

Local gyrokinetic simulations of the DTT pedestal

DTT full-power, impurity-seeded H-mode scenario

GENE flux-tube simulations

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DTT: an integrated power-exhaust experiment

Divertor Tokamak Test facility — Frascati, Italy

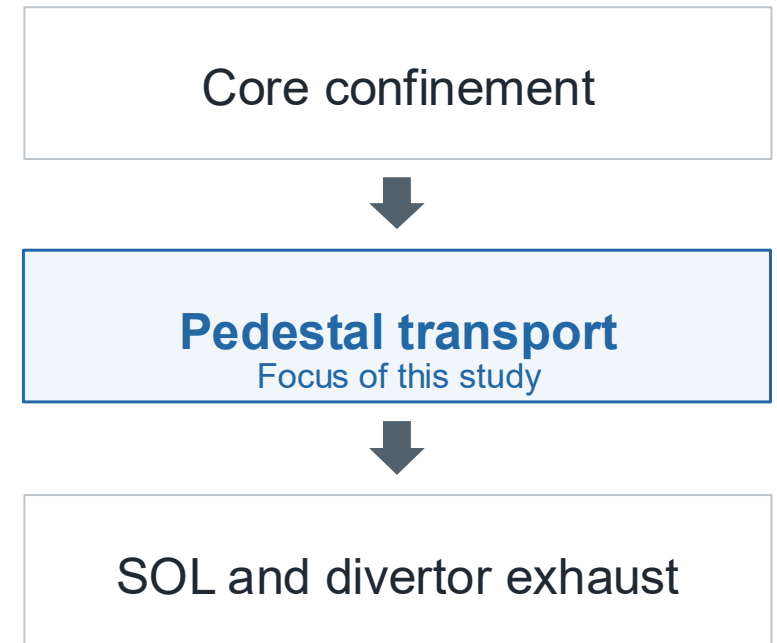
Goal of DTT

- A superconducting tokamak under construction to test heat-exhaust solutions for DEMO.
- Flexible magnetic configurations allow comparisons of alternative divertor designs.
- H-mode is the primary reference scenario for high-performance plasma operation in DTT, particularly during Phases 2 and 3.

Planned full-power operation

Up to 45 MW of auxiliary heating coupled to the plasma.

An integrated core–edge problem



Motivation and scope

Why the H-mode pedestal matters

- In H-mode, the edge transport barrier forms a steep pedestal that sets the core boundary condition and strongly influences confinement.
- Steep pedestal gradients drive microinstabilities that can limit confinement.
- GENE provides an independent gyrokinetic test of transport predicted by integrated modelling.

Local studies and global simulations

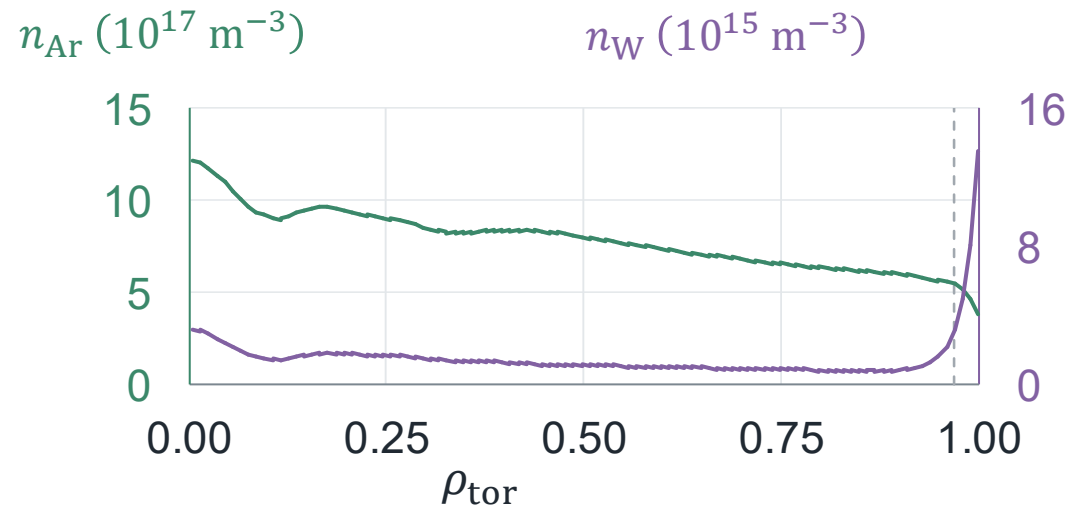
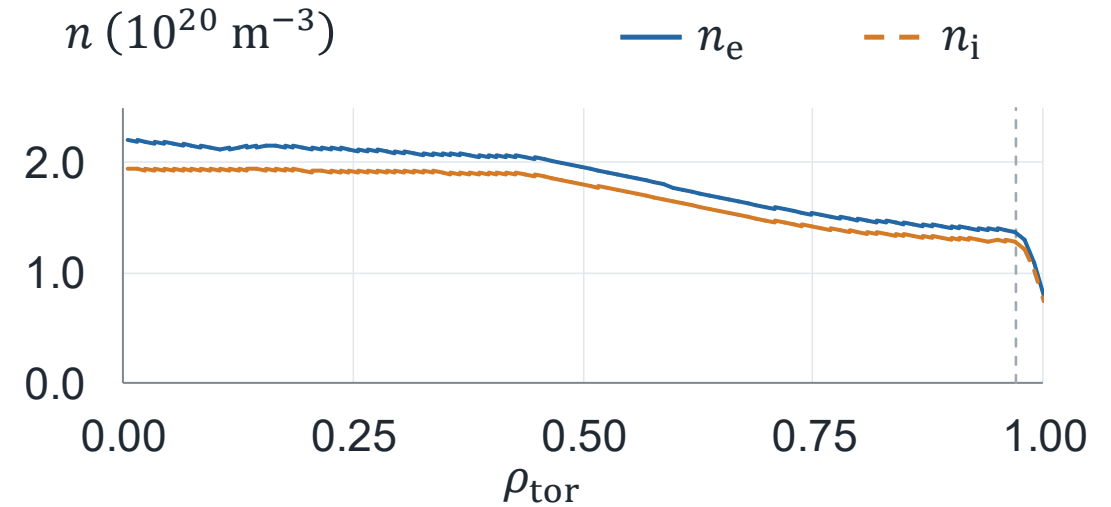
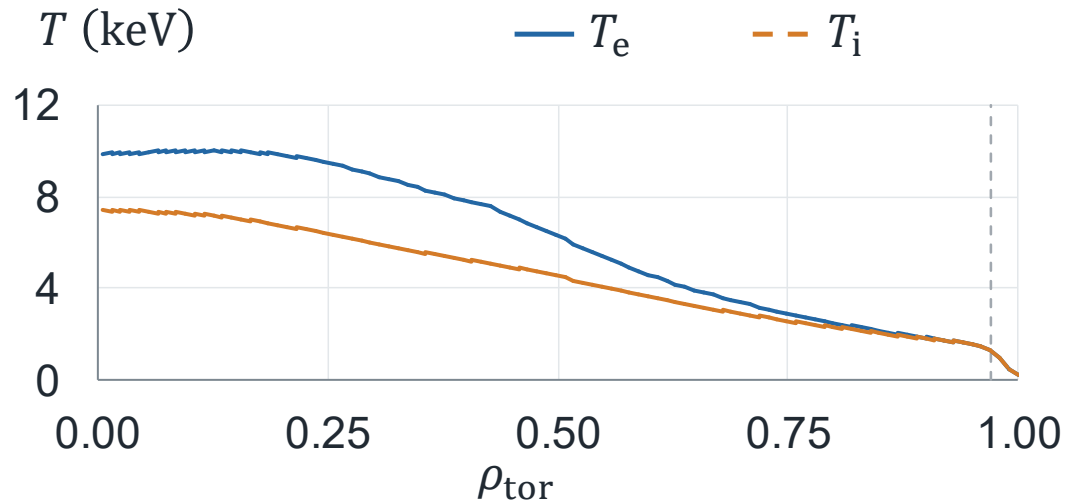
- Current work: multiscale local linear scans and local nonlinear simulations.
- Next: global linear and nonlinear simulations to study radial profile effects.

