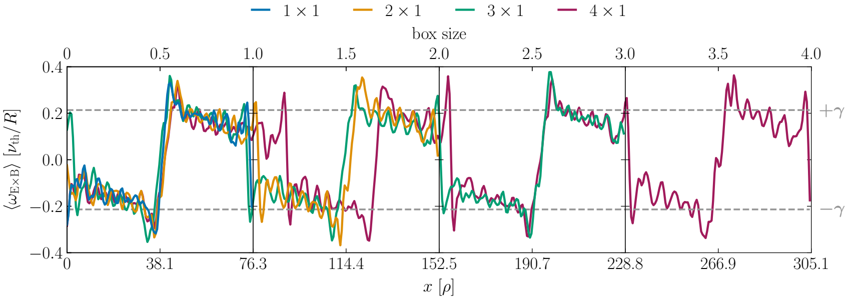
SIZE CONVERGENCE OF THE E$\times$B STAIRCASE PATTERN IN FLUX TUBE SIMULATIONS OF ION TEMPERATURE GRADIENT-DRIVEN TURBULENCE

June 22, 2023

Manuel Lippert

Theoretical Physics V



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Does the basic pattern size always converges to the box size, or is there a typical mesoscale size inherent to staircase structures also in a local flux-tube description?

CHARGED PARTICLE MOTION

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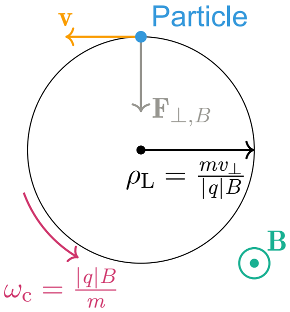
Lorentz force

$$F_{\perp,B} = |q| v_\perp B$$



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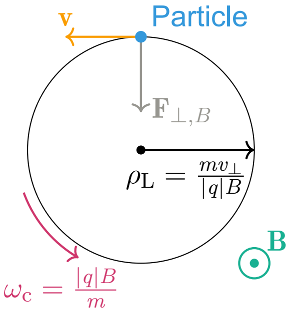

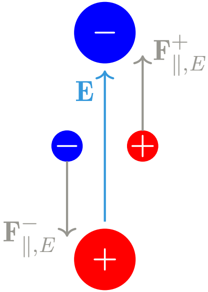

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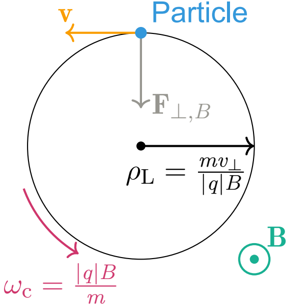

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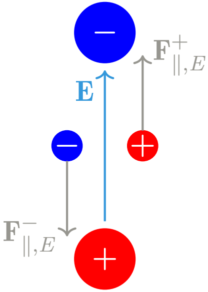
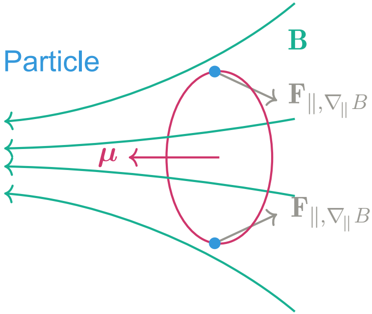


Inhomogeneous magnetic field

$$F_{\parallel,\nabla_\parallel B} = -\underbrace{\frac{m v_\perp^2}{2B}}_{\mu} \nabla_\parallel B$$



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$\mathbf{E} \times \mathbf{B}$ Drift

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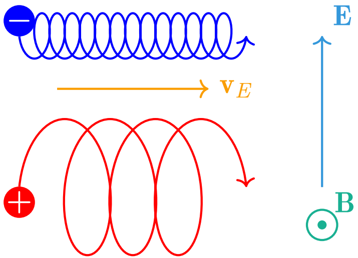

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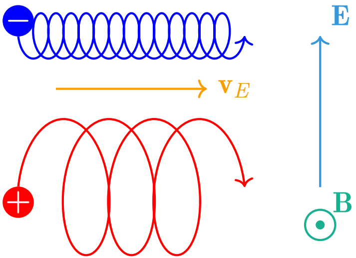
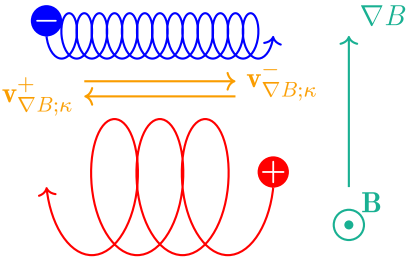
∇B Drift

$$\mathbf{v}_{\nabla B} = \frac{mv_\perp^2}{2q}\frac{\mathbf{B}\times\nabla B}{B^3}$$

Curvature Drift

$$\mathbf{v}_\kappa = \frac{mv_\parallel^2}{qB^2}\mathbf{B}\times\underbrace{\boldsymbol{\kappa}}_{\frac{\nabla B}{B}} = \frac{mv_\parallel^2}{q}\frac{\mathbf{B}\times\nabla B}{B^3}$$





MAGNETIC CONFINEMENT IN TOKAMAK

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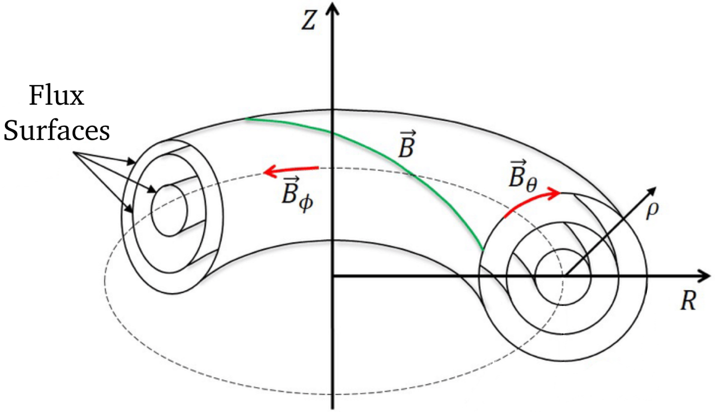

