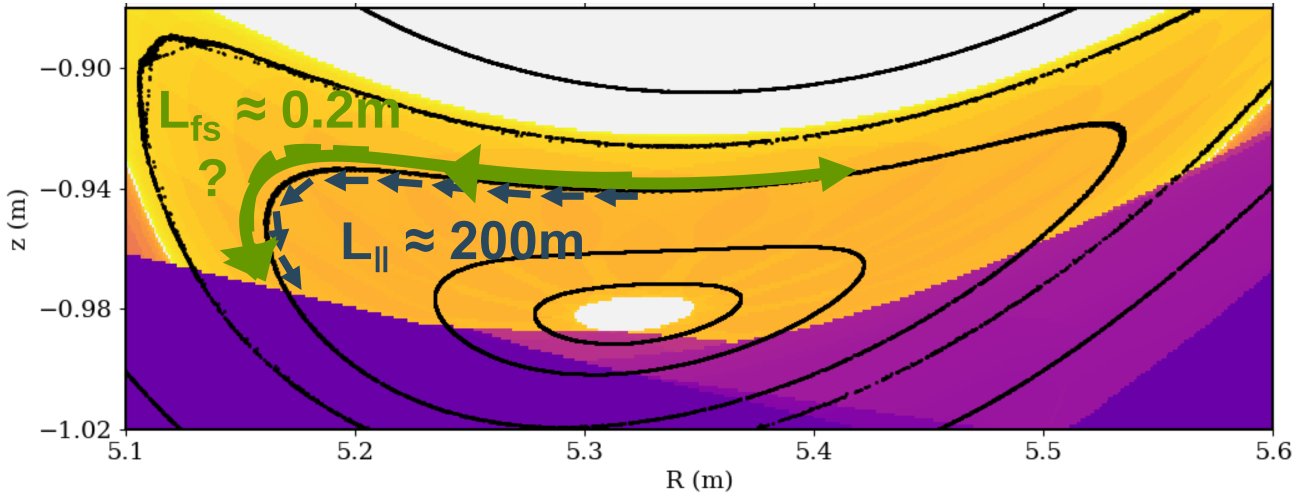
2D (time-averaged) plasma potential Φ_{plasma} map from reciprocating probe array

→ radial electric field $E_r = -\nabla\Phi_{plasma}$

→ expect bi-normal drift flows from $\frac{E_r \times B}{B^2}$ of order km/s → agreement with GPI

[Killer et al. NF 65 (2025) 056026]

Convective heat transport by drift flows is significant due to the small island pitch angle



for typical values of

T_e, T_i=50eV, n=1e19m^{-3}, v=3km/s

typical parallel SOL heat fluxes:

$$q_{\parallel} = q_{cond} + q_{conv} \sim 10\mathrm{MW/m^2}$$

ExB drift flux

$$q_{E\times B} = \frac{5}{2} T_e n_e v_{E\times B} \sim 500\mathrm{kW/m^2}$$

projecting ExB flux onto the parallel direction

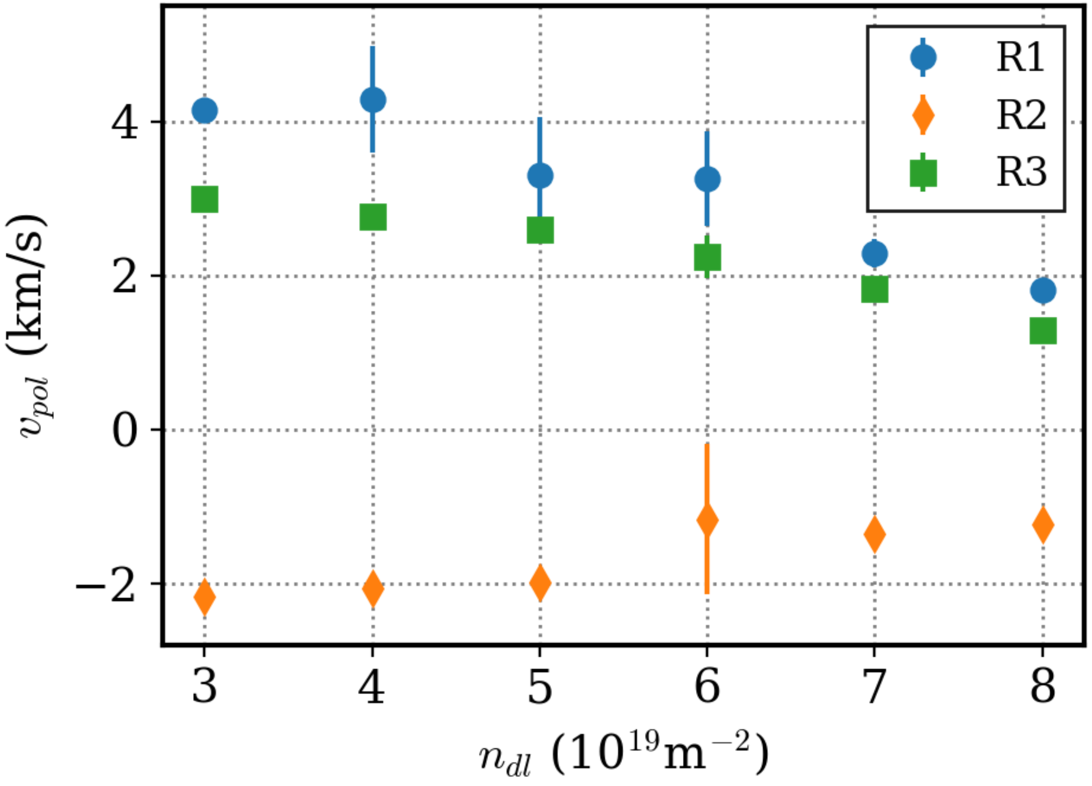
$$q_{E\times B,eff} = \Theta^{-1} q_{ExB} > \frac{100\mathrm{MW}}{\mathrm{m^2}} \gg \mathrm{q}_{\parallel}$$

