Turbulent regimes in the tokamak Scrape-Off layer

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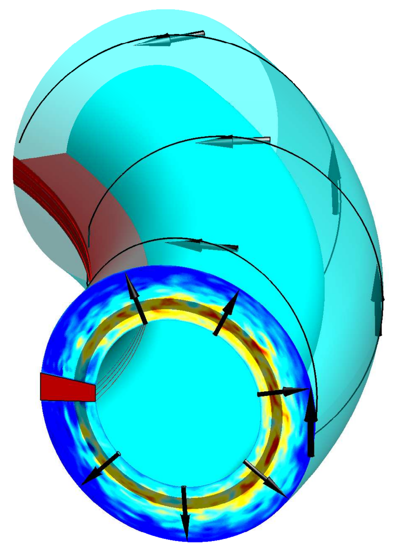
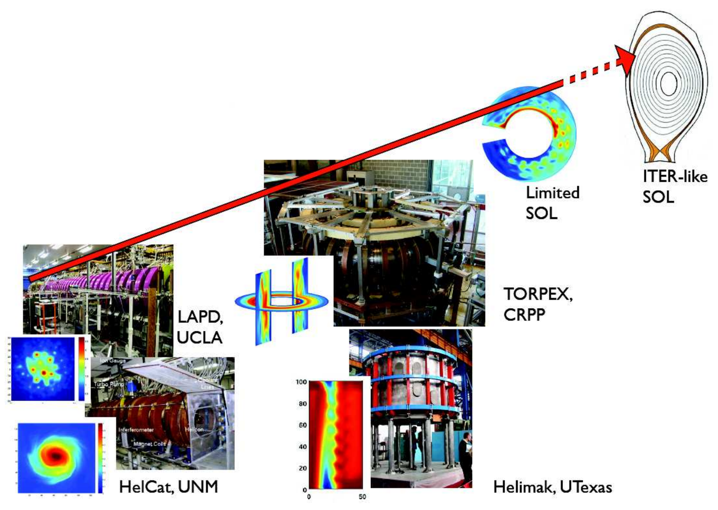
1- Introduction

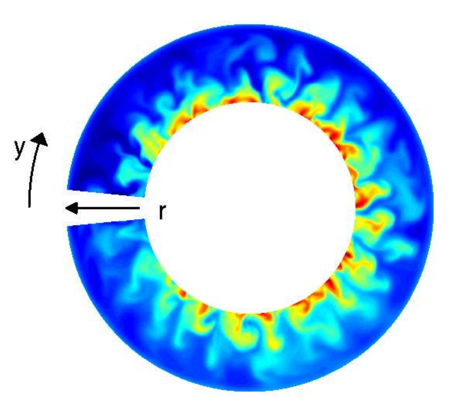
- We study Scrape-Off Layer (SOL) turbulence through simulations that evolve the plasma dynamics as the interplay of plasma source from the core, perpendicular transport, and losses at the limiter plates
- We identify the SOL turbulence regimes, defining the regions of existence of the Ballooning Modes [resistive (RBM) and inertial (IBM)] and the Drift Waves [resistive (RDW) and inertial (IDW)] instabilities, focusing on the role of magnetic shear



2- The Global Braginskii Solver (GBS) code



- The code is based on the non-linear, drift-reduced two-fluid Braginskii equations ([1],[2] and [3])
- Self-consistent global evolution of equilibrium and fluctuations
- The understanding of SOL plasma turbulence has been approached by studying systems of increasing complexity



Topics currently under investigation:

- **turbulent saturation mechanism**
- **identification of the main instabilities**
- **magnetic shear**
- size scaling
- intrinsic rotation (J. Loizu talk I3.409 on Wednesday)
- toroidicity effects (finite aspect ratio, Shafranov shift, ...)
- impurity transport

Continuity: $\frac{\partial n}{\partial t} = \frac{c}{B}[\Phi, n] + \frac{c}{eRB}\left(\hat{C}p_e - n\hat{C}\Phi\right) - \nabla_{||}\left(nV_{||e}\right)$

