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Progress in turbulence simulations in stellarators

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EUROfusion

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Extension of the GBS code to 3D equilibria

- **Electrostatic** with **Boussineq approximation** GBS equations in (R, φ, Z)

- Geometrical operators expanded in

$$\delta = B_R/B \sim B_Z/B$$

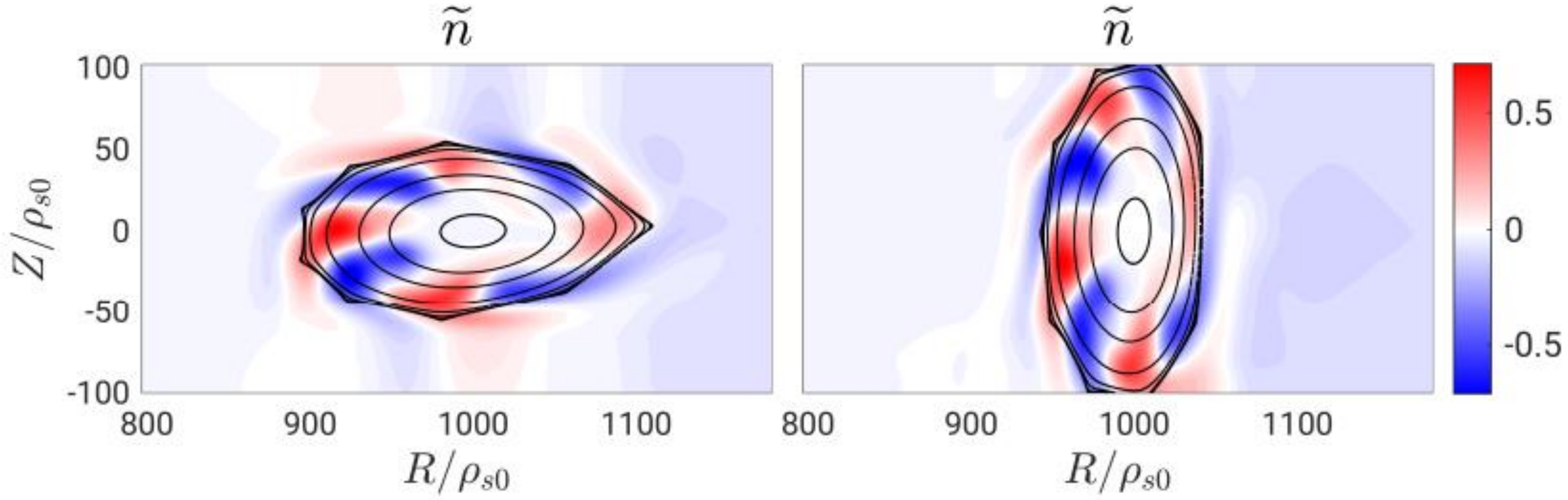
$$\Delta = (B_{max} - B_{min})/\bar{B}$$

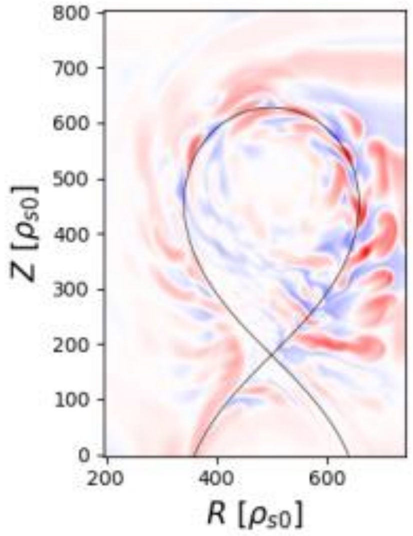
$$\sigma = l_\perp / l_{||}$$

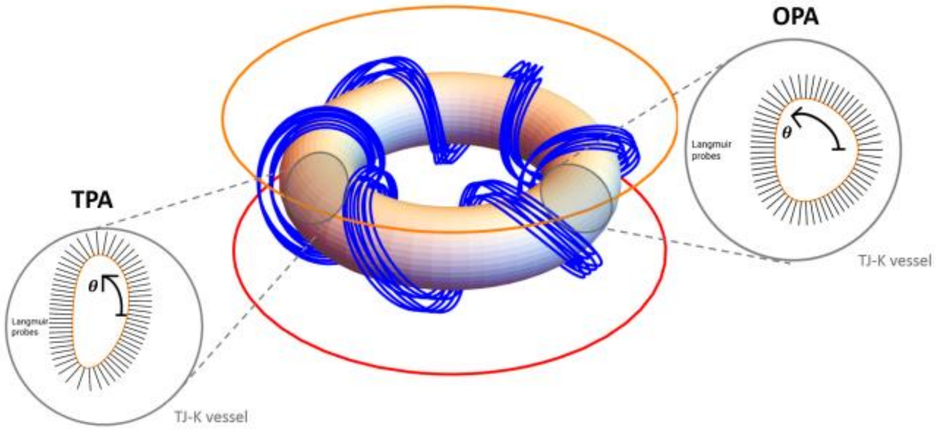
$$C(u) = R_0\left[\frac{1}{B}\frac{\partial B_\phi}{\partial Z}\right]\frac{\partial u}{\partial R} + R_0\left[-\frac{1}{B}\frac{\partial B_\phi}{\partial R}\right]\frac{\partial u}{\partial Z}$$