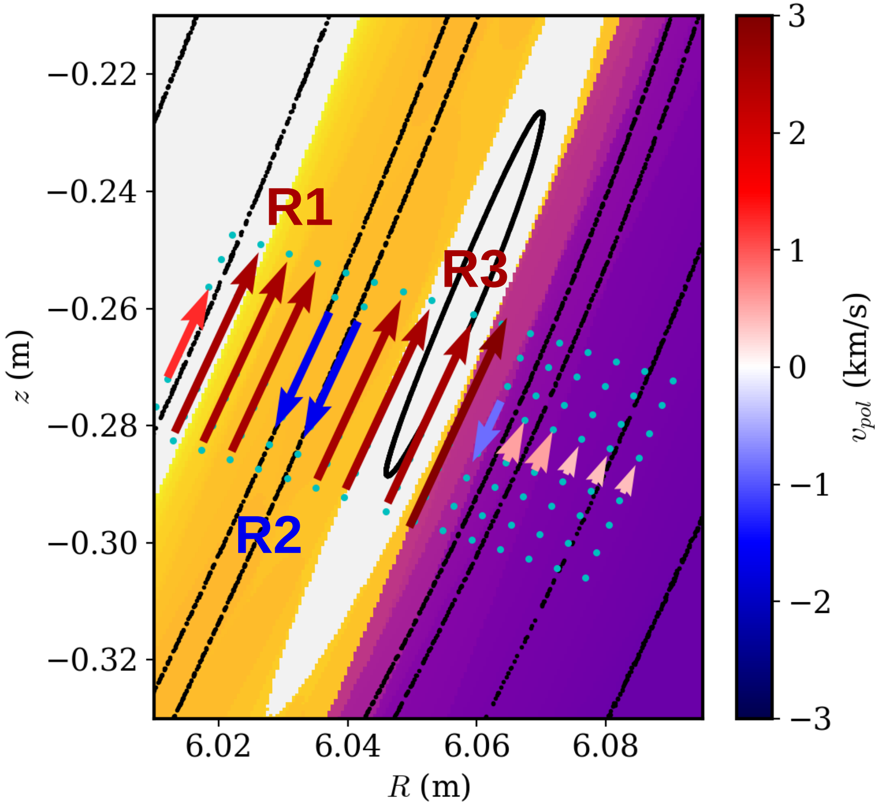
Disclaimer: this is an over-simplification for illustration purpose

- **assumption of constant potential on island flux surfaces not verified**
- **no evidence of enormous drift flow velocities up to the targets**