$$\beta = \frac{nT}{\mu_0 B^2/2}$$

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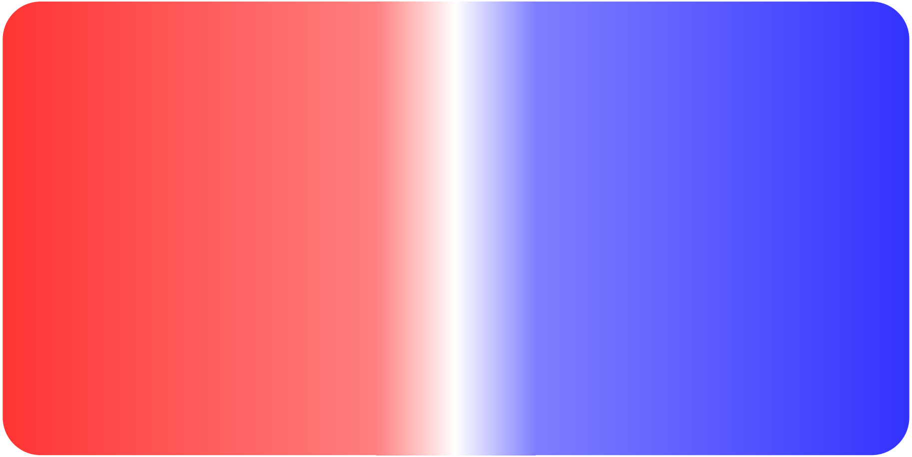

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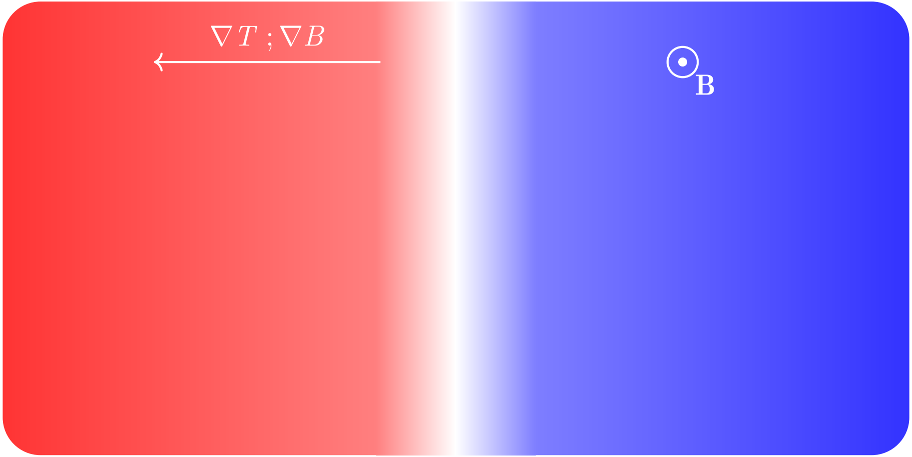

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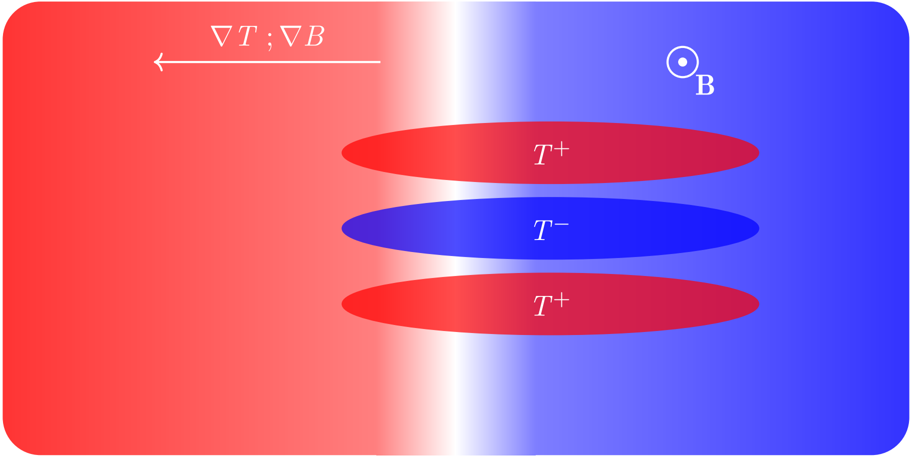

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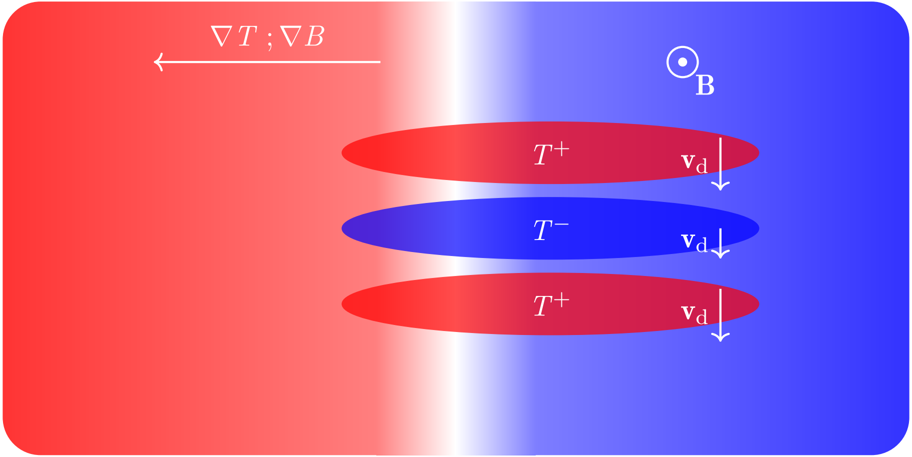

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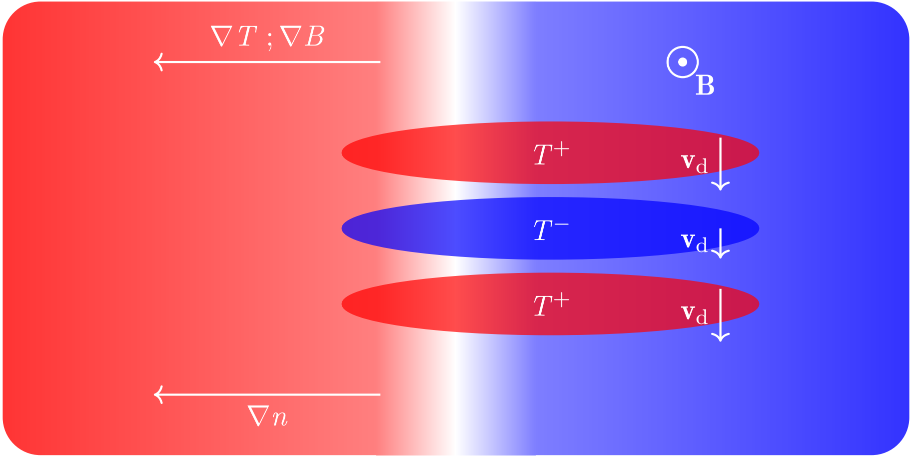