Linear scans at $\rho_{\text{tor}} = 0.96, 0.97, 0.98$

Nonlinear focus at $\rho_{\text{tor}} = 0.97$

Background profiles across the plasma

DTT H-mode profiles from integrated modelling with TGLF-SAT2 transport



Profile features

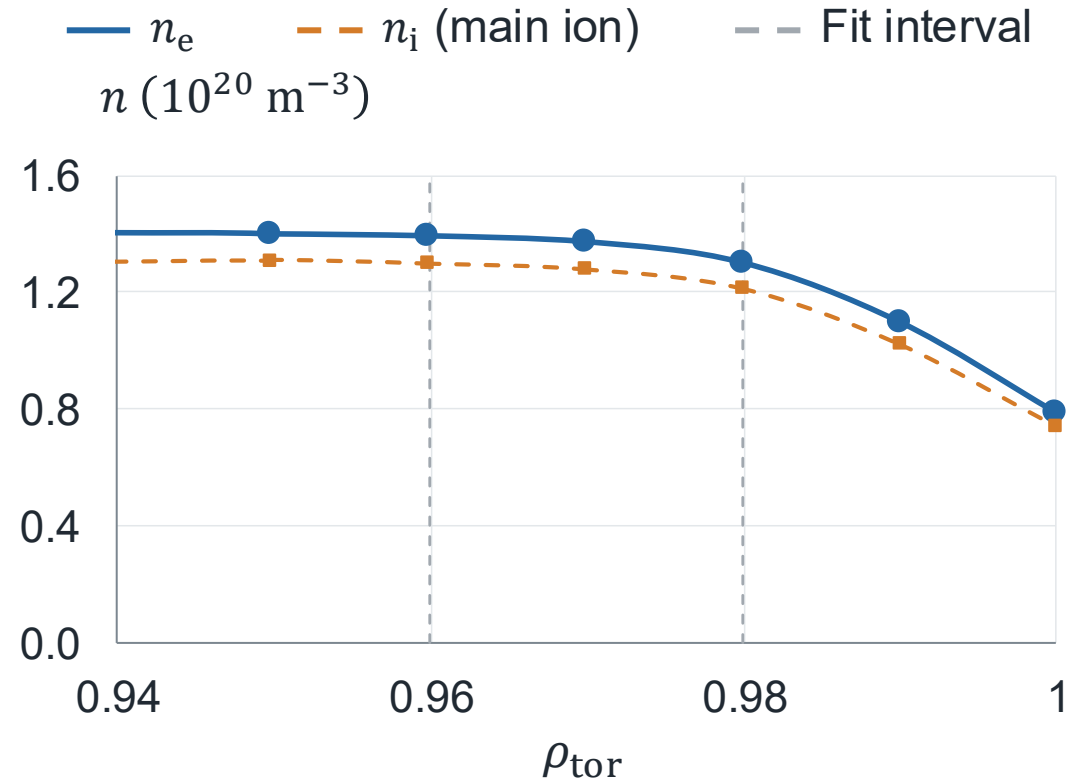
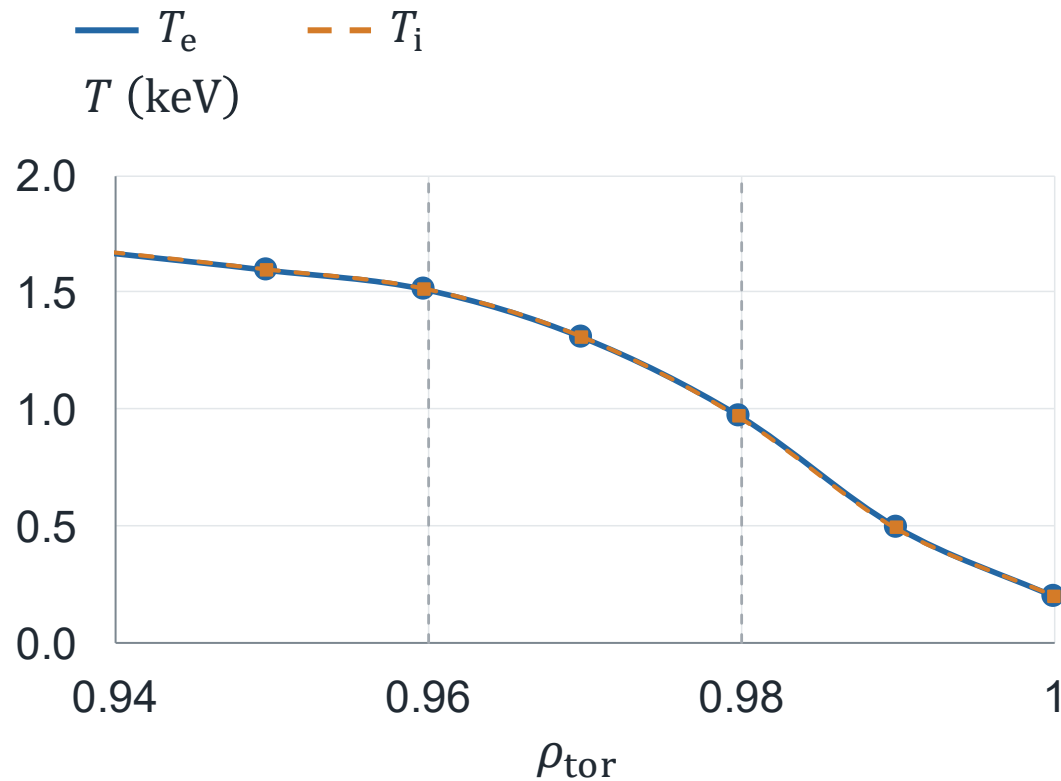
- Core $T_e > T_i$, edge $T_e \approx T_i$.
- Steep temperature and density changes near the outer boundary.
- Argon falls at the edge while tungsten rises.

Local scan positions: $\rho_{\text{tor}} = 0.96, 0.97, 0.98$

Dashed line: $\rho_{\text{tor}} = 0.97$

Local gradients

Background profiles for linear scans, take $\rho_{\text{tor}} = 0.97$ for example



- A log-linear fit over $[0.96, 0.98]$ uses 3 sampled points.

$$-\frac{d \ln T_e}{d \rho} = 22.17$$

$$-\frac{d \ln T_i}{d \rho} = 22.14$$

$$-\frac{d \ln n_e}{d \rho} = 3.40$$

$$-\frac{d \ln n_i}{d \rho} = 3.36$$

$$\rho \equiv \rho_{\text{tor}}$$

Linear grid convergence

Ion scale at $\rho_{\text{tor}} = 0.97$, $k_y \rho_{\text{ref}} = 0.3$

- Vary one coordinate resolution while holding the other grid settings fixed.
- Require $\varepsilon_\gamma < 3\%$, $\varepsilon_\omega < 3\%$ relative to the finest point in each scan.

Axis	Physical meaning	Selected resolution
x	Radial coordinate	$n_x = 48$
z	Coordinate along the magnetic field	$n_z = 128$
v	Parallel velocity	$n_v = 48$
w	Magnetic moment	$n_w = 16$
y	Binormal coordinate (field-line label)	$n_{k_y} = 1$

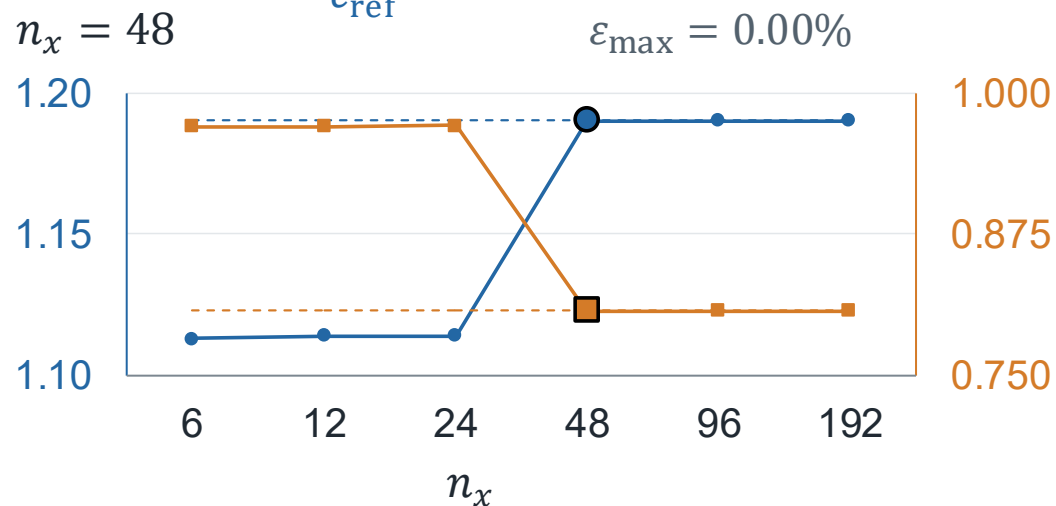
- Linear eigenvalue convergence does not establish nonlinear flux or box-size convergence.