Drift flow velocity decreases for higher densities

density dependence of GPI flow velocities for three main flow regions



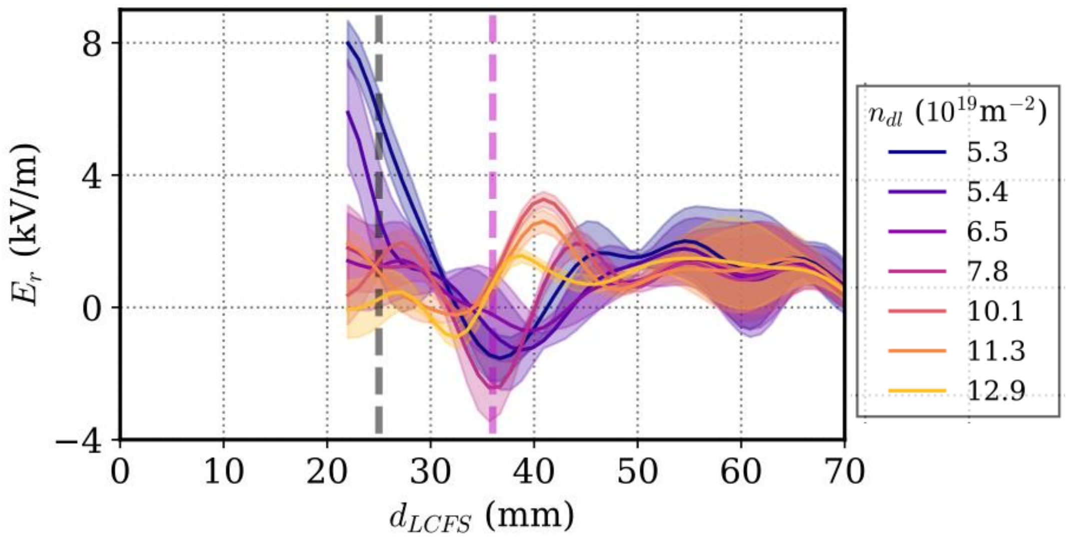


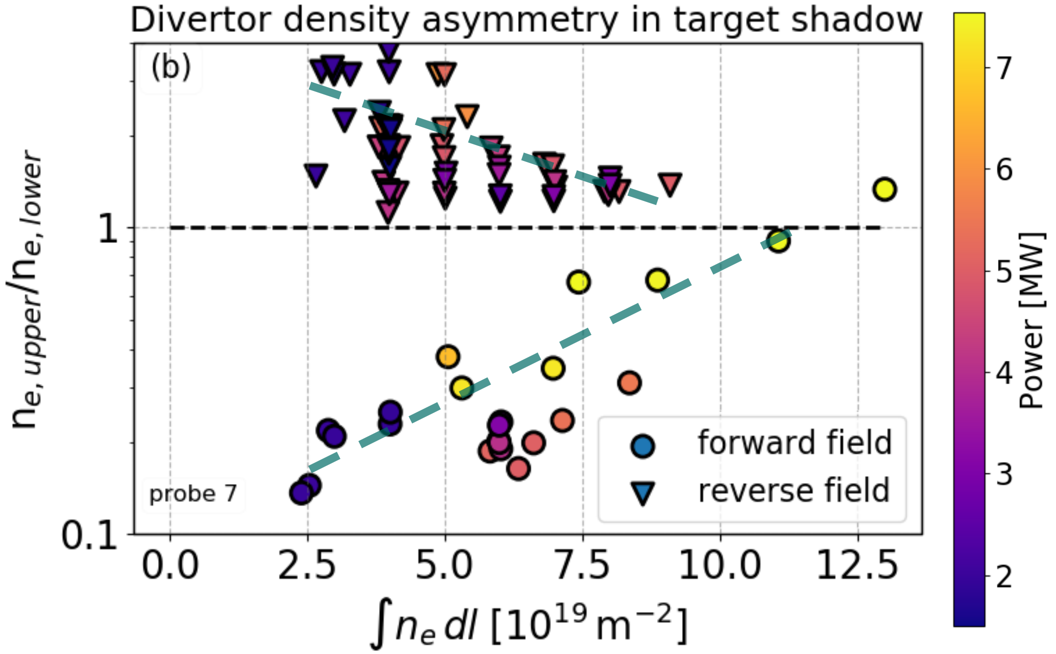
Effects associated to drift flows get weaker for higher densities

strong up-down asymmetry for low densities

small up-down asymmetry for high densities

electric field decrease for higher densities





Summary

- **bi-normal drift flows with v~km/s redistribute SOL plasma**
  - highly efficient transport channel due to small island pitch angle
  - resulting in heat + particle fluxes to “shadowed” divertor regions

    ↘ *disagreement of experimental and modeled divertor heat loads*

    ↘ *asymmetries between upper and lower divertors*

- **flow velocities and divertor asymmetries decrease for higher plasma densities**
- **the lack of drift flows in state-of-the-art 3D edge transport models imposes a challenge**

    ↘ *for future W7-X divertor operation towards higher heating power*

    ↘ *for the development of stellarator reactor divertor scenarios*