Davide Gatti[1,2], Maurizio Quadrio[1]

Turbulent Drag Reduction at Moderate Reynolds Numbers via Spanwise Velocity Waves

[1]POLITECNICO DI MILANO

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Technische Universität Darmstadt

Turbulent skin-friction Drag Reduction

Motivation

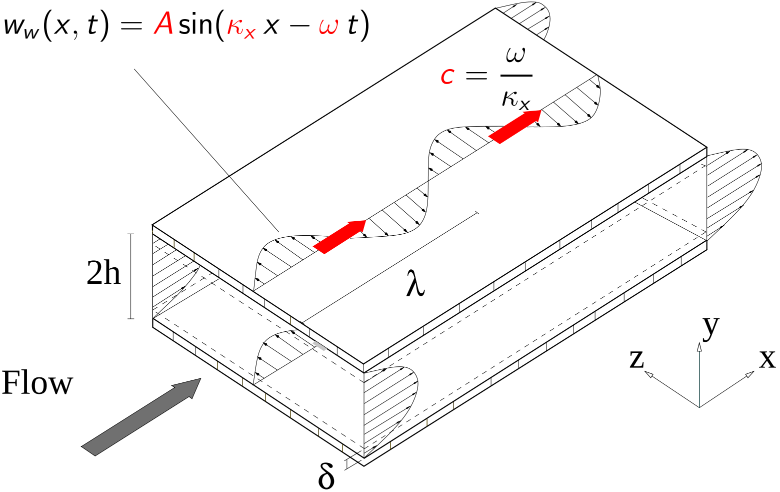
- Economical benefits
- Environmental benefits
- Better understanding of turbulence

Our focus

- The effects of *Re* on a particular control strategy

A promising strategy

Streamwise-traveling waves of spanwise wall velocity (Quadrio *et al.*, JFM 2009)



High performances

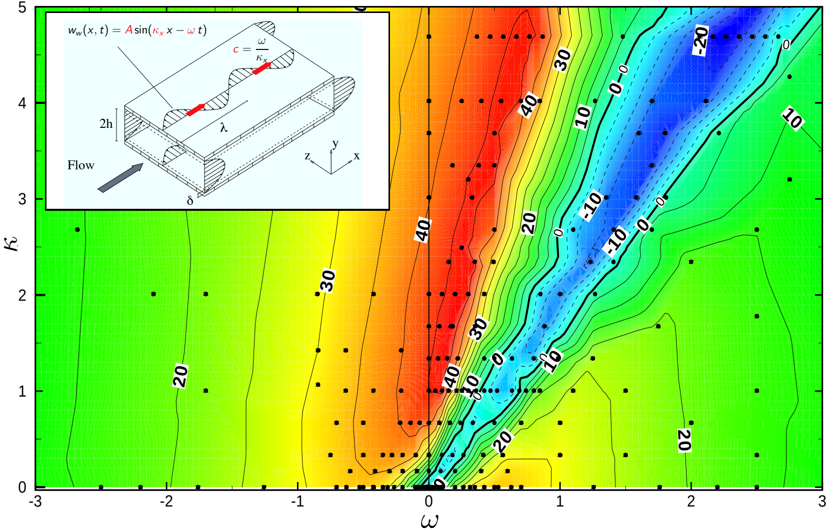
Drag reduction rate: $$R = \frac{P_0 - P}{P_0}$$

Input power: $$P_{in} = \frac{1}{L_x\, L_z\, T} \int_0^{L_x}\int_0^{L_z}\int_0^{T} w_w \frac{\partial w}{\partial y}\, \mathrm{d}t\mathrm{d}x\mathrm{d}z$$