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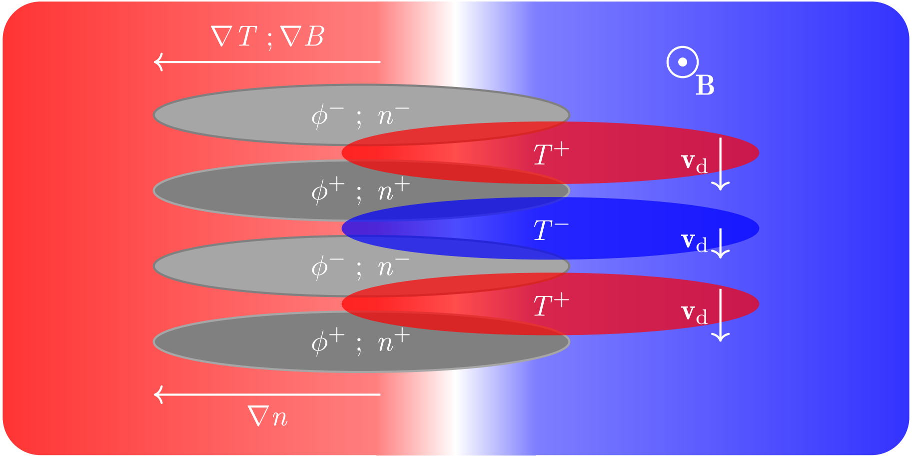

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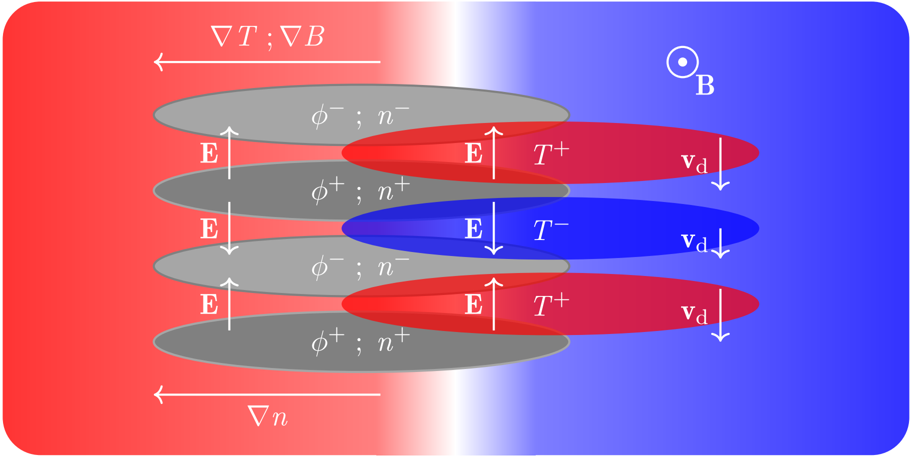

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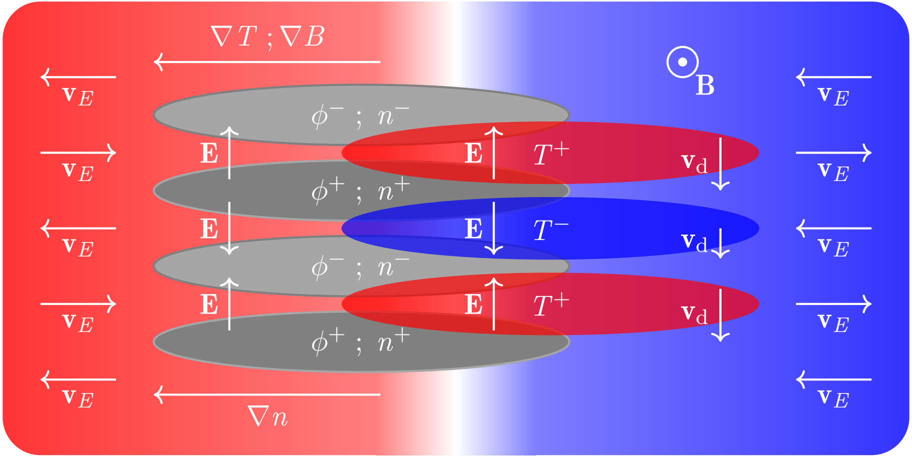

ZONAL FLOWS

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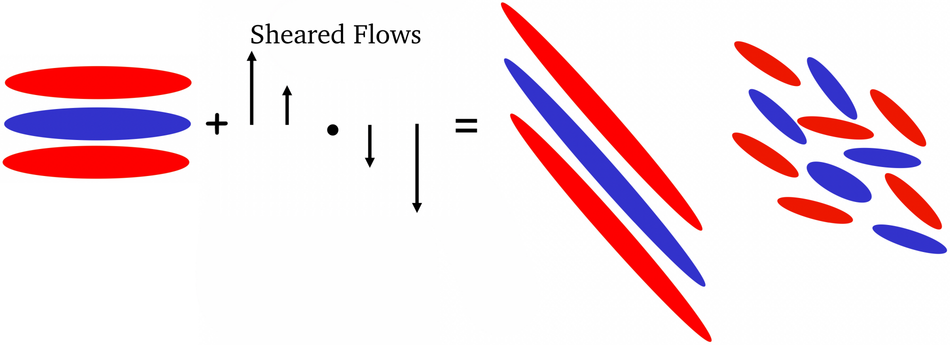

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$$\omega_{\mathrm{E\times B}} = \frac{1}{2}\frac{\partial^2 \langle\phi\rangle}{\partial x^2} \quad \langle\phi\rangle = \frac{1}{L_y}\int_0^{L_y} \mathrm{d}y\, \phi(x, y, s=0)$$