Vorticity: $\frac{\partial \nabla_\perp^2 \Phi}{\partial t} = \frac{c}{B}\left[\Phi, \nabla_\perp^2 \Phi\right] + \frac{B}{m_i c n R}\hat{C}p_e - V_{||i}\nabla_{||}\nabla_\perp^2\Phi + \frac{m_i \Omega_{ci}^2}{e^2 n}\nabla_{||}j_{||}$

Ohm's law: $m_e n\frac{\partial V_{||e}}{\partial t} + \frac{en}{c}\frac{\partial \psi}{\partial t} = m_e n\frac{c}{B}\left[\Phi, V_{||e}\right] - m_e n V_{||e}\nabla_{||}V_{||e} - T_e\nabla_{||}n + en\nabla_{||}\Phi - 1.71 n\nabla_{||}T_e + \frac{\nu m_i}{e}j_{||}$

Parallel ion velocity: $\frac{\partial V_{||i}}{\partial t} = \frac{c}{B}\left[\Phi, V_{||i}\right] - V_{||i}\nabla_{||}V_{||i} - \frac{1}{nm_i}\nabla_{||}p_e$

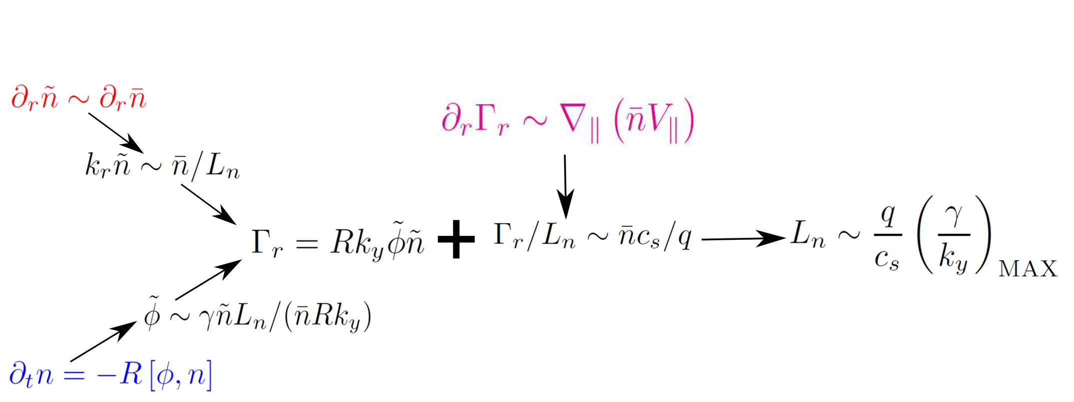
Electron temperature: $\frac{\partial T_e}{\partial t} = \frac{c}{B}[\Phi, T_e] + \frac{2c}{3eRB}\left(\frac{7}{2}T_e\hat{C}T_e + \frac{T_e^2}{n}\hat{C}n - T_e\hat{C}\Phi\right) + \frac{2}{3}\frac{T_e}{en}0.71\nabla_{||}j_{||} - \frac{2}{3}T_e\nabla_{||}V_{||e} - V_{||e}\nabla_{||}T_e$

Parallel gradient: $\nabla_{||} = \frac{\partial}{\partial z} + \frac{\bar{B}}{B^2}\times\nabla\psi\cdot\nabla$

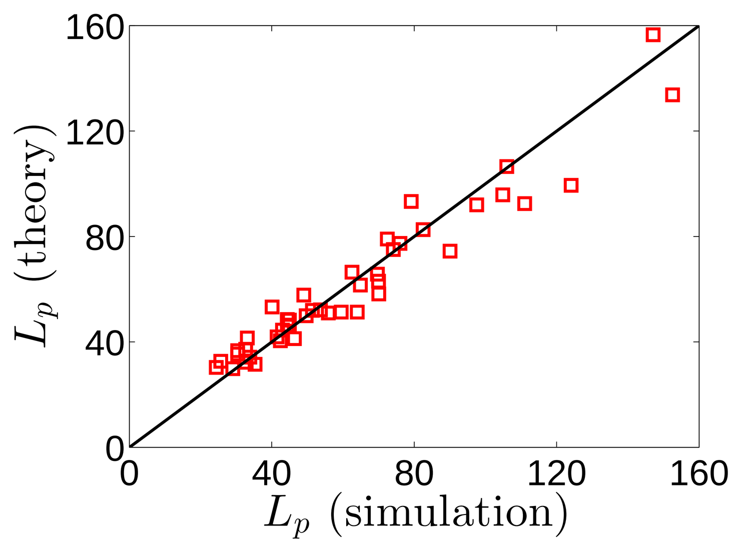
Curvature operator: $\hat{C} = -2\left[\sin\theta\frac{\partial}{\partial x} + \left(\sin\theta\frac{y\hat{s}}{a} + \cos\theta\right)\frac{\partial}{\partial y}\right]$