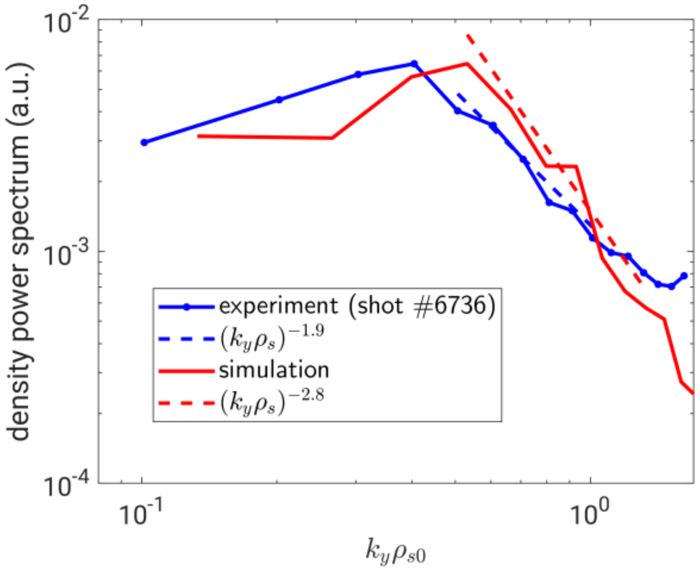
- Further development with no Boussineq + Electromagnetics + Neutrals **under development**

Large scale modes in previous GBS stellarator simulations

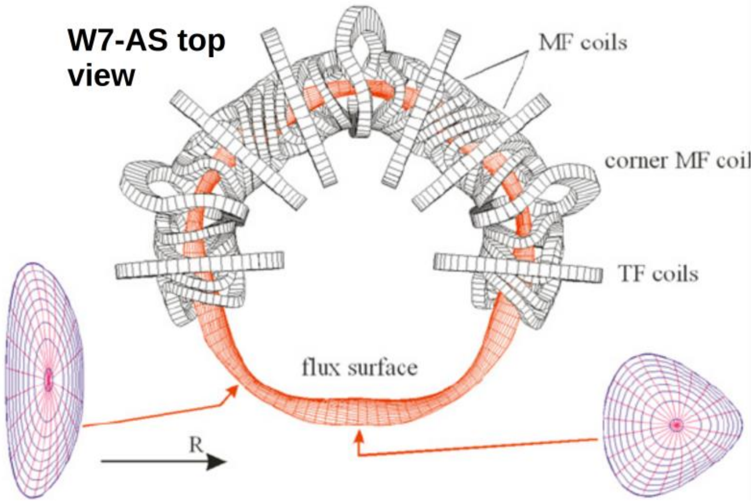




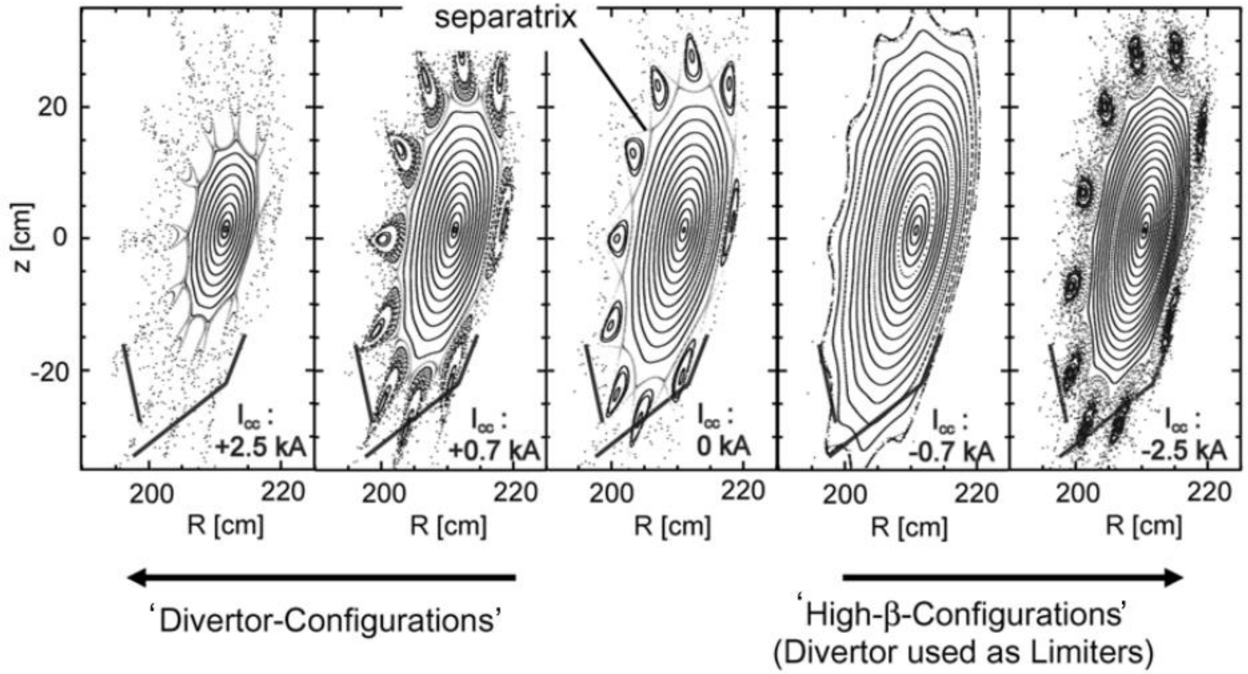




Simulating W7-AS stellarator for turbulence studies in mid-size machines



$$R_0 \sim 2\,m$$
$$a \sim 0.2\,m$$
$$B_0 \sim 1.25 - 2.5T$$
$$0.3 < \iota < 0.6$$