Grid scan results

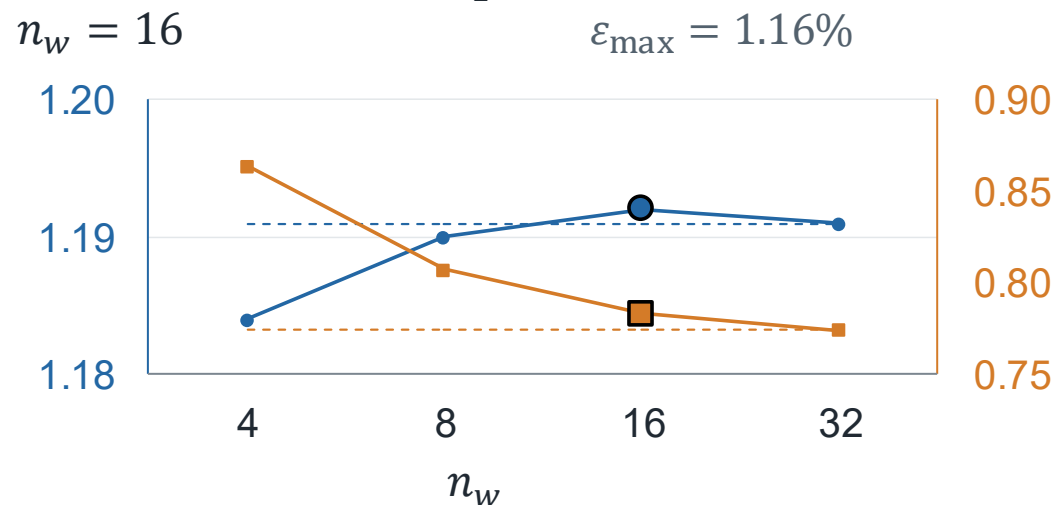
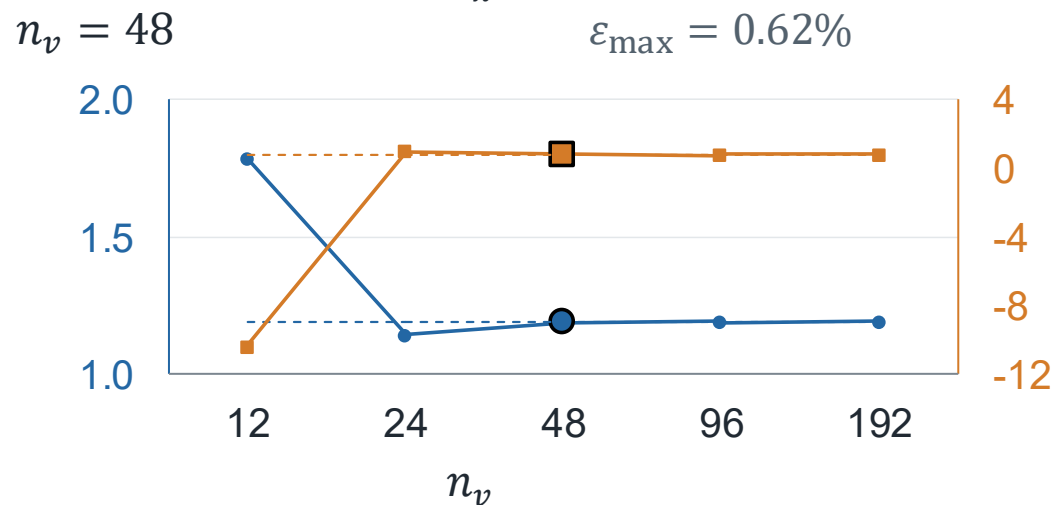
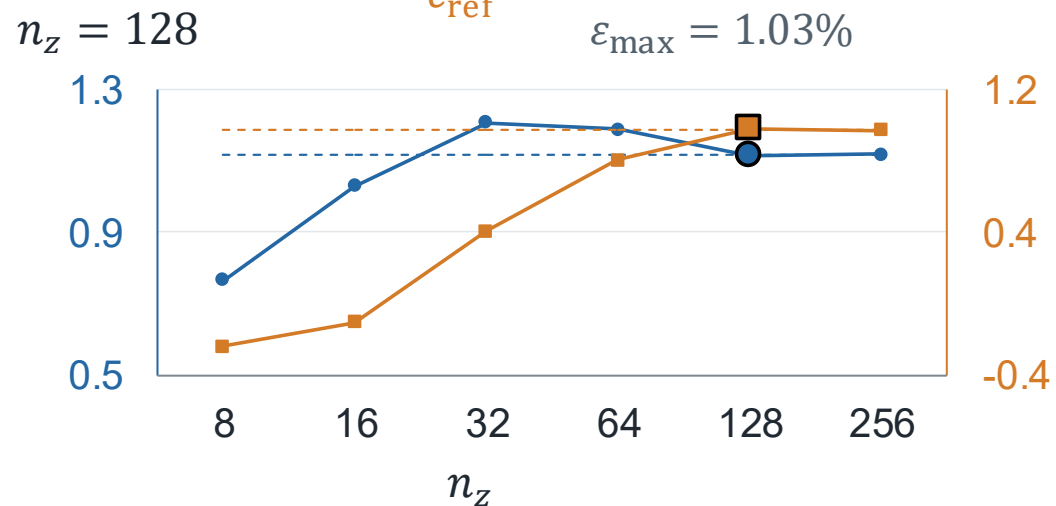
Ion scale at $\rho_{\text{tor}} = 0.97$, $k_y \rho_{\text{ref}} = 0.3$

Rings: selected grid. Dashes: finest grid.

Growth rate $\frac{\gamma L_{\text{ref}}}{c_{\text{ref}}}$



Real frequency $\frac{\omega L_{\text{ref}}}{c_{\text{ref}}}$



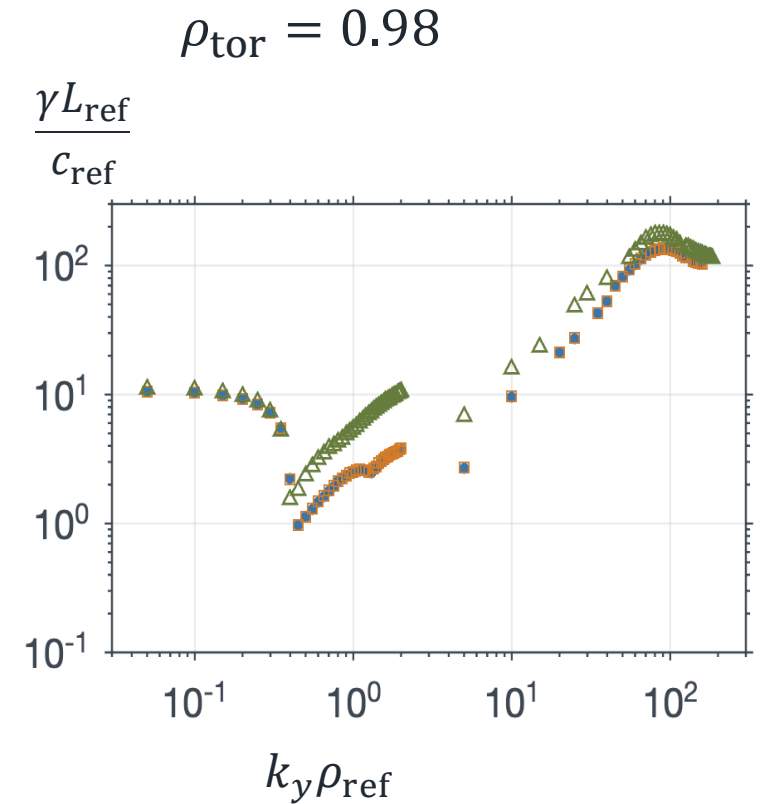
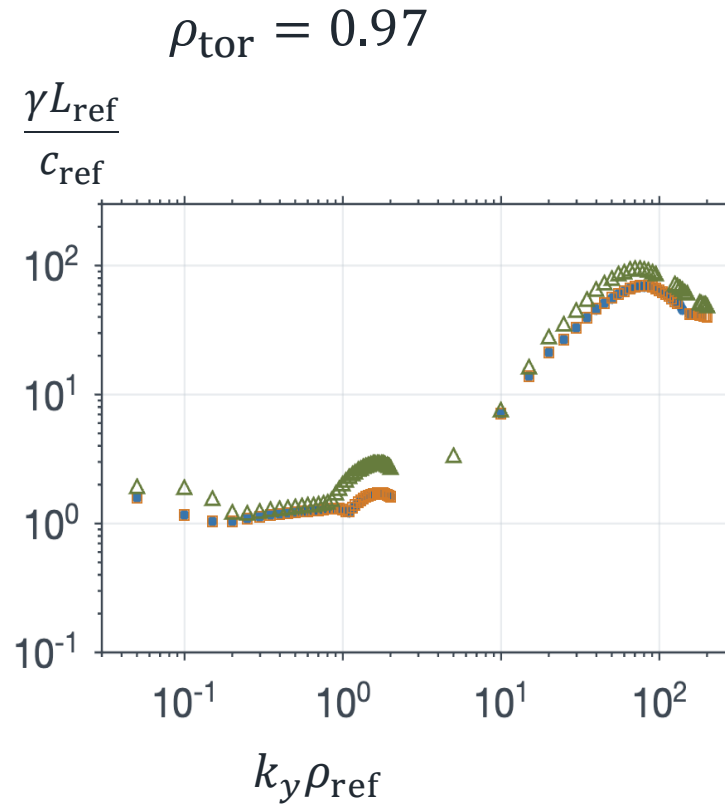
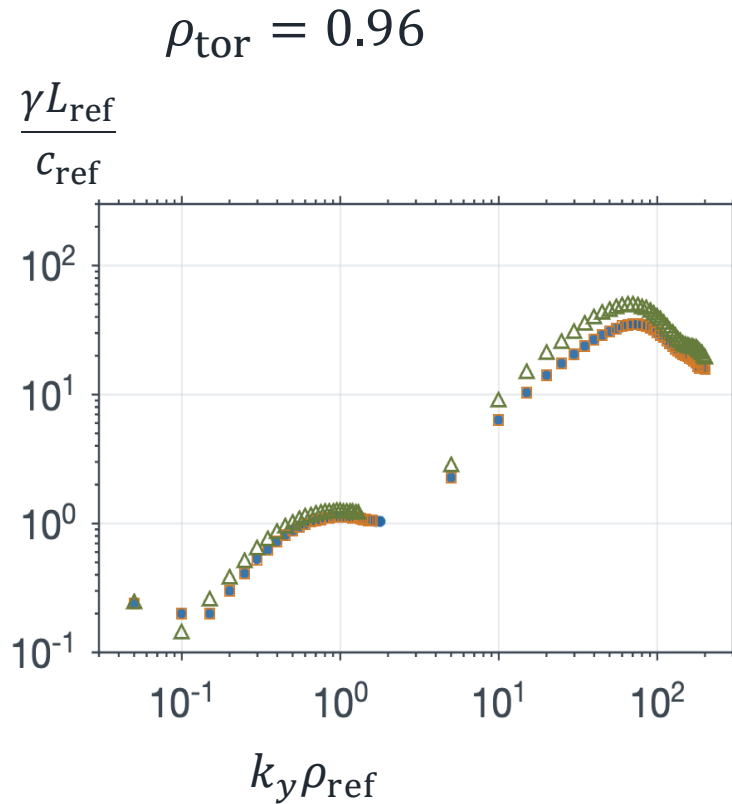
Multiscale linear growth rate spectra

Dominant eigenmode at each wave number

Argon and tungsten

Argon only

No impurities



- Ion-scale KBM, ITG and TEM branches coexist with electron-scale ETG modes.
- Argon generally reduces growth rates. The additional tungsten effect is small in these scans.