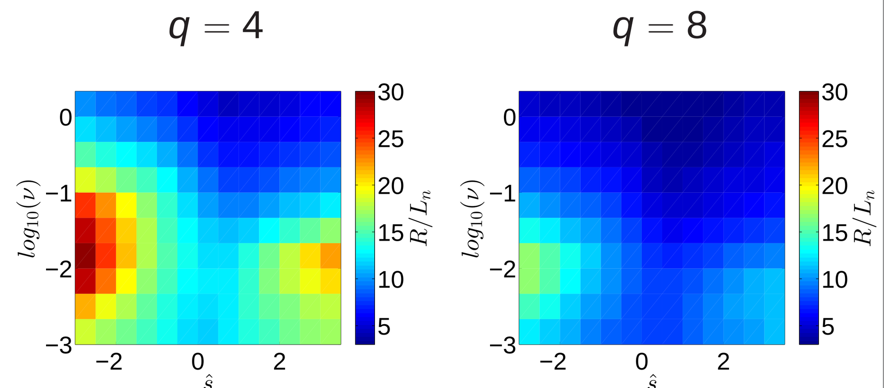
Boundary conditions: see Ref. [4]

3- Gradient removal saturation mechanism



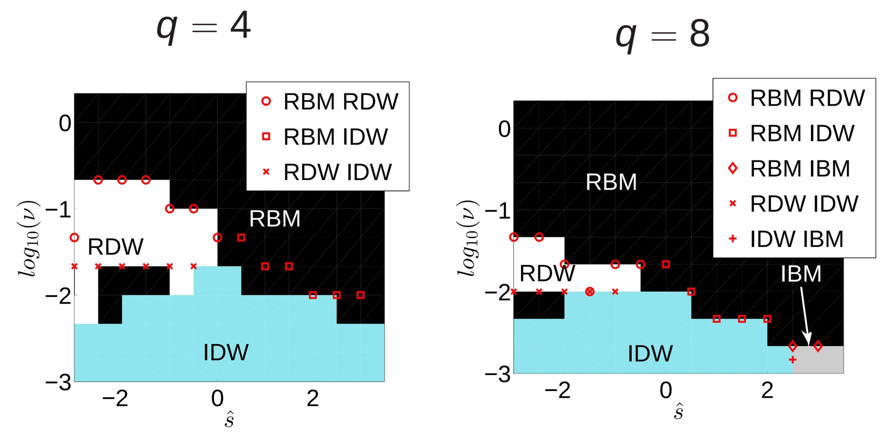
- red: saturation occurs when the radial gradient of the perturbed density becomes comparable to the radial gradient of the background density
- blue: potential estimate from the leading order term of the density equation
- magenta: balance between radial particle flux and parallel losses