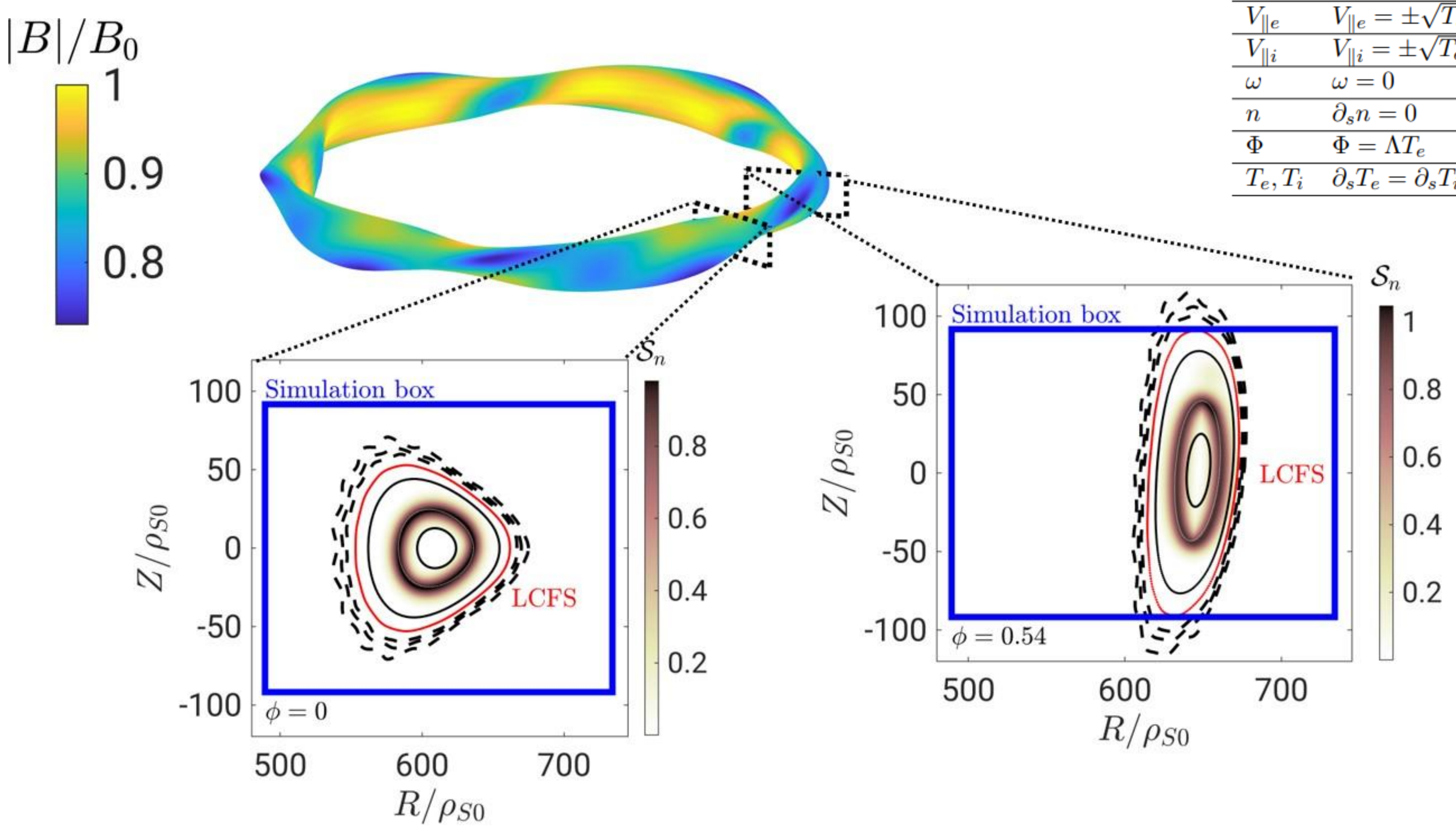


- Great **flexibility in vacuum magnetic cofigurations**
- **Typically,** $\nu^* \sim 10$ **in the edge**
- Large body of **literature on experimental measurements** [Hirsch, 2008]

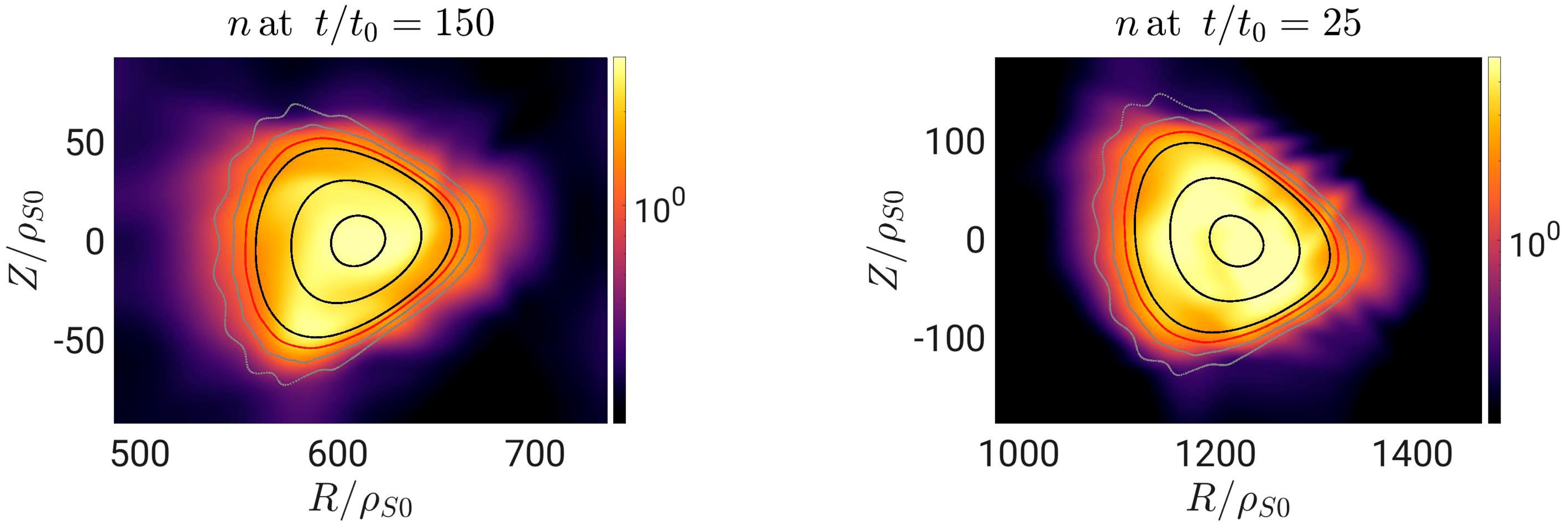
Limited W7-AS in a GBS box

- Simulating reference configuration **via Dommashk potentials** in a scan from **quarter-size** $R_0/\rho_{s0} \sim 600$ to **full-size** $R_0/\rho_{s0} \sim 2400$ $m_i/m_e = 600, \nu_0 = 1.0, \tau = 1,$