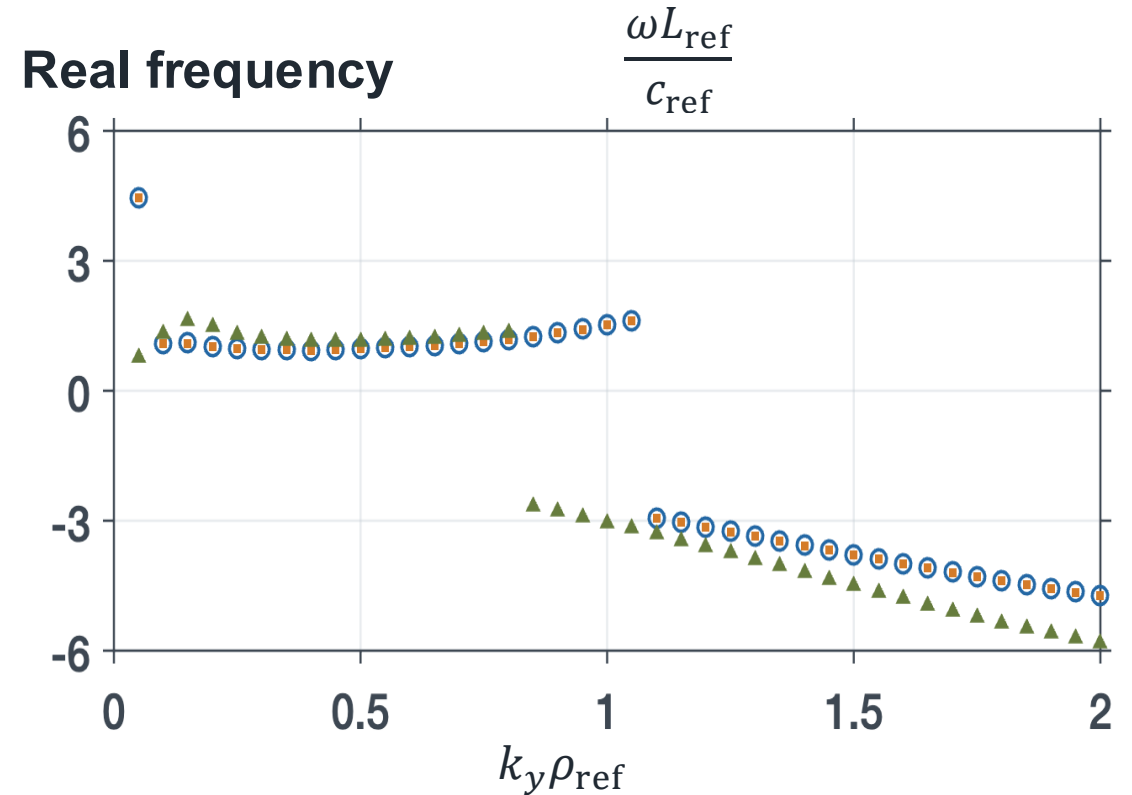
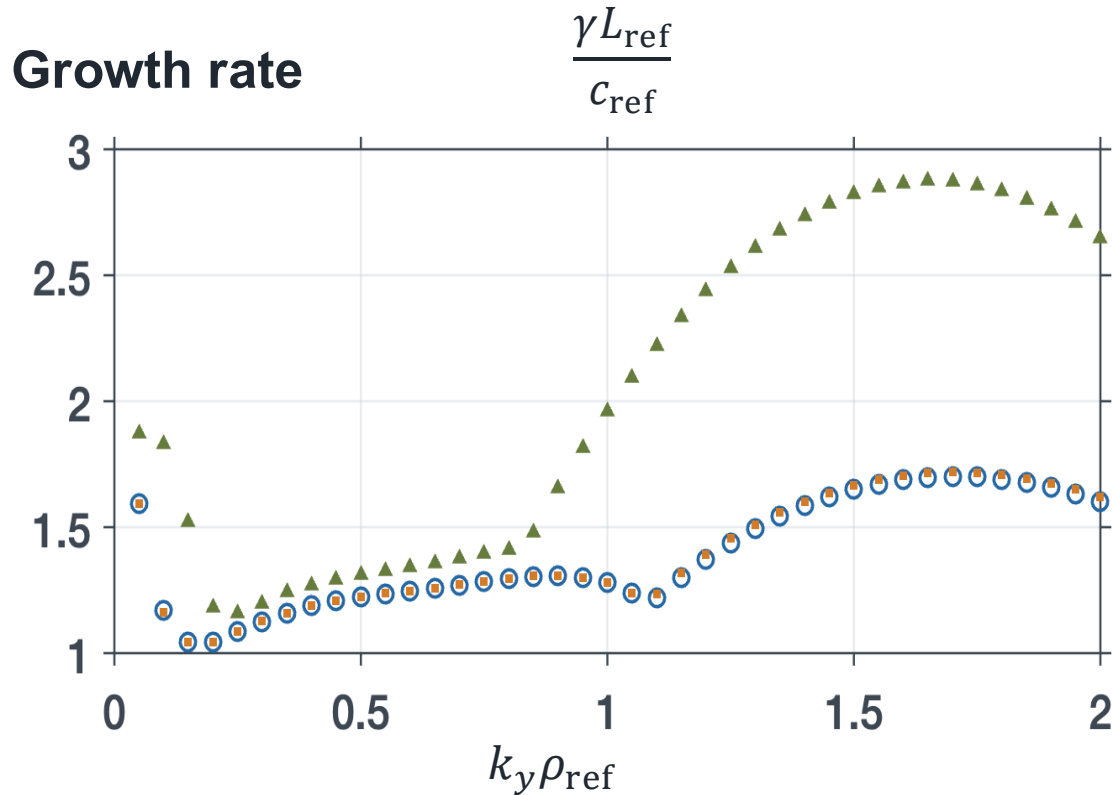
Ion-scale spectrum

Take $\rho_{\text{tor}} = 0.97$ as example

Argon and tungsten (circles)

Argon only (squares)

No impurities (triangles)



- KBM appears at the smallest wave numbers, followed by ITG and TEM branches.
- Spectral trends and eigenfunction parity jointly identify the modes.
- Near branch crossings, comparable growth rates can prevent convergence.

Electromagnetic effect (β_e) linear scans

$$\rho_{\text{tor}} = 0.97$$

Fixed background profiles and equilibrium

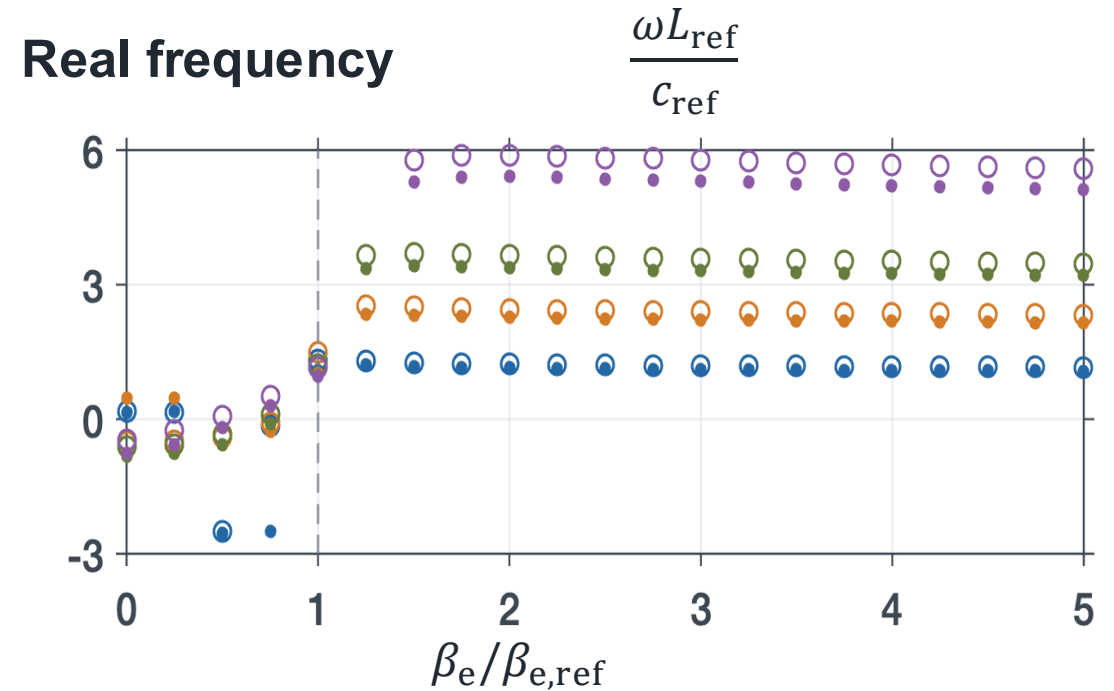
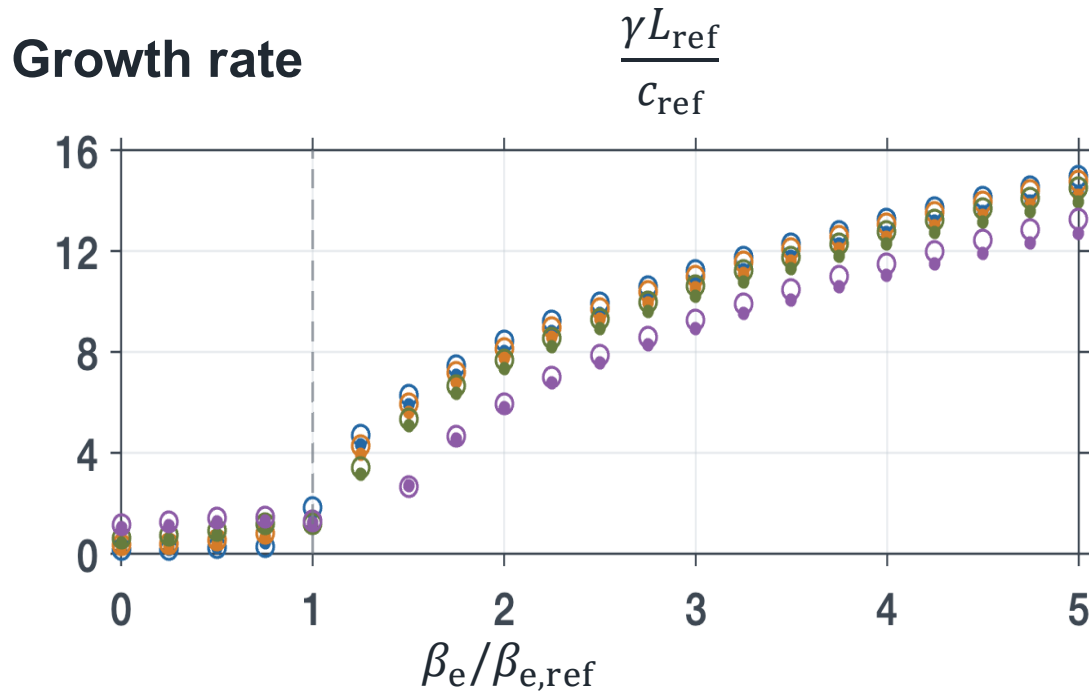
$$k_y \rho_{\text{ref}} = 0.1$$