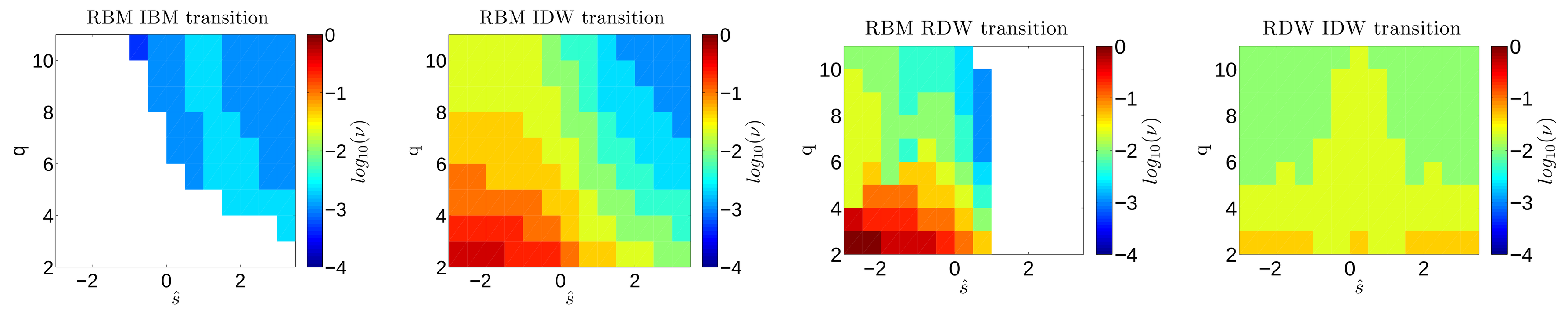
Estimate of R/L_n obtained with the *gradient removal theory*

4- Identification of the SOL turbulent regimes



- The turbulence regime is identified as the one having the maximum γ/k_y for the R/L_n predicted by the *gradient removal theory*
- The transitions among different regimes are identified by comparing γ/k_y for each pair of instabilities (red symbols)

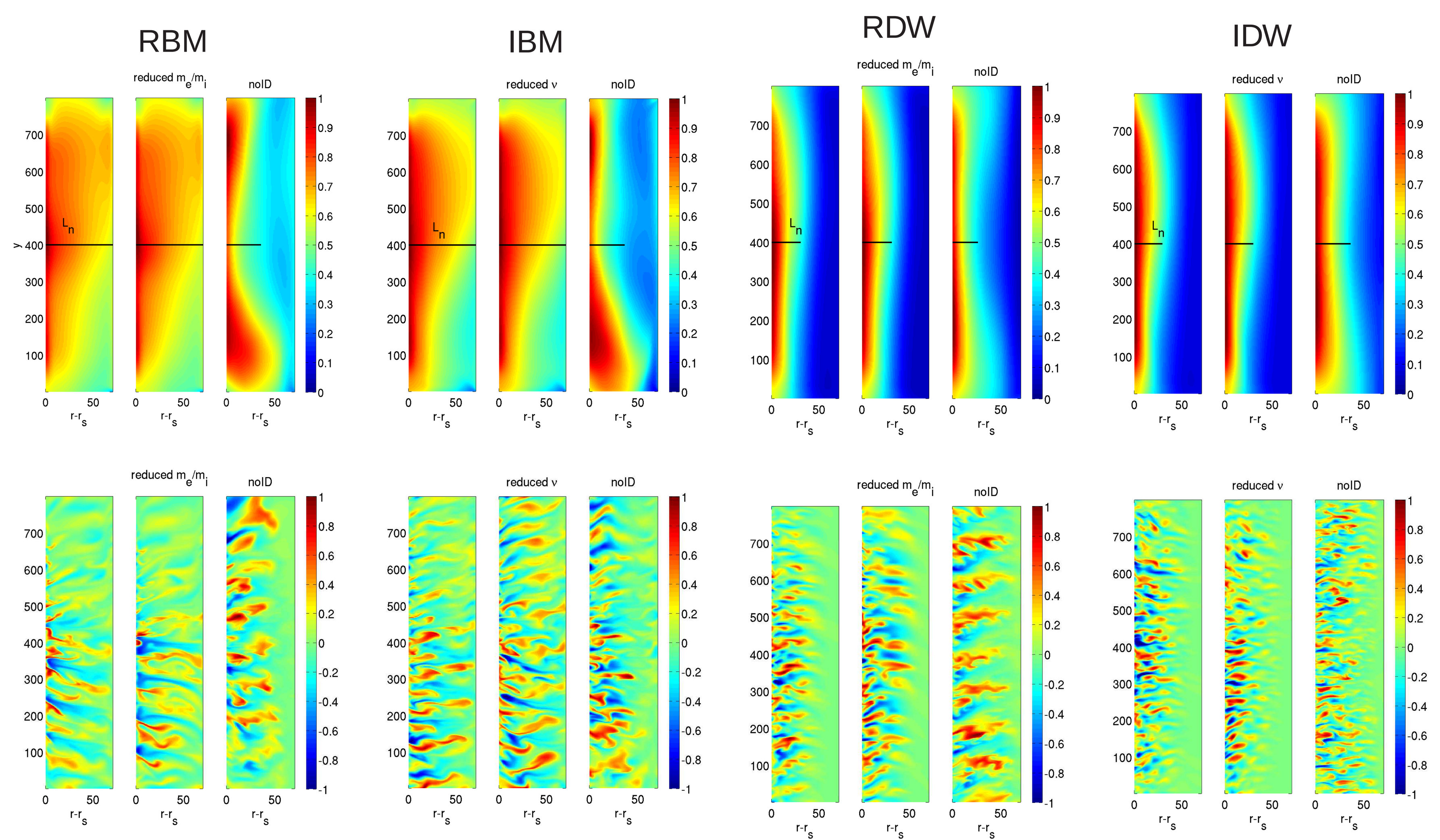
Transitions:



- For each graph: value of ν at which the transition between the first and the second instability takes place (white region: the first instability prevails on the second one for any value of ν)
- The transition between IBM and IDW is independent of ν; for $\hat{s} \lesssim 1$ IDW prevails over IBM; for $\hat{s} \gtrsim 1$ IBM prevails over IDW for $q > -3/2\hat{s} + 23/2$

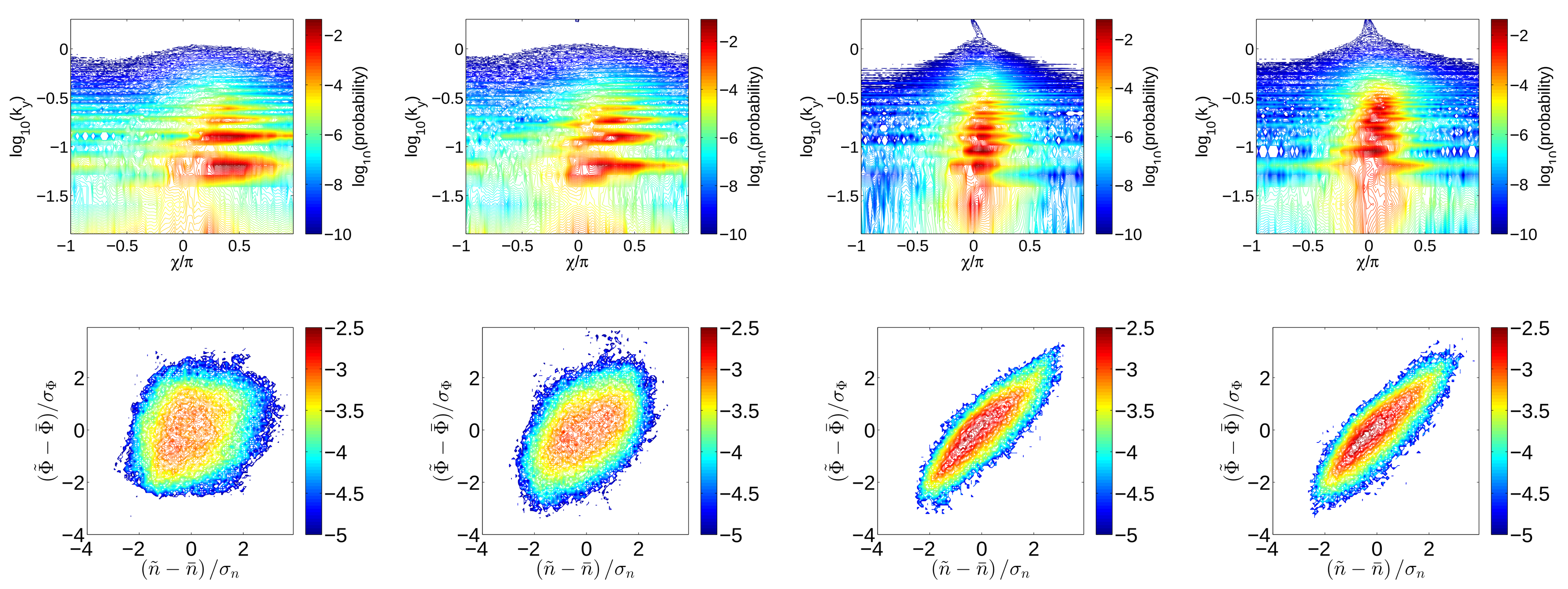
5- Verification of the non-linear turbulent regimes with GBS