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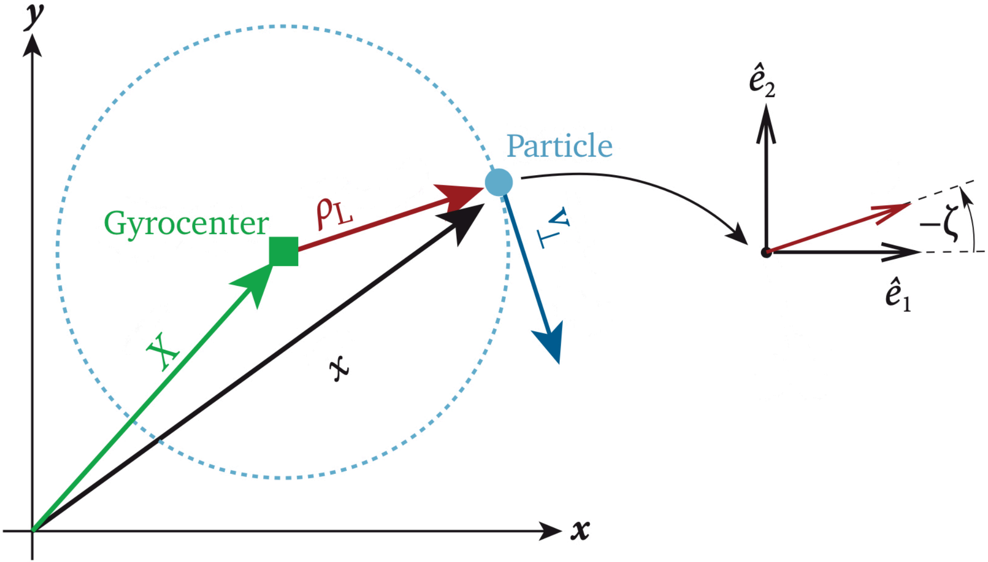

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$$\frac{\partial g}{\partial t} + \mathbf{v}_\chi \cdot \nabla g + (v_\parallel \mathbf{b} + \mathbf{v}_\mathrm{D}) \cdot \nabla(\delta f) - \frac{\mu B}{m} \frac{\mathbf{B}\cdot\nabla B}{B^2} \frac{\partial(\delta f)}{\partial v_\parallel} = S$$

Gyrokinetic Equation

$$g \sim (f_0 + \delta f) \qquad S \sim (f + f_0) \qquad \mathbf{v}_\mathrm{D} \sim \nabla B \qquad \mathbf{v}_\chi \sim \mathrm{E} \times \mathrm{B} \qquad f(x, y, s, v_\parallel, \mu)$$

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S6	21	83	16	64	9	1	$\lvert\nu_\parallel\rvert$	0.2	0.1	0.1	6	1.4	2.1

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- Standard box size $(L_x,\ L_y) = (76.3,\ 89.8)\,\rho$

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- The basic mode exhibits the maximum amplitude in the spectrum $|\widehat{\omega}_{\mathrm{E\times B}}|_{n_{\mathrm{ZF}}}$

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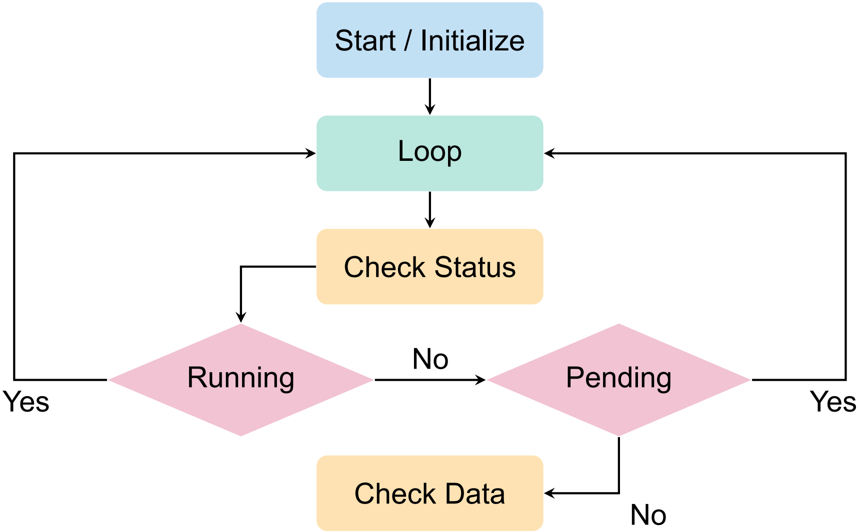

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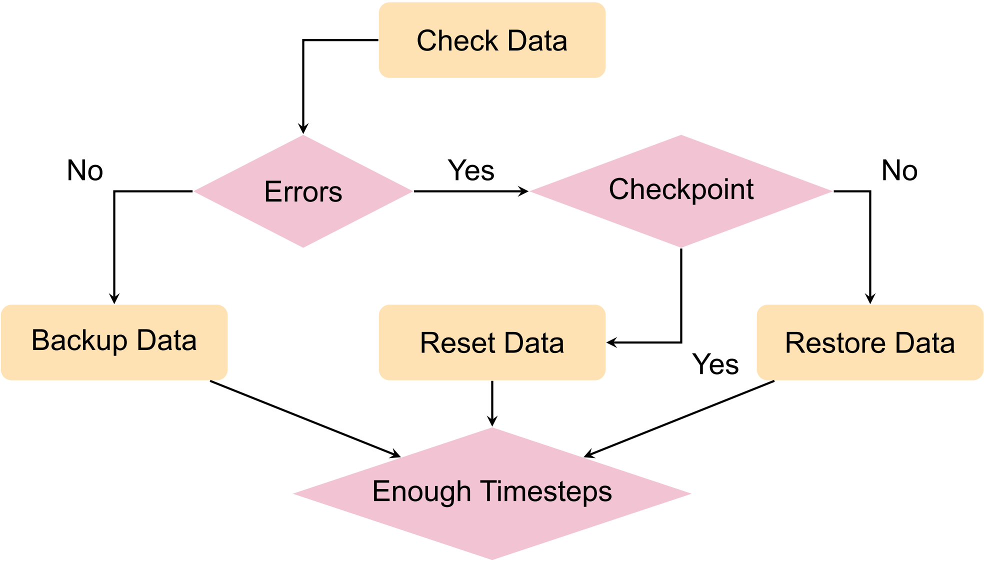