$$k_y \rho_{\text{ref}} = 0.2$$

$$k_y \rho_{\text{ref}} = 0.3$$

$$k_y \rho_{\text{ref}} = 0.5$$

Filled markers: argon and tungsten. Open markers: no impurities.



- A rapidly growing KBM branch becomes dominant near the reference β_e .
- The same transition appears with and without impurities.

$$\beta_{e,\text{ref}} = 1.984 \times 10^{-3}$$

KBM identification and nonlinear relevance

$$\rho_{\text{tor}} = 0.97$$

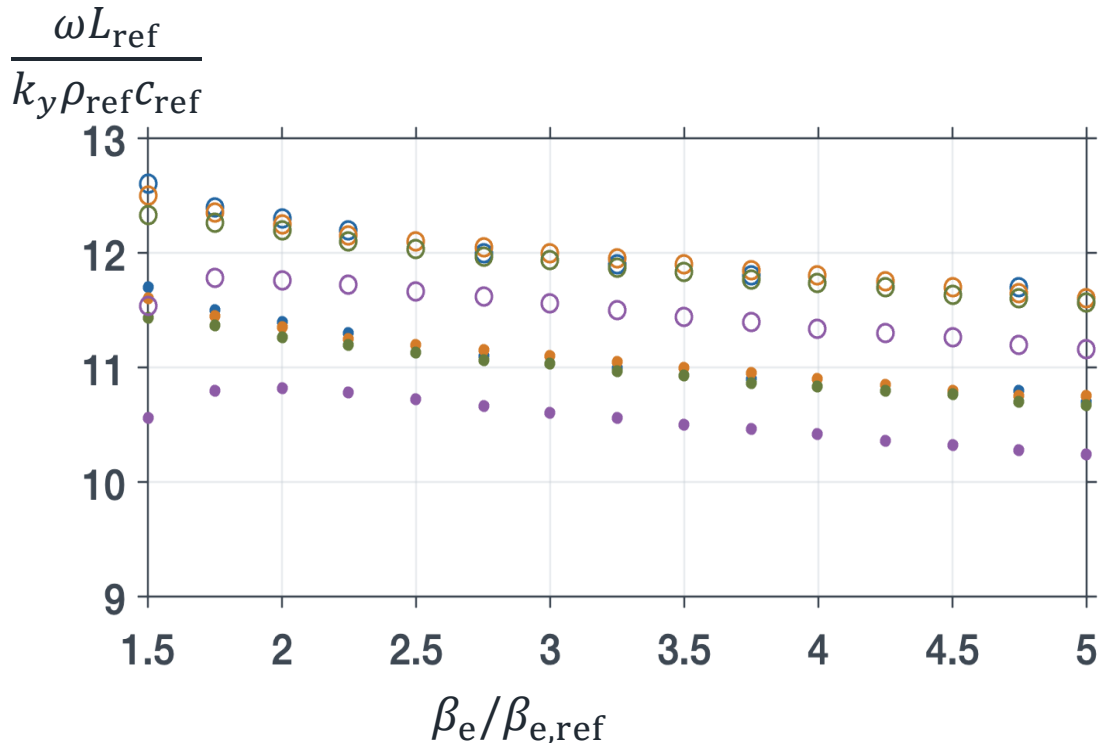
The low-wave-number branch at higher β_e

$$k_y \rho_{\text{ref}} = 0.1$$

$$k_y \rho_{\text{ref}} = 0.2$$

$$k_y \rho_{\text{ref}} = 0.3$$

$$k_y \rho_{\text{ref}} = 0.5$$



Strong-drive KBM approximation

$$\omega_{\text{KBM}} \approx \frac{k_y T_i}{2eB} \left(\frac{1}{L_n} + \frac{1}{L_{T_i}} \right)$$

Consistent KBM signatures

Filled: impurities. Open: no impurities.

- Real frequency changes weakly at high β_e .
 - Frequency is approximately proportional to wave number.
 - Eigenfunction parity supports the spectral identification.
-
- KBM is a candidate driver of the local nonlinear instability.
 - Global runs will test whether finite radial mode width reduces KBM drive and heat flow.

Nonlinear setup and gradient sensitivity

$$\rho_{\text{tor}} = 0.97$$

Local ion-scale simulations

Why reduce the gradients?

- Edge profiles from the reduced model may contain errors.
 - A 20% reduction tests whether excessive gradient drive explains the transport gap.
 - The reduction is a sensitivity test. Its size is not an established profile uncertainty.
-
- Plots show only electrostatic heat flow.
 - In bounded flux cases, mean EM contributions are below 4% (electrons) and 0.3% (main ions).

Shared nonlinear configuration

$$(n_x, n_{k_y}, n_z, n_v, n_w) = (512, 48, 64, 48, 16)$$

Turbulence develops first, then saturates, followed by $E \times B$ shear and independent branches with finite β_e .

Gradient prescription

$$g_X = -\frac{d \ln X}{d \rho_{\text{tor}}}$$

Original gradients

$$(g_{T_e}, g_{T_i}, g_n) = (22.17, 22.14, 3.40)$$

0.8× gradients

$$(g_{T_e}, g_{T_i}, g_n) = (17.73, 17.71, 2.72)$$

Both species use the electron density gradient to preserve quasineutrality in runs without impurities.