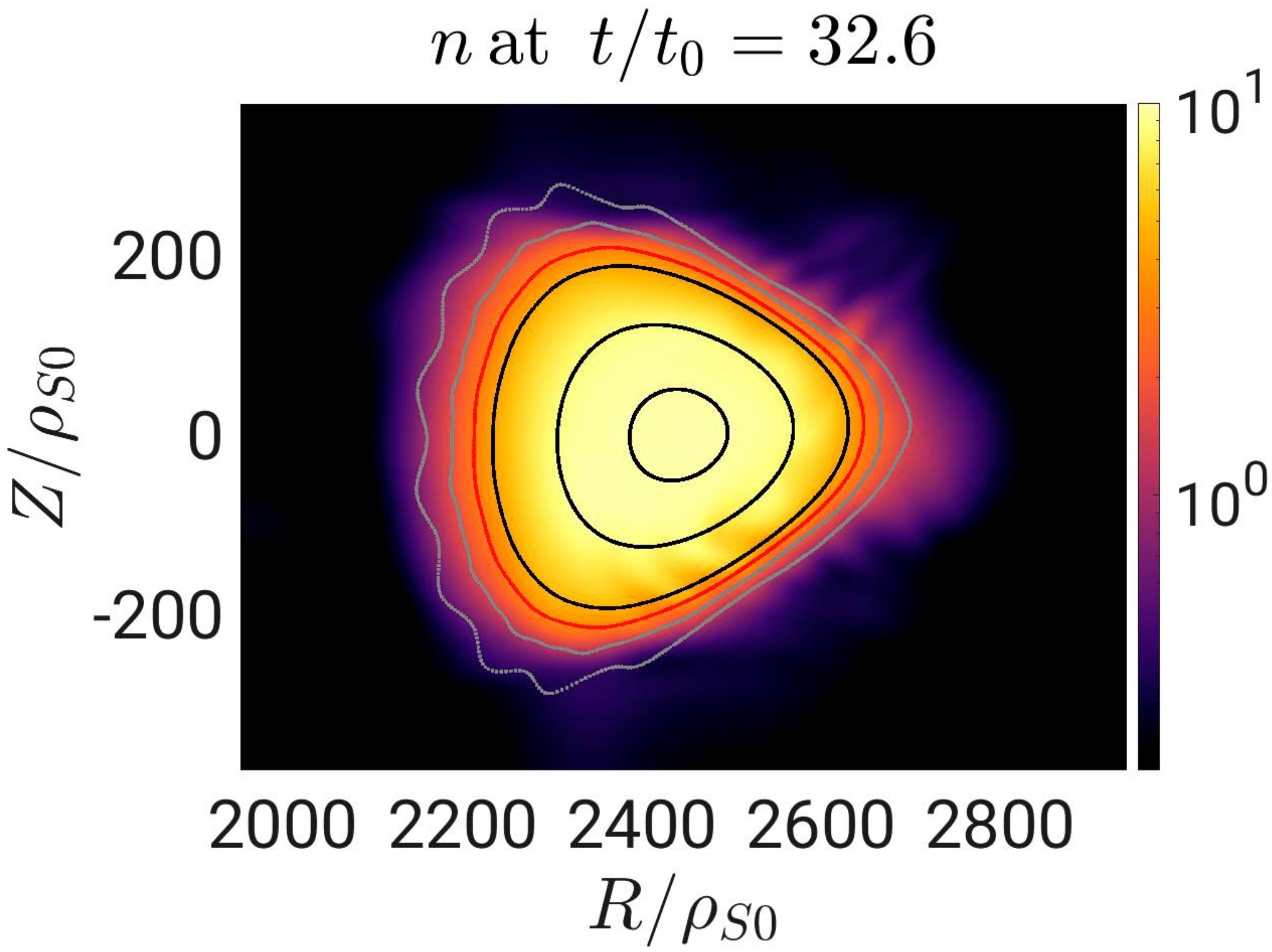
	Top and bottom walls	Inner and outer walls
$V_{\parallel e}$	$V_{\parallel e} = \pm\sqrt{T_e}\exp(\Lambda - \Phi/T_e)$	$V_{\parallel e} = \pm\sqrt{T_e}\exp(\Lambda - \Phi/T_e)$
$V_{\parallel i}$	$V_{\parallel i} = \pm\sqrt{T_e}F_T$	$\partial_s V_{\parallel i} = 0$
ω	$\omega = 0$	$\omega = 0$
n	$\partial_s n = 0$	$\partial_s n = 0$
Φ	$\Phi = \Lambda T_e$	$\Phi = \Lambda T_e$
T_e, T_i	$\partial_s T_e = \partial_s T_i = 0$	$\partial_s T_e = \partial_s T_i = 0$