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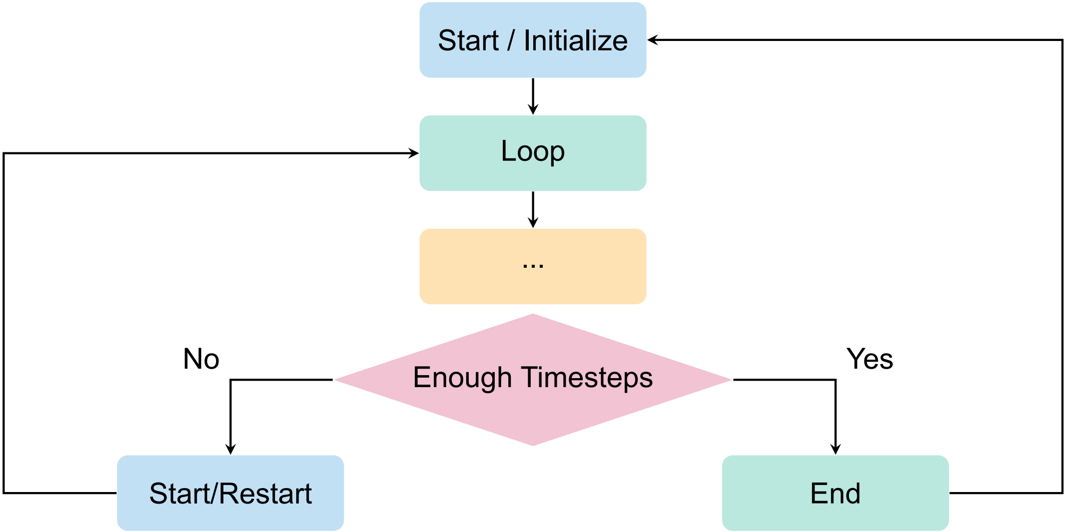

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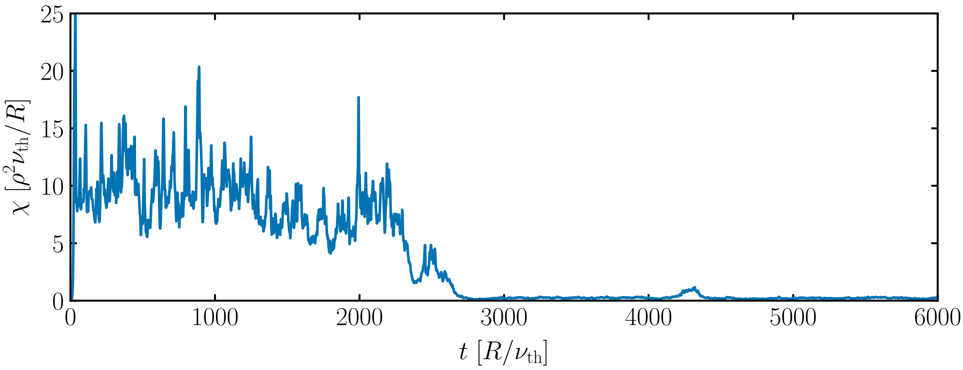
Verification:

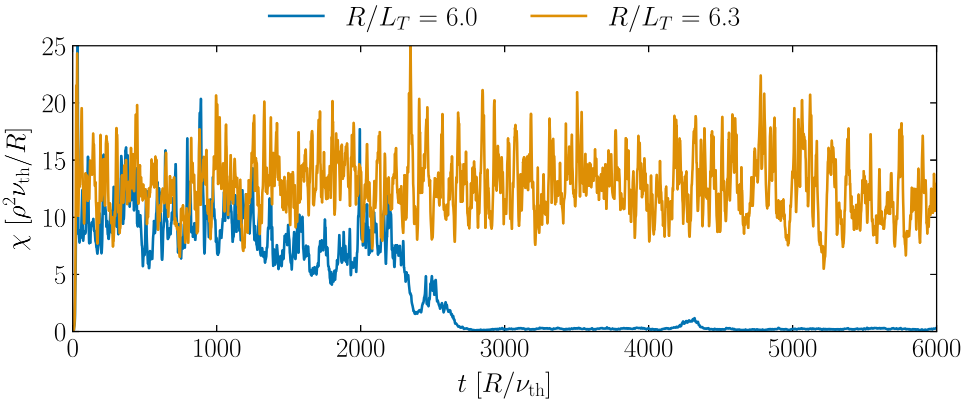
1. Reduce only one number of grid points and look if criterias **(1), (2)** are satisfied
2. Reduce to known the minimum number of grid points to verify result in general.

BENCHMARK

BENCHMARK


25
20
15
10
5
0
$\chi\ [\rho^2 \nu_{\mathrm{th}}/R]$
0
1000
2000
3000
4000
5000
6000
$t\ [R/\nu_{\mathrm{th}}]$

BENCHMARK


$R/L_T = 6.0$
$R/L_T = 6.3$
25
20
15
10
5
0
$\chi\ [\rho^2 \nu_{\mathrm{th}}/R]$
0
1000
2000
3000
4000
5000
6000
$t\ [R/\nu_{\mathrm{th}}]$

REDUCTION OF GRID POINTS

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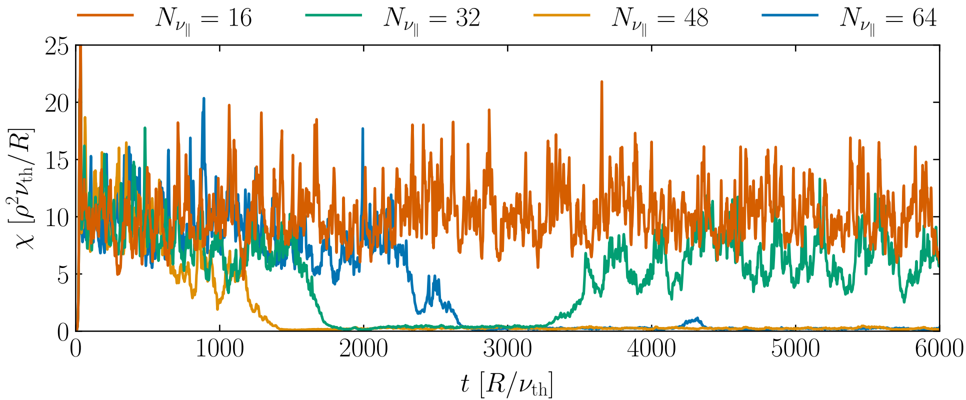