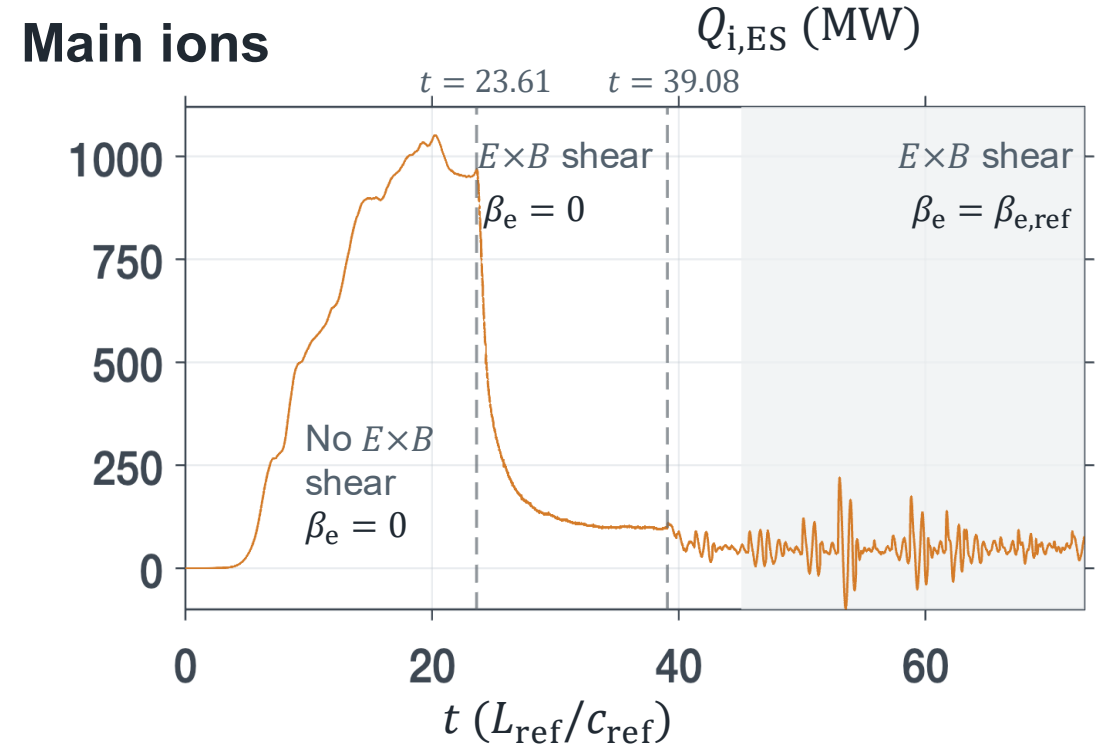
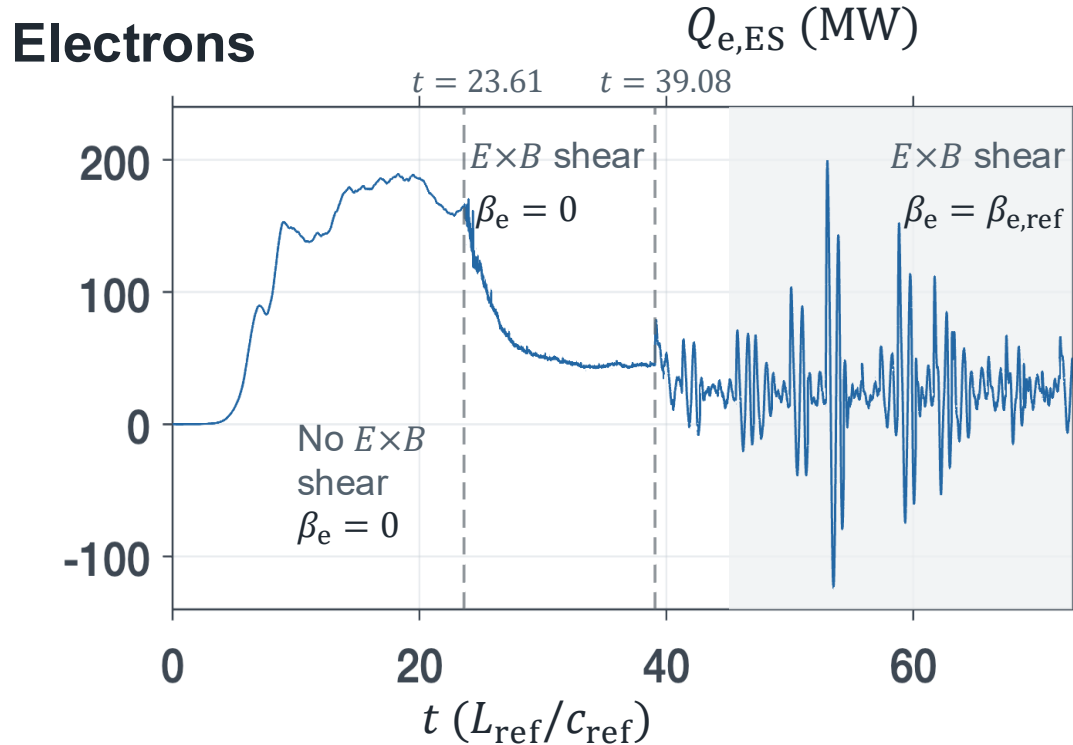
Box size: $(L_x, L_y) = (200, 209) \rho_{\text{ref}}$

$$\frac{\gamma_{E \times B} L_{\text{ref}}}{c_{\text{ref}}} = 0.72$$

Complete evolution from the initial state

$\rho_{\text{tor}} = 0.97$, $0.8\times$ gradients. Final branch: $\beta_e = \beta_{e,\text{ref}}$

Applied $E\times B$ shear after the first stage: $\gamma_{E\times B} L_{\text{ref}}/c_{\text{ref}} = 0.72$. Dashed lines mark the stage boundaries.



- Switching on $E\times B$ shear suppresses the initially saturated high transport.
- After nonzero β_e is enabled, transport becomes oscillatory. Shading marks the averaging interval.

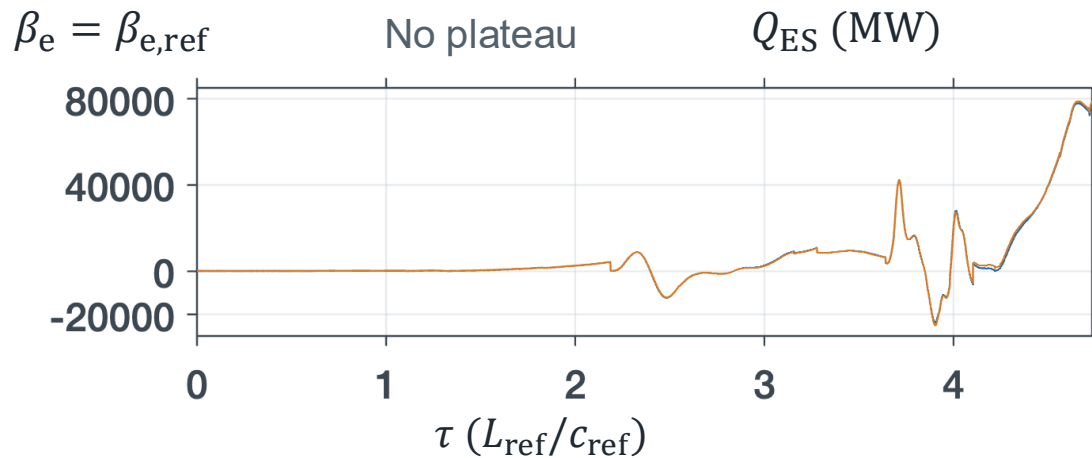
Heat flow after β_e is turned on

$$\rho_{\text{tor}} = 0.97, \quad \gamma_{\text{E} \times \text{B}} L_{\text{ref}} / c_{\text{ref}} = 0.72$$

Electrons

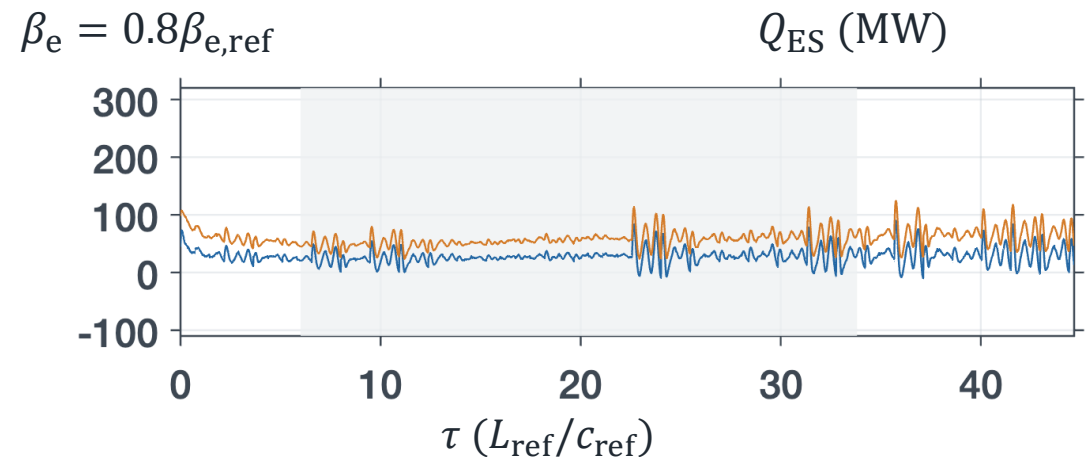
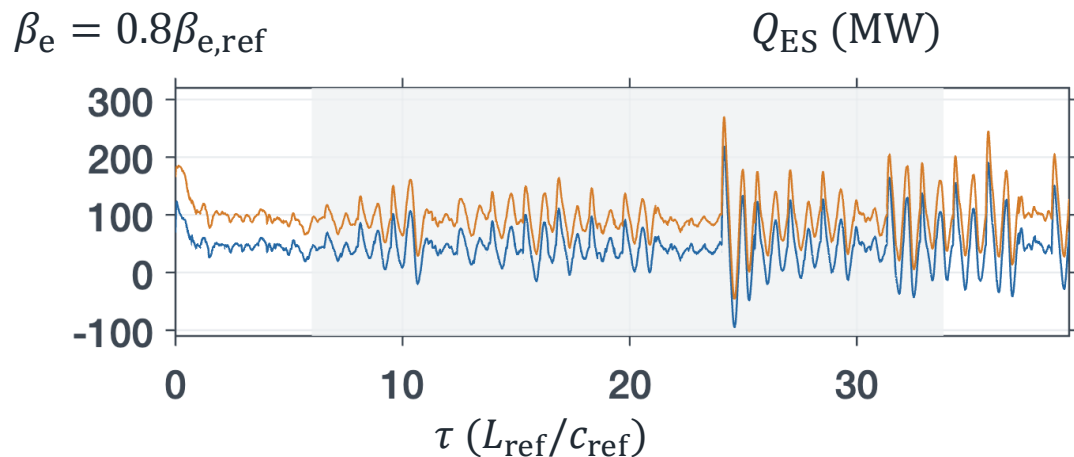
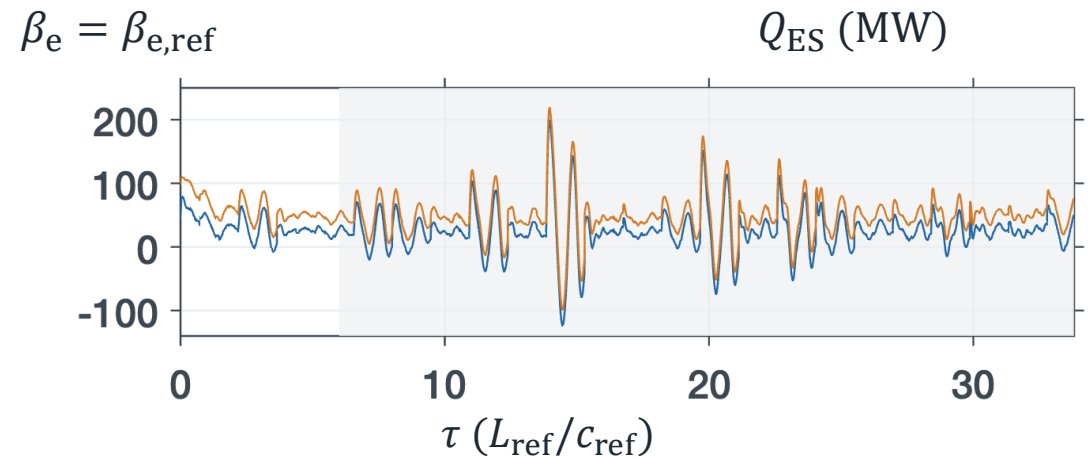
Main ions