Equilibrium and fluctuation profiles of the turbulent regimes



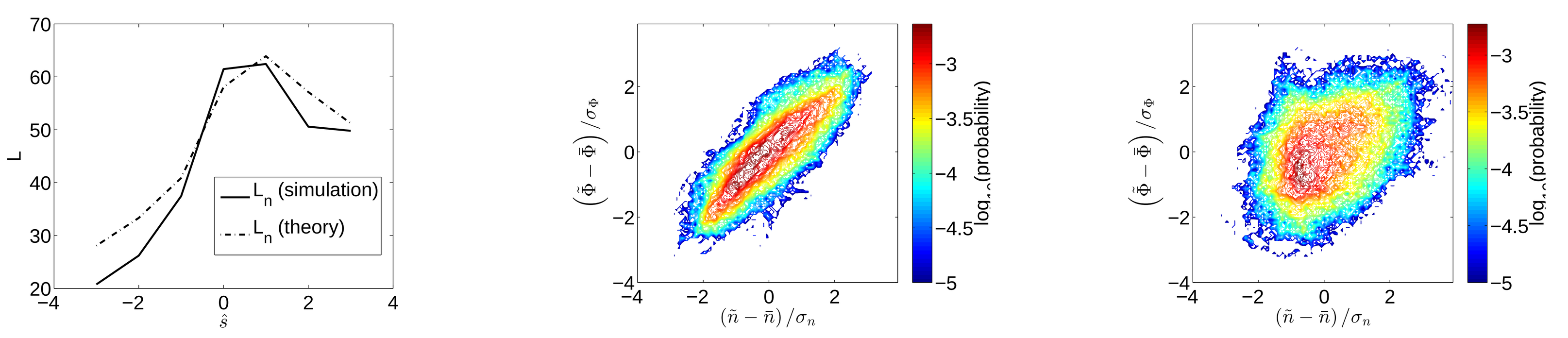
- No changes if ν (m_e/m_i) is reduced → identification of an inertial (resistive) regime
- Turning off of the Interchange Drive (ID): no effect → DW, significative changes → BM

Phase shift probability and cross coherence between $\tilde{n}$ and $\tilde{\phi}$



- Phase shift probability: maximum at $\chi/\pi \approx 0$ → DW, maximum at $\chi/\pi \approx 0.5$ → BM
- Cross coherence: remarkable coherence → DW, no coherence → BM

6- Influence of the magnetic shear



- Reduction of L_n due to magnetic shear
- Cross coherence between $\tilde{\phi}$ and $\tilde{n}$ for $\hat{s} = -2$: remarkable coherence → IDW
- Cross coherence between $\tilde{\phi}$ and $\tilde{n}$ for $\hat{s} = 2$: no coherence → RBM

7- Conclusions

- Estimate of the gradient length by means of the *gradient removal theory*
- Identification of the SOL turbulent regimes
- Study of the shear induced steepening of the pressure profile and turbulence regime transition

References :

[1] A. Zeiler *et al.*, *Phys. Plasmas*, Vol. 4, Issue 6, 1997
[2] B. N. Rogers and P. Ricci, *Physical Review Letters*, 104, 225002 (2010)
[3] P. Ricci and B. N. Rogers, *Physical Review Letters*, 104, 145001 (2010)
[4] J. Loizu, F. D. Halpern, S. Jolliet and P. Ricci., *Phys. Plasmas*, Vol. 19, Num 12, 2012
[5] A. Mosetto, F. D. Halpern, S. Jolliet, J. Loizu and P. Ricci., *submitted to Phys, Plasmas*