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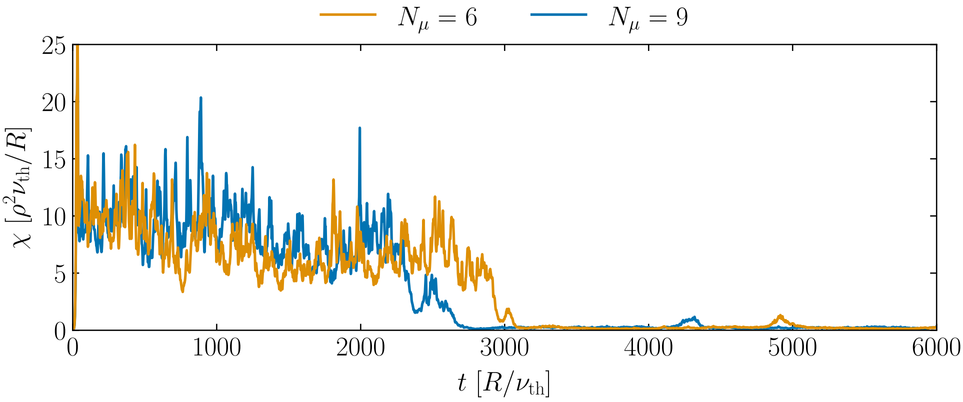
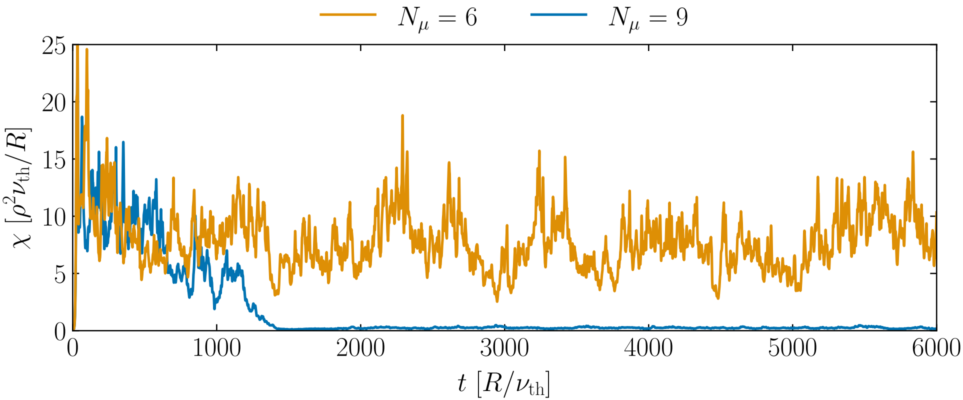
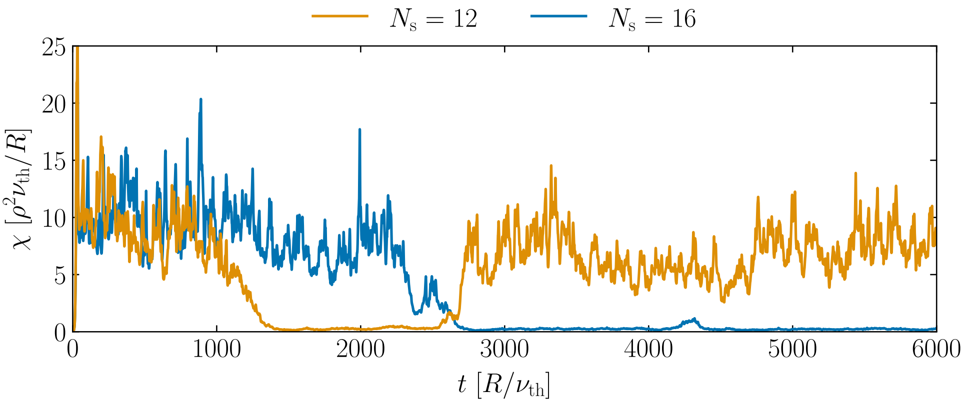


REDUCTION OF GRID POINTS



REDUCTION OF GRID POINTS



REDUCTION OF GRID POINTS

Final Resolution

	N_m	N_x	N_s	$N_{\nu_\parallel}$	N_μ	D	ν_d	$D_{\nu_\parallel}$	D_x	D_y	Order	$k_y\rho$	$k_x\rho$
S6	21	83	16	48	9	1	$\lvert\nu_\parallel\rvert$	0.2	0.1	0.1	6	1.4	2.1

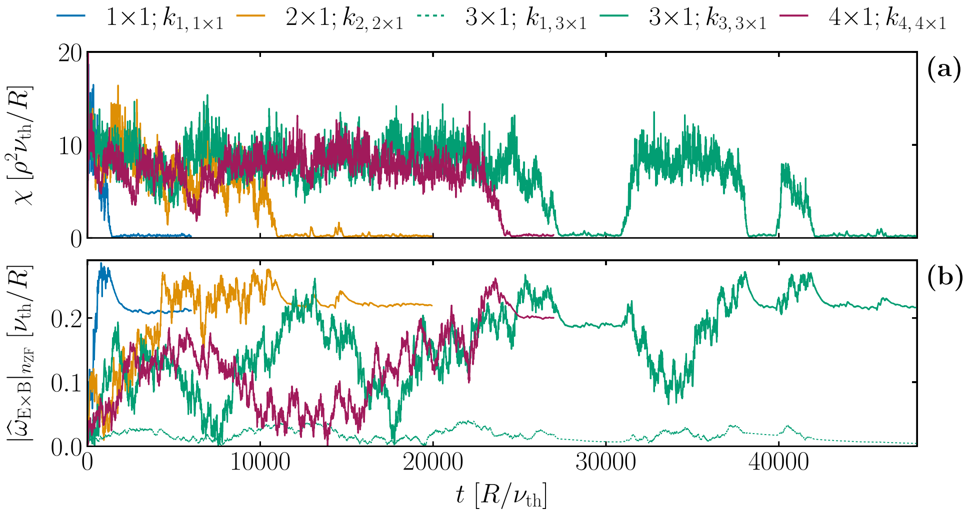
SIZE CONVERGENCE OF $\mathrm{E} \times \mathrm{B}$ STAIRCASE PATTERN

SIZE CONVERGENCE OF $\mathrm{E} \times \mathrm{B}$ STAIRCASE PATTERN

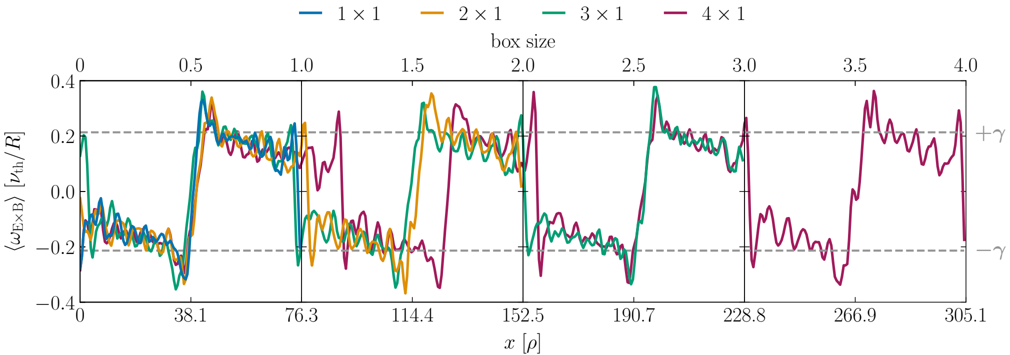
(1) Radial

$$N_{\mathrm{R}} \times N_{\mathrm{B}} \in [1 \times 1,\ 2 \times 1,\ 3 \times 1,\ 4 \times 1]$$