Original gradients



Shading: common averaging interval

0.8× gradients



β_e dependence and gradient sensitivity

Points are time averages. Vertical lines show the standard deviation of fluctuations.

This measures fluctuation amplitude, rather than uncertainty of the mean.

Mean window: $\tau \in [6, 33.82]$ ($L_{\text{ref}}/c_{\text{ref}}$), after β_e is turned on.

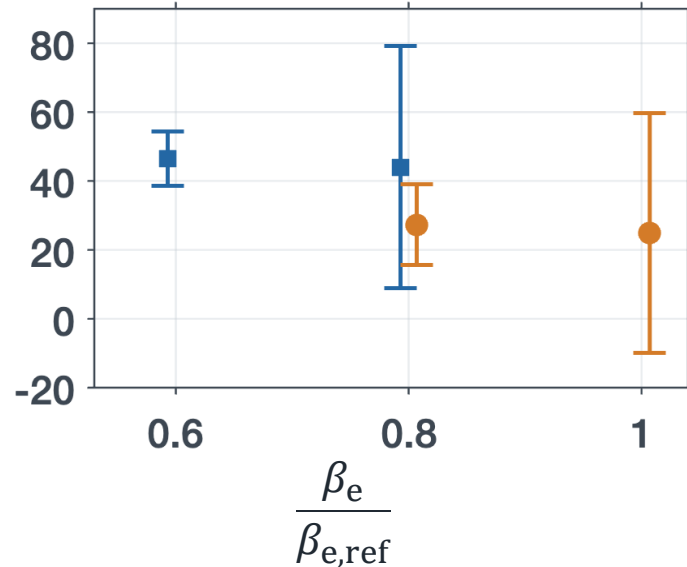
Original gradients (squares)

0.8× gradients (circles)

Reference source integral

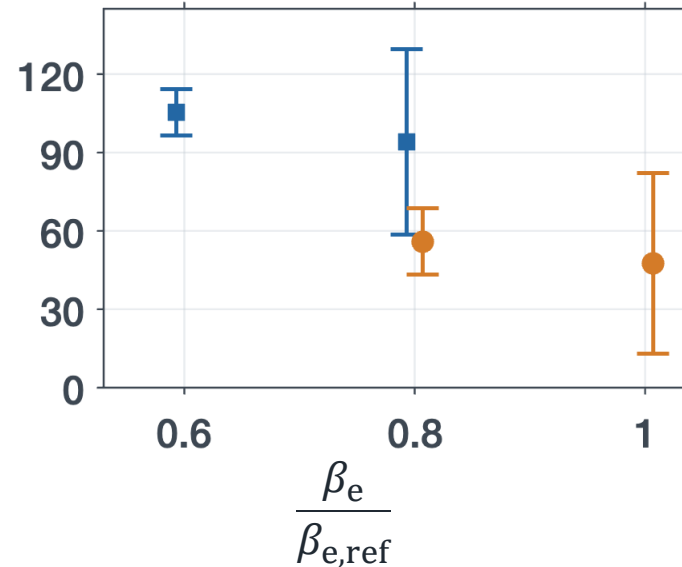
Electrons

$\langle Q_{e,ES} \rangle$ (MW)



Main ions

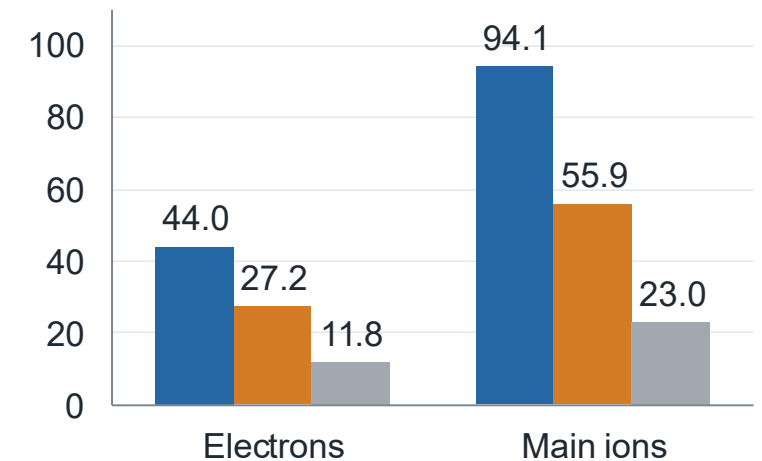
$\langle Q_{i,ES} \rangle$ (MW)



Gradient comparison

$\beta_e = 0.8\beta_{e,\text{ref}}$

$\langle Q_{ES} \rangle$ (MW)



- Reducing the gradients lowers the electron and main-ion means by about 38% and 41%.
- Reduced-gradient means remain about 2.3 and 2.4 times the reference powers.

Argon and grid dependence in the first stage

$\rho_{\text{tor}} = 0.97$, $\beta_e \approx 0$, $\gamma_{E \times B} L_{\text{ref}} / c_{\text{ref}} = 0$, original gradients

No argon, fine grid

(512,48,64,48,16)

No argon, reduced grid

(256,48,64,36,8)

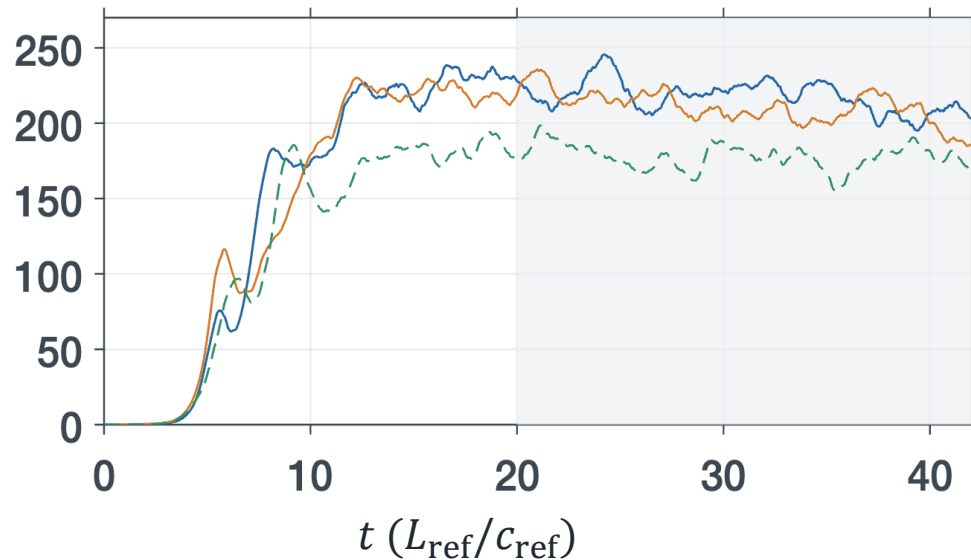
Argon, reduced grid

(256,48,64,36,8)

Grid order: $(n_x, n_{k_y}, n_z, n_v, n_w)$. Fine grid $\beta_e = 10^{-5}$, reduced grid $\beta_e = 0$.