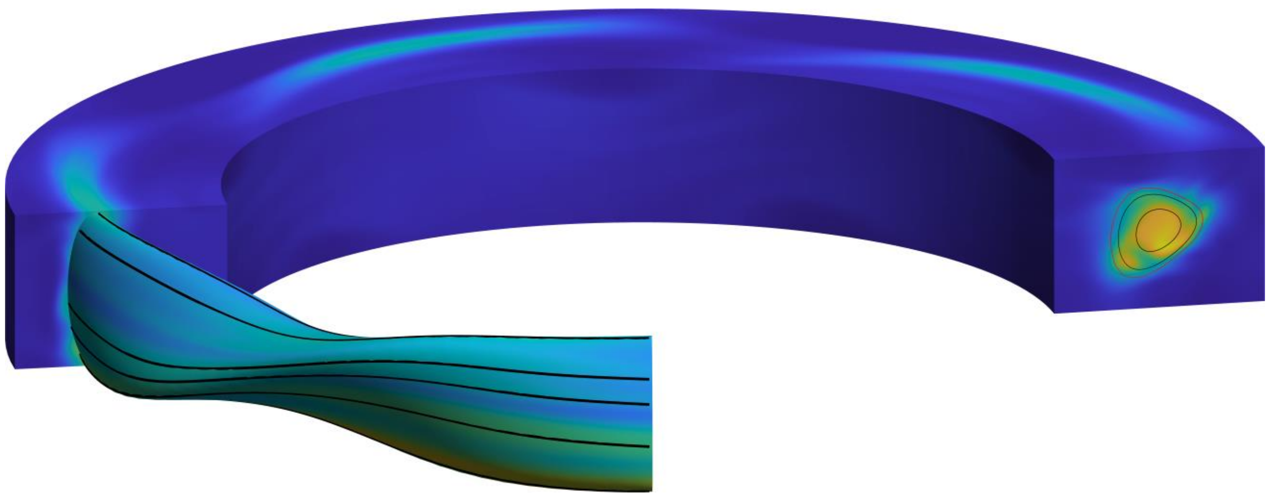
Density evolution in size

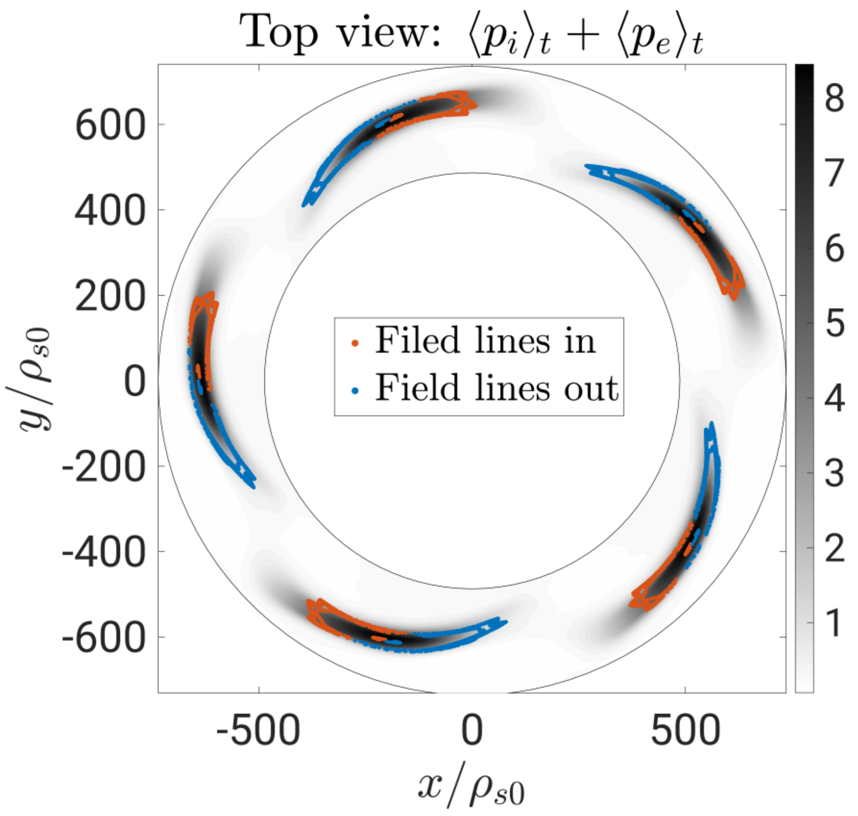


Density evolution of full-size simulation

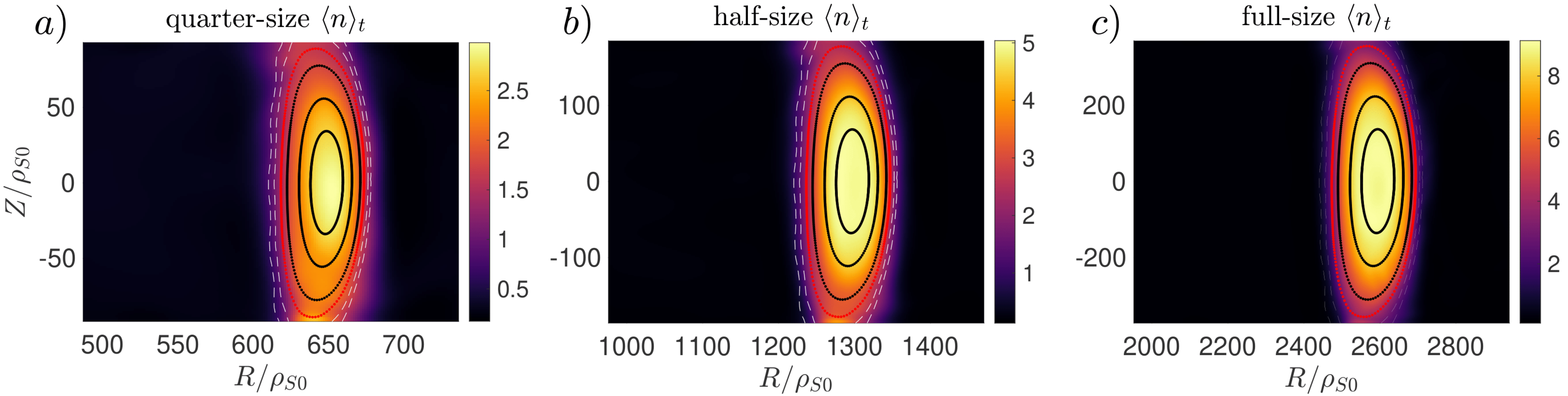


Heat and particles deposited at the limiter position

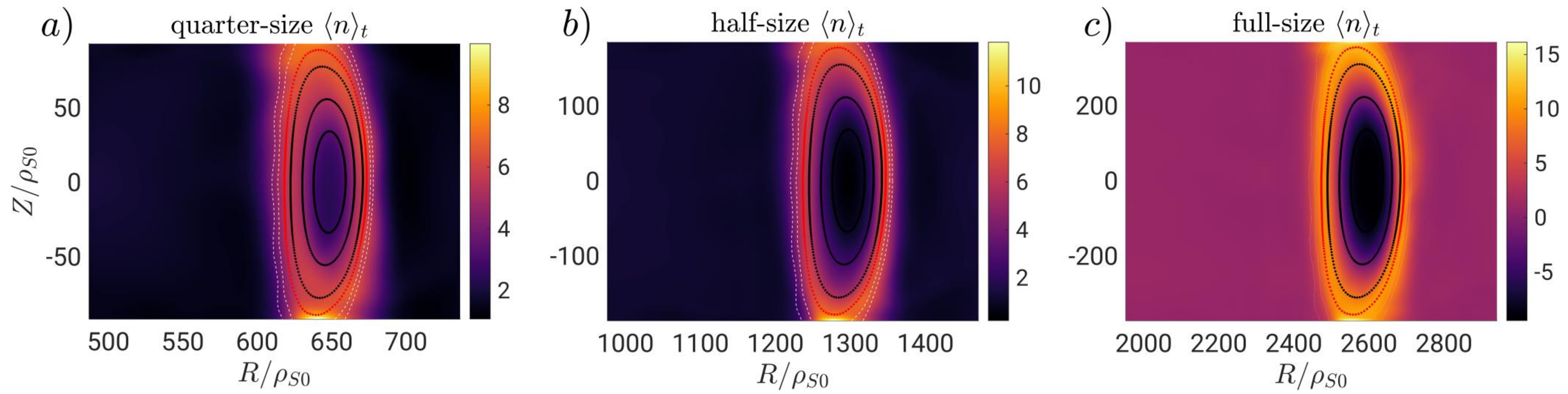


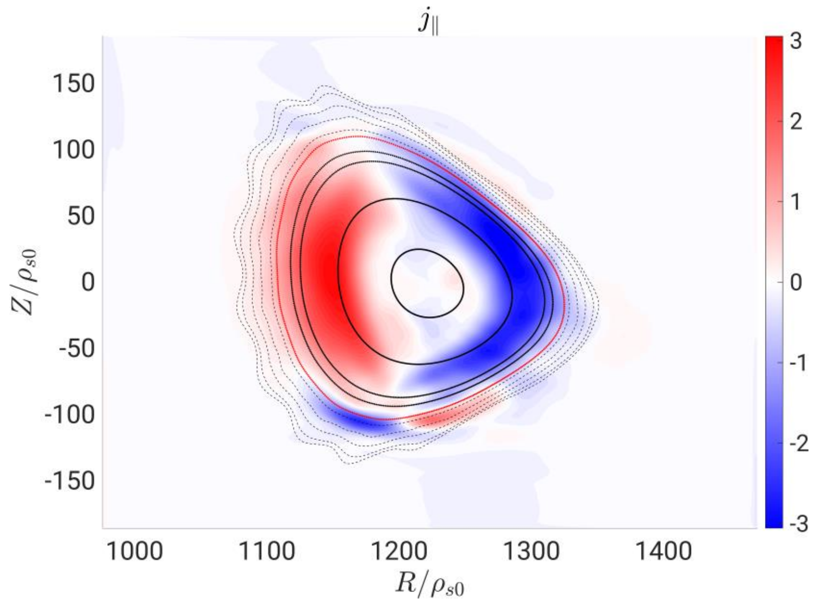


Time averaged profiles recover the confinement properties