Power saving rate: $$S = R - \frac{P_{in}}{P_0}$$

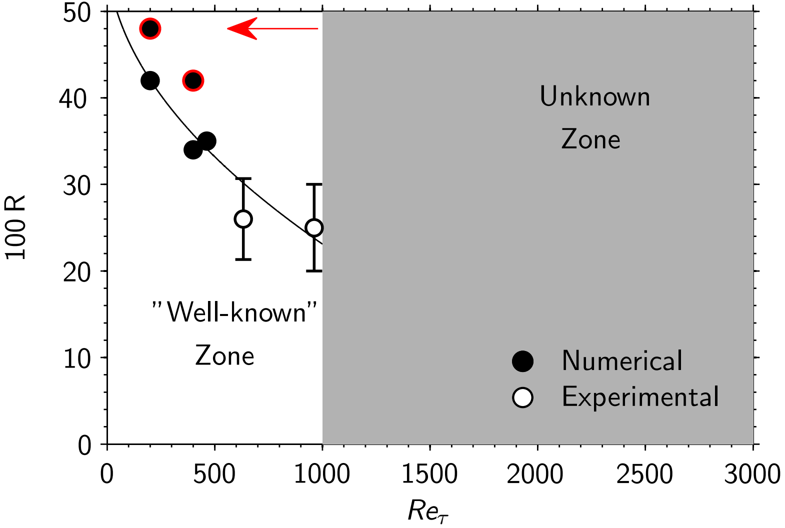
High drag reduction achievable

(Quadrio *et al.*, JFM 2009)



What happens at high *Re*?

Two possible scenarios



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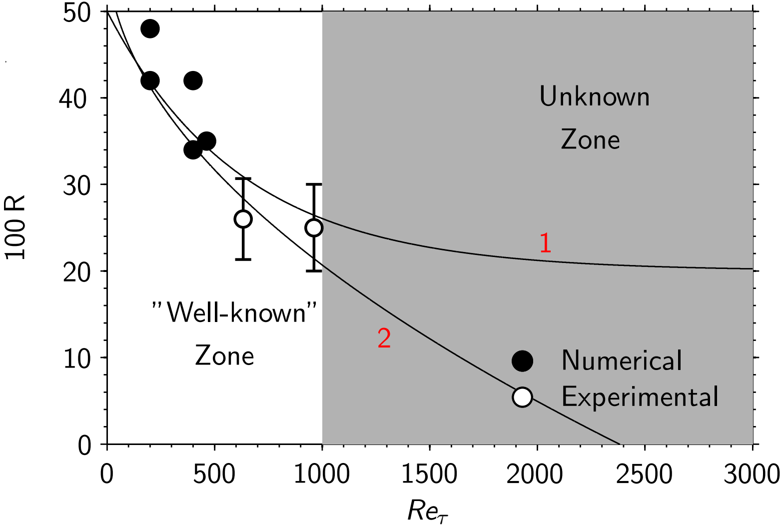


Several means of investigation

Modeling error

Modeling error	Method	Comment
high	RANS	exceeds present modeling skills
	LES	our attempt: Smagorinsky model fails Touber and Leschziner, JFM 2012 : high computational costs and low reliability
	DNS	prohibitive computational costs for a parametric study
none	Experiments	difficult drag measurements and more

Our approach

Up to $Re_\tau = 2000$ with DNS of channels of reduced size

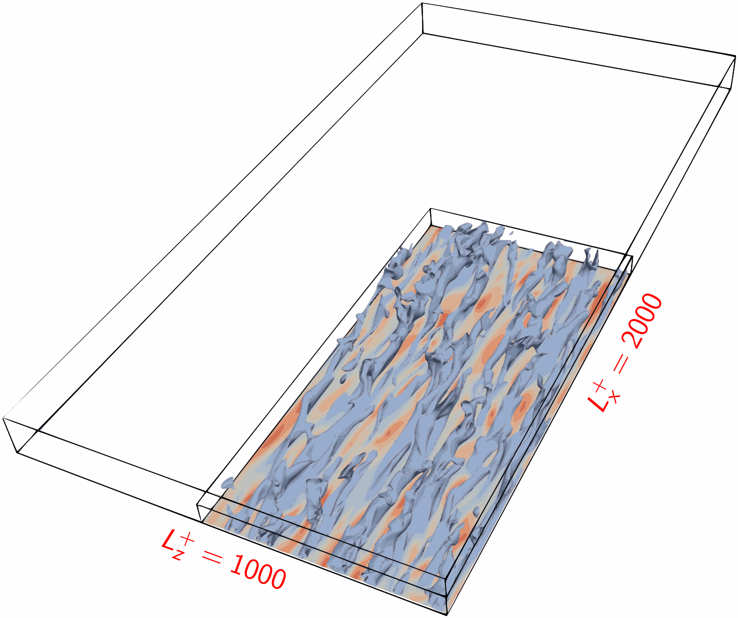
Pros

- No modeling errors
- No resolution errors