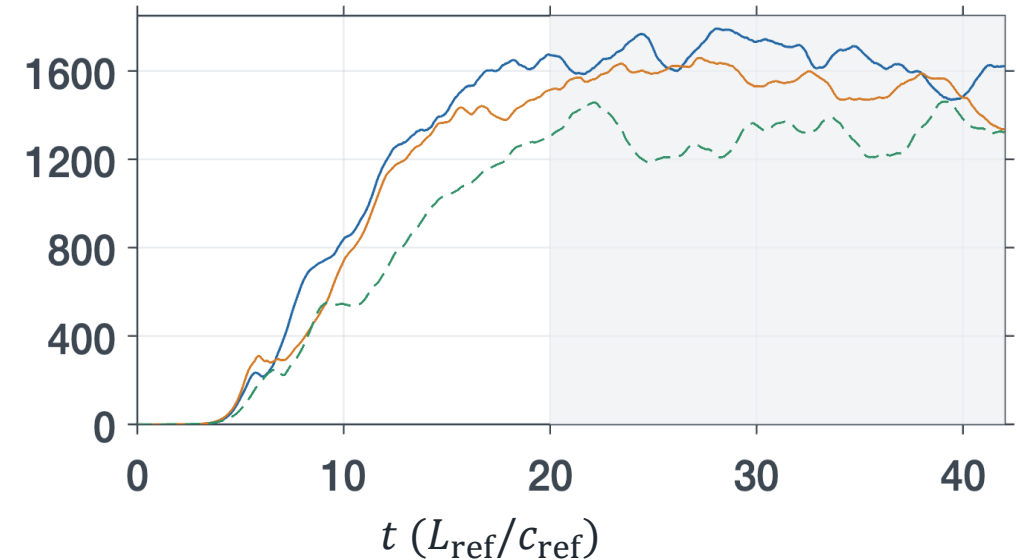
Electrons

$Q_{e,ES}$ (MW)



Main ions

$Q_{i,ES}$ (MW)



- Grid changes shift the mean heat flow by about 3% for electrons and 6% for main ions.
- Argon lowers both channels on the same reduced grid. Shading marks the mean window.

Argon gives a partial transport reduction

Preliminary first-stage results without imposed $E \times B$ shear

$\rho_{\text{tor}} = 0.97$, $\beta_e \approx 0$. Mean window: $t \in [20, 42.03]$ ($L_{\text{ref}}/c_{\text{ref}}$)

Fine grid, no argon

Reduced grid, no argon

Reduced grid, argon

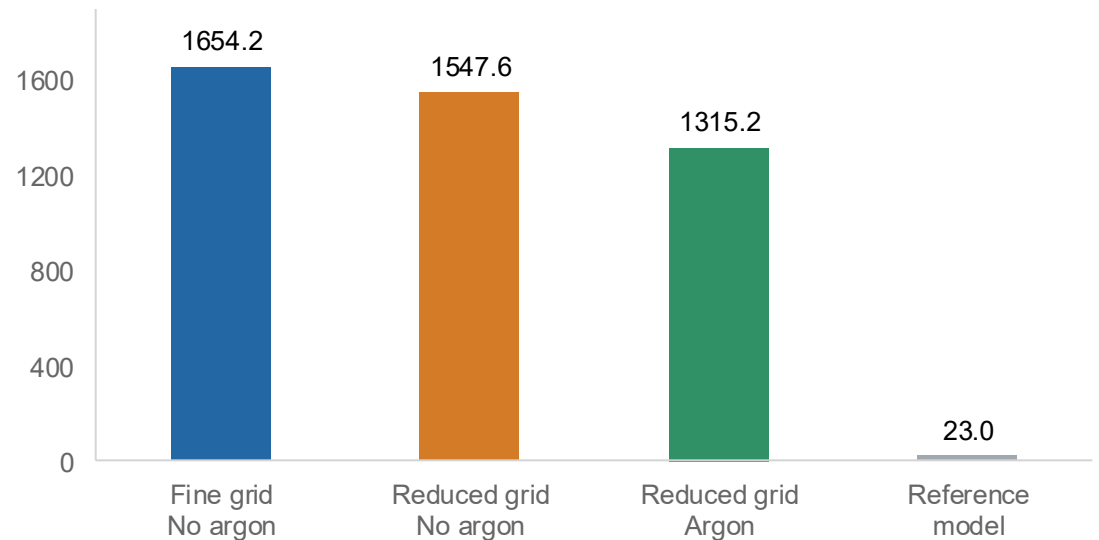
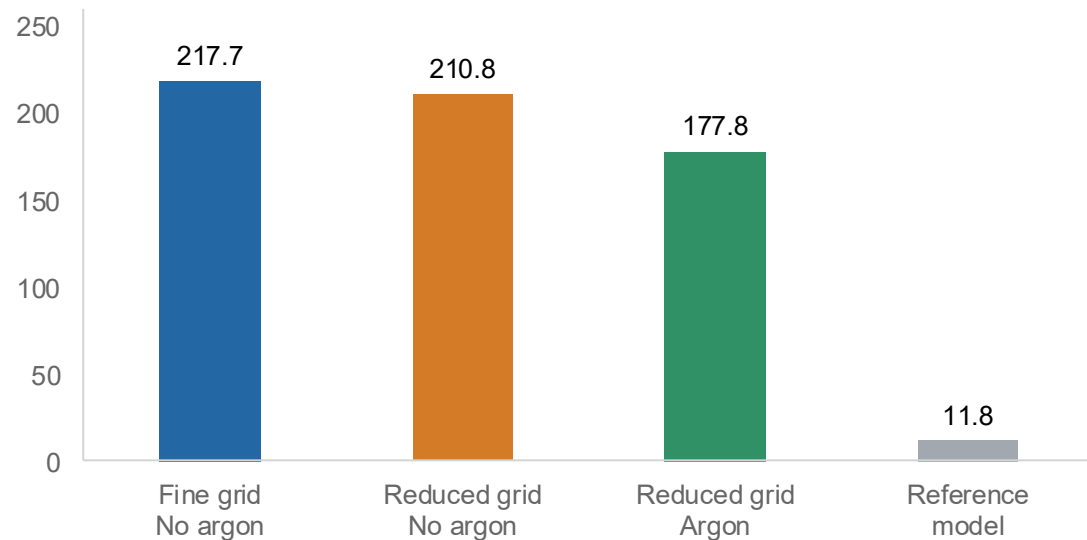
Reference model

Electrons

$\langle Q_{e,ES} \rangle$ (MW)

Main ions

$\langle Q_{i,ES} \rangle$ (MW)

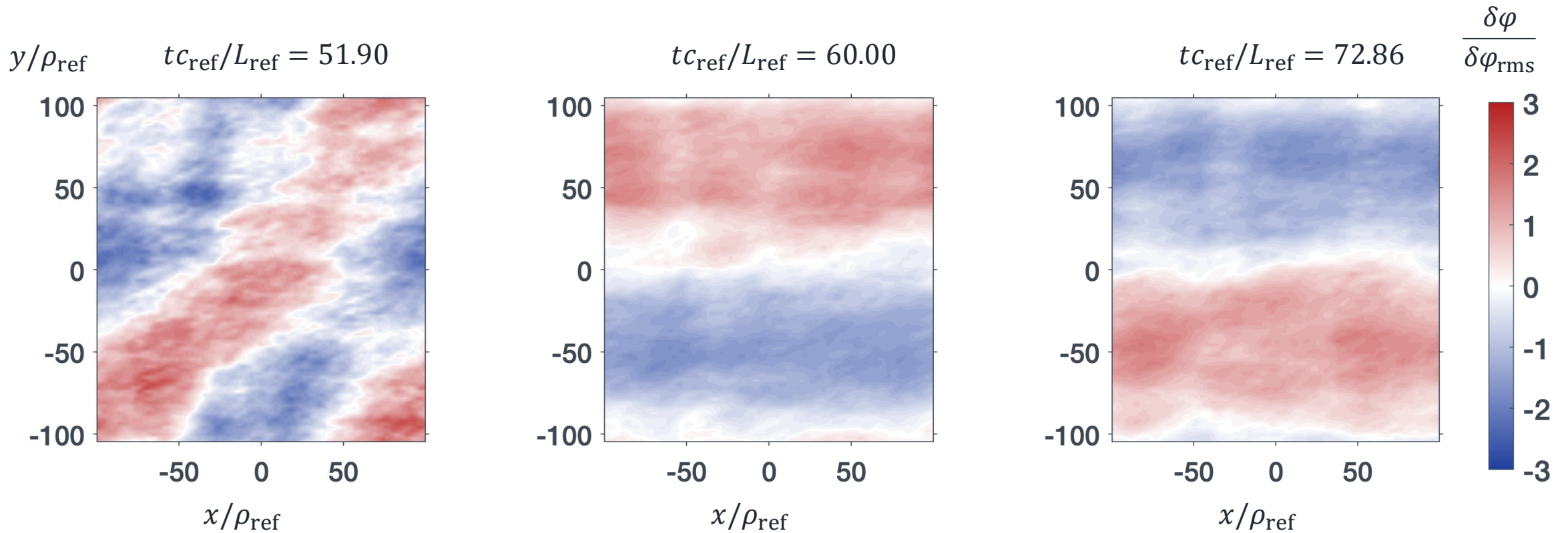


- At fixed grid, argon reduces the electron and main-ion means by about 16% and 15%.
- A large gap remains. The final state with $E \times B$ shear and argon is still untested.

Radial structures and box-size tests

$$\rho_{\text{tor}} = 0.97, \beta_e = \beta_{e,\text{ref}}, 0.8\times \text{gradients}, L_x/\rho_{\text{ref}} = 200$$

Midplane snapshots in field-line coordinates; each panel normalized by its own RMS.



- Radial structures recur; these plots alone do not establish a heat-flow error.
- Test at fixed spatial resolution: $L_x \rightarrow 2L_x$.

Next steps

Necessary local simulations

- Extend the argon case through the $E \times B$ shear and electromagnetic stages.
- Check the required resolution and radial box size, with longer averaging records.

Priority: global linear and nonlinear simulations

- Global linear runs will test how finite pedestal width changes the low-wave-number KBM branch.
 - The expected global correction is weaker KBM drive, which may reduce nonlinear heat flow.
 - Global nonlinear runs will quantify the heat flow and compare it with the reference powers.
-
- The remaining discrepancy may combine profile uncertainty, impurity effects and the local approximation.