Electrostatic potential and parallel current



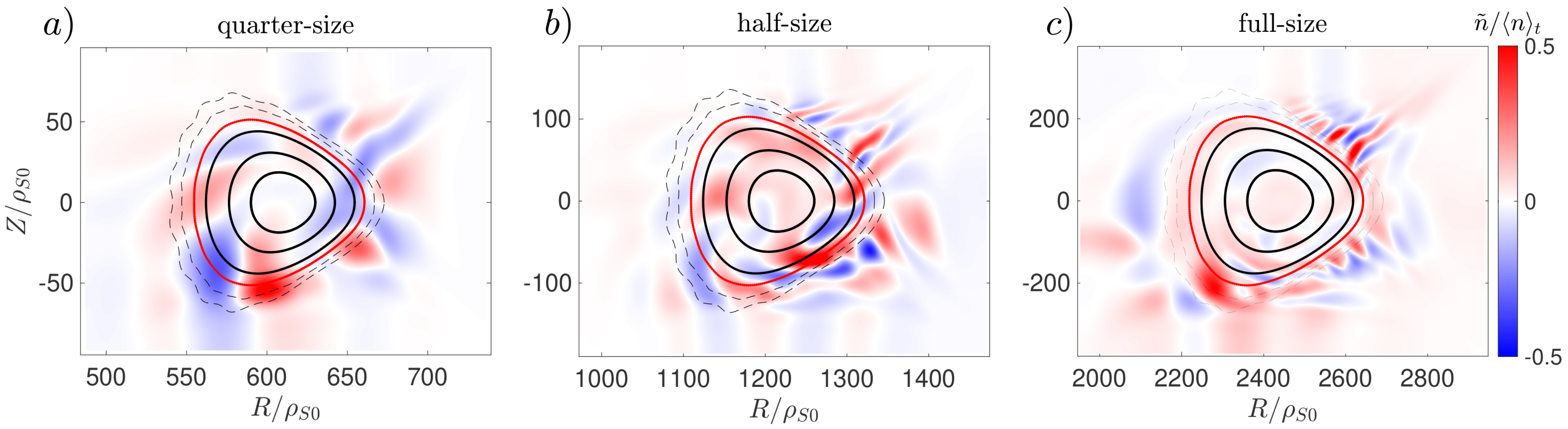


- Radial electric field **changing sign at the LCFS** with core characterized by ion-root regime [1]

- $\langle J_{||} \rangle_t \sim \cos\theta$ **as designed in W7-AS** [2]

1] Kick, M., et al. " *Plasma physics and controlled fusion* (1999)
[2] Hirsch, M., et al *Plasma Physics and Controlled Fusion* 50.5 (2008)