SIZE CONVERGENCE OF $\mathrm{E}\times\mathrm{B}$ STAIRCASE PATTERN



SIZE CONVERGENCE OF $\mathrm{E} \times \mathrm{B}$ STAIRCASE PATTERN

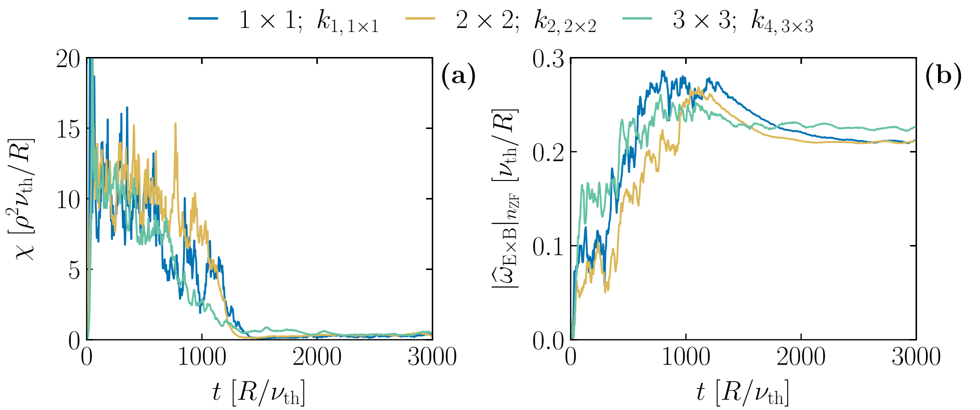


SIZE CONVERGENCE OF $\mathrm{E} \times \mathrm{B}$ STAIRCASE PATTERN

(2) Isotropic

$$N_\mathrm{R} \times N_\mathrm{B} \in [1 \times 1,\ 1.5 \times 1.5,\ 2 \times 2,\ 2.5 \times 2.5,\ 3 \times 3]$$

SIZE CONVERGENCE OF $\mathrm{E} \times \mathrm{B}$ STAIRCASE PATTERN



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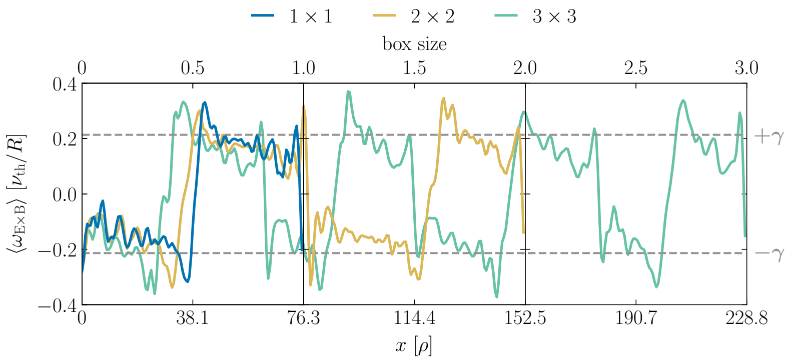

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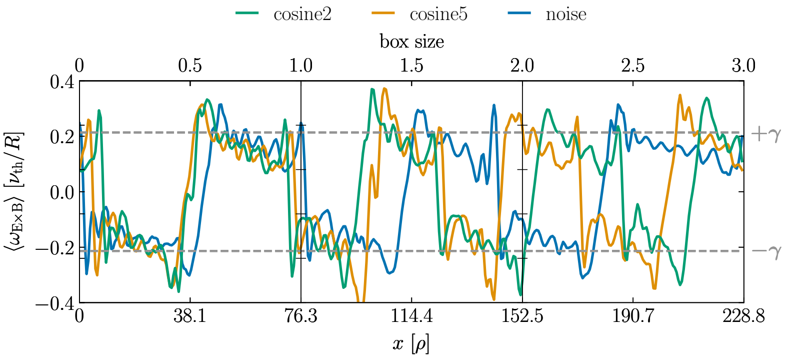
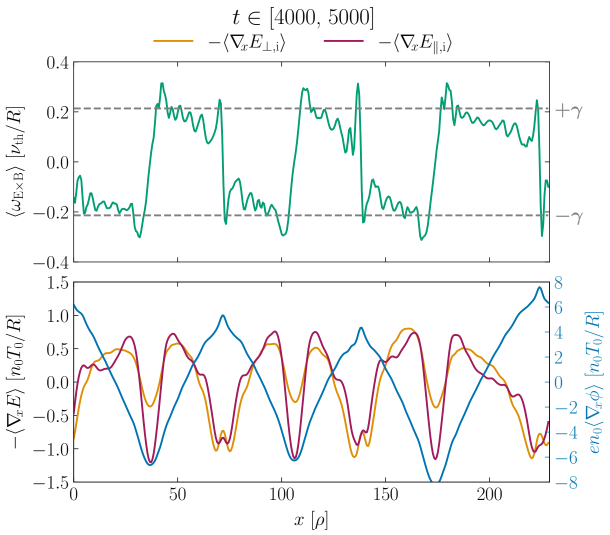