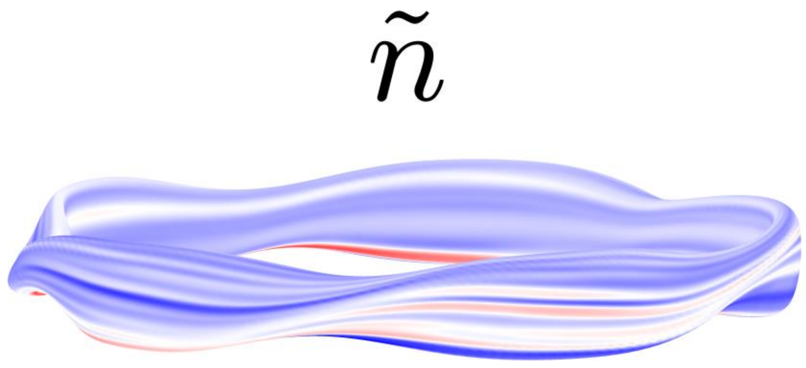
Fluctuations properties are in line with experimental observations

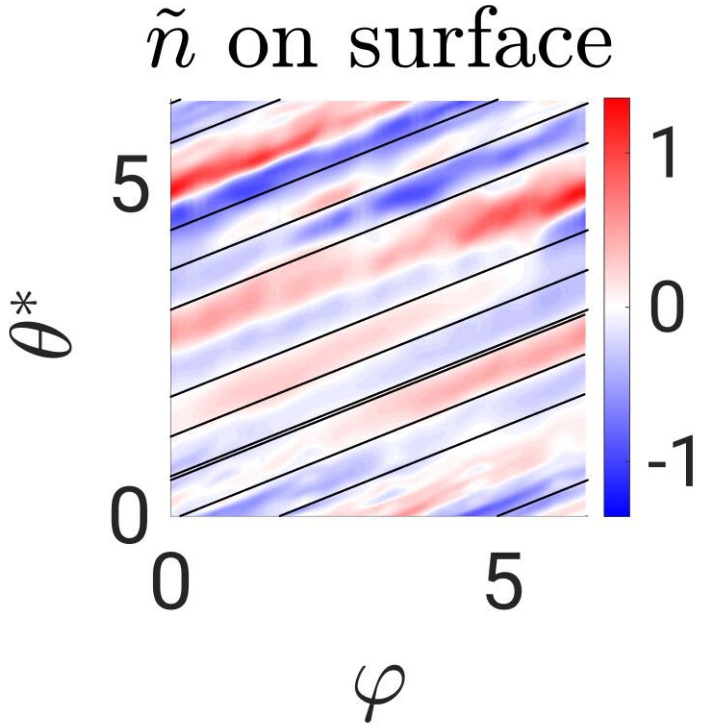


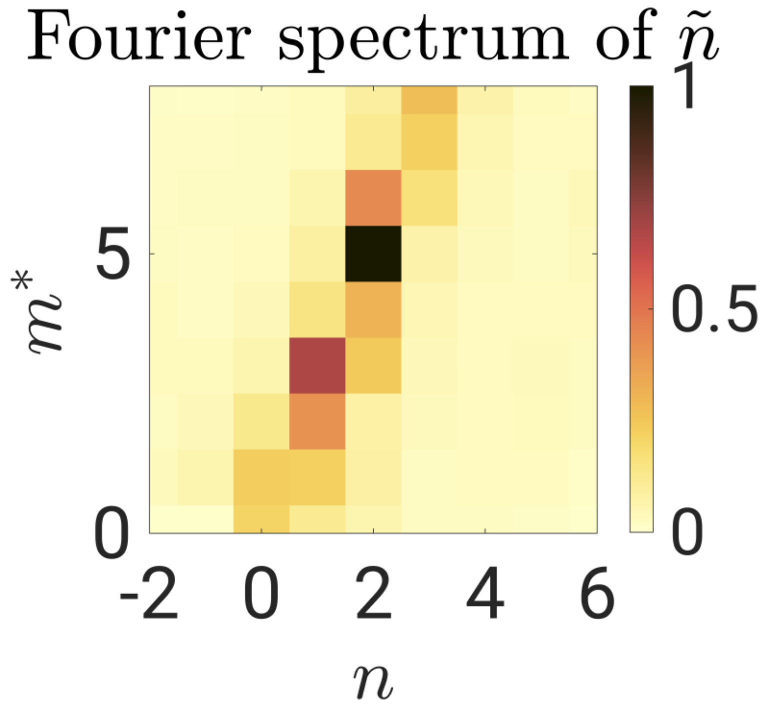
- Coherency decreases with size
- Structure sizes is of the same order with increasing domain size.
- Similarly to experiments, **cross-field transport dominated by the** $E \times B$ **drift** as reported in experiments in the SOL [2].

[1] J Bleuel, et all. New Journal of Physics, (2002).
[2] Martin Schubert. Fluctuations of temperature and turbulent radial energy transport in the edge plasma in W/-AS. 2006

Inside the LCFS a global field aligned mode with (n, m) = (2, 5)



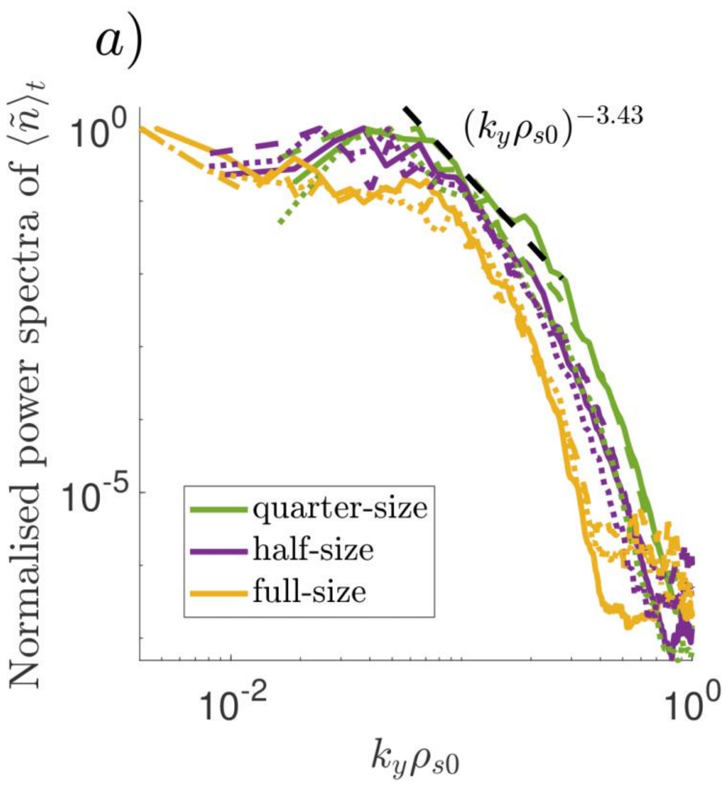


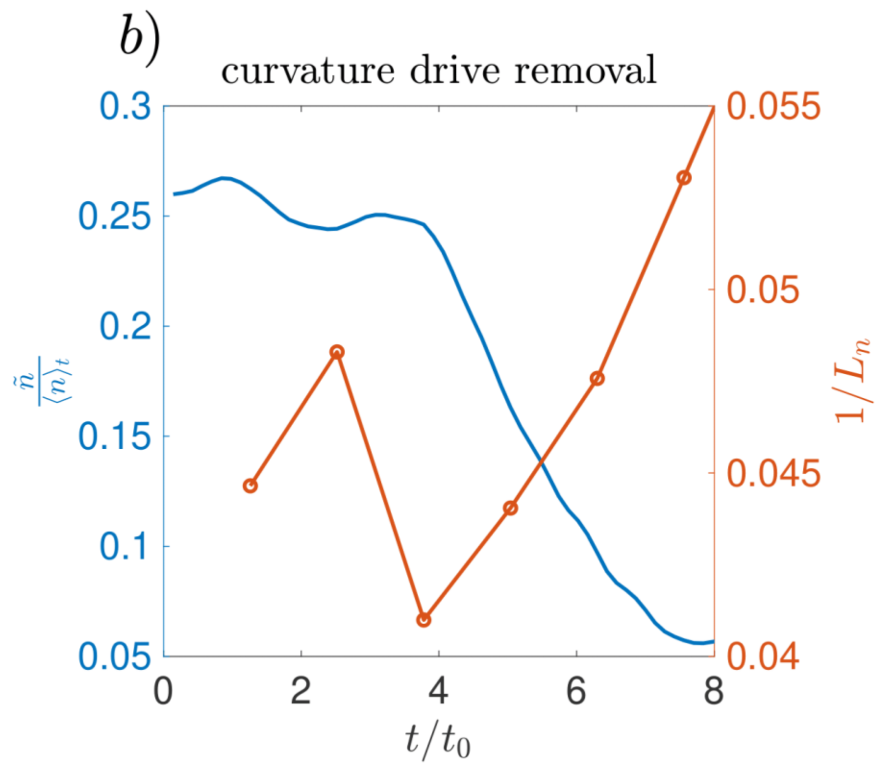


- $k_{||} \sim 0$ with flat $\iota = n/m = 0.4$, field aligned turbulence [1].
- Dominant toroidal mode number **breaks the magnetic field periodicity.**

[1] Hirsch, M., et al *Plasma Physics and Controlled Fusion* 50.5 (2008)

Field-aligned turbulence is ballooning driven





- $(k_y \rho_{s0})^{-3.43}$ scaling **overestimates the measured exponents** of -2.5 [1] and -3.0 [2]
- Removing the curvature drive points to **ballooning driven turbulence.**

[1] Martin Schubert. Fluctuations of temperature and turbulent radial energy transport in the edgeplasma of the wendelstein 7-as stellarator. 2006.
[2] J Bleuel, et all. New Journal of Physics, (2002).

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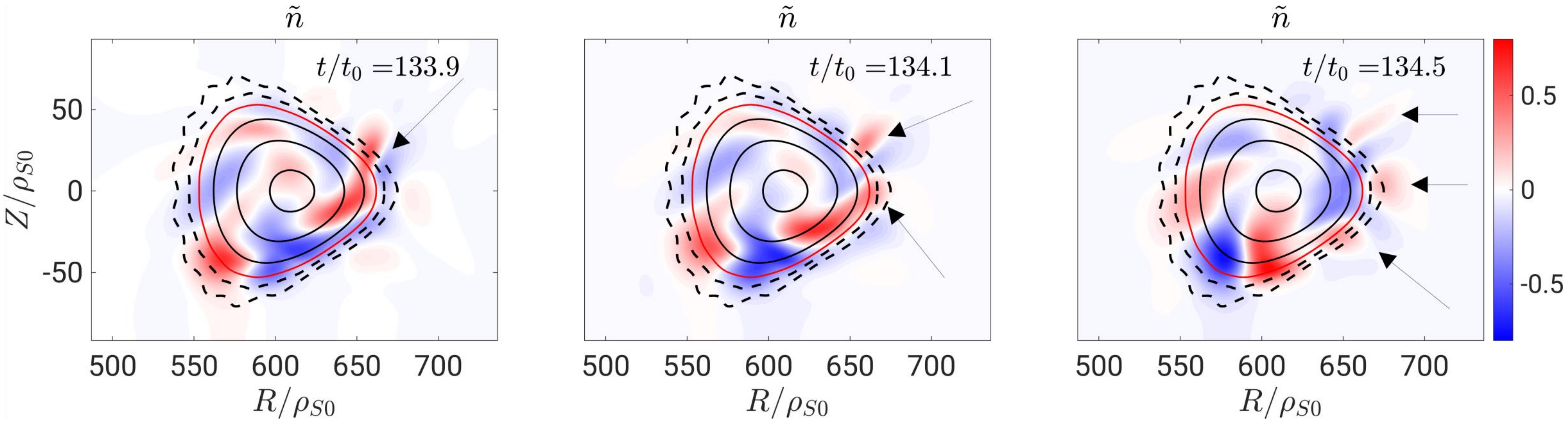
Blobs originating at the LCFS and propagating in the SOL



- **Blobs have been documented** in W7-AS [P. Simon 2014, D.A. D’Ippolito 2011]

Outlook: simulation of island diverted W7-AS