SIZE CONVERGENCE OF $\mathrm{E} \times \mathrm{B}$ STAIRCASE PATTERN

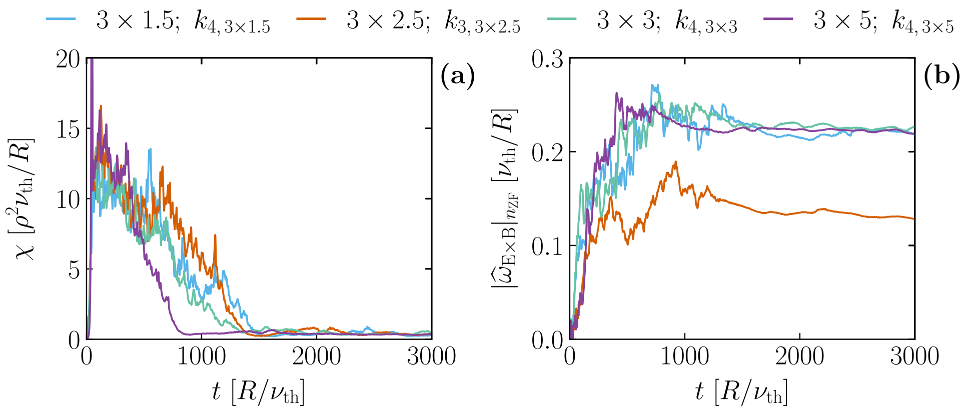


SIZE CONVERGENCE OF $\mathrm{E} \times \mathrm{B}$ STAIRCASE PATTERN

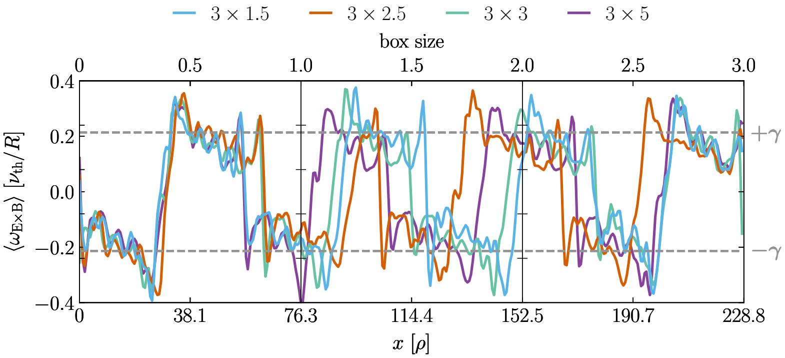
(3) Binormal

$$N_{\mathrm{R}} \times N_{\mathrm{B}} \in [3 \times 1.5,\ 3 \times 2.5,\ 3 \times 3,\ 3 \times 5]$$

SIZE CONVERGENCE OF $\mathrm{E} \times \mathrm{B}$ STAIRCASE PATTERN



SIZE CONVERGENCE OF $\mathrm{E} \times \mathrm{B}$ STAIRCASE PATTERN



SIZE CONVERGENCE OF $\mathrm{E} \times \mathrm{B}$ STAIRCASE PATTERN

$\Rightarrow$ Mesoscale pattern size of:

$$\boxed{\sim 57 - 76\,\rho}$$

- Non-locality is inherent to ITG-driven turbulence
- Avalanches are spatially organized by the E × B staircase pattern

THE FINITE HEAT FLUX THRESHOLD

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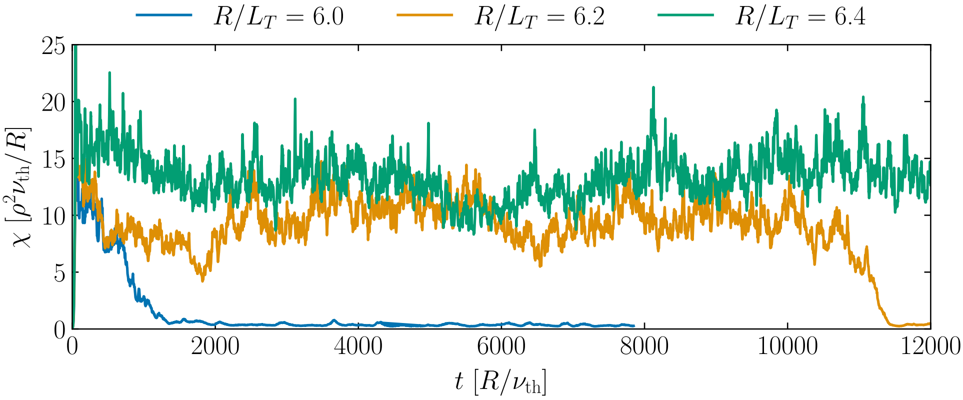
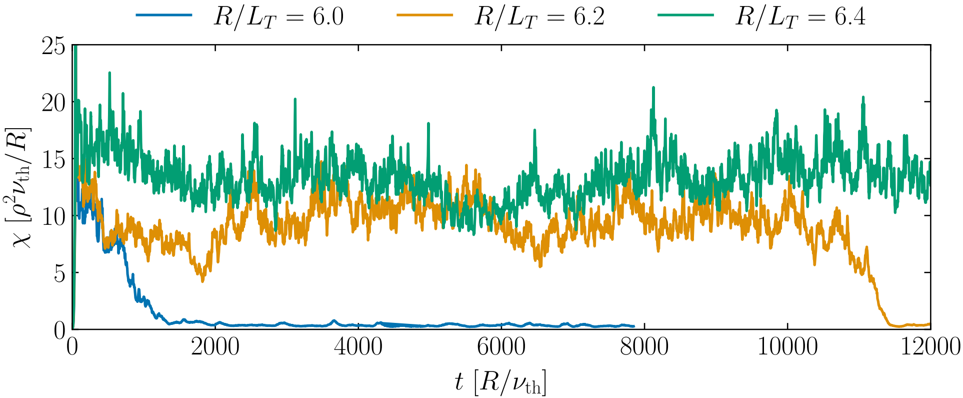


THE FINITE HEAT FLUX THRESHOLD



$$\Rightarrow \boxed{R/L_T|_{\mathrm{finite}} = 6.3 \pm 0.1}$$

CONCLUSION

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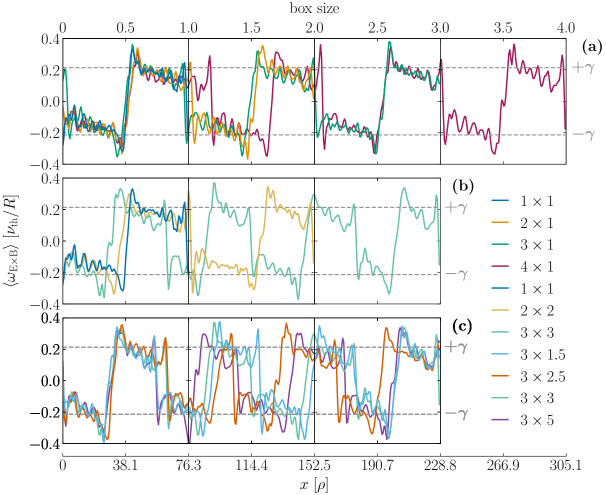

CONCLUSION

- Parallel velocity $N_{\nu_{\parallel}}$ could be reduced from 64 to 48, which halfed the time until suppression of turbulence
- Restart Script with `python` led to further convenience during the task of performing simulations
- Mesoscale pattern size of $\sim 57 - 76\,\rho$ is found to be intrinsic to ITG-driven turbulence for Cyclone Base Case parameters
- Finite heat flux threshold is located at $R/L_T|_{\text{finite}} = 6.3 \pm 0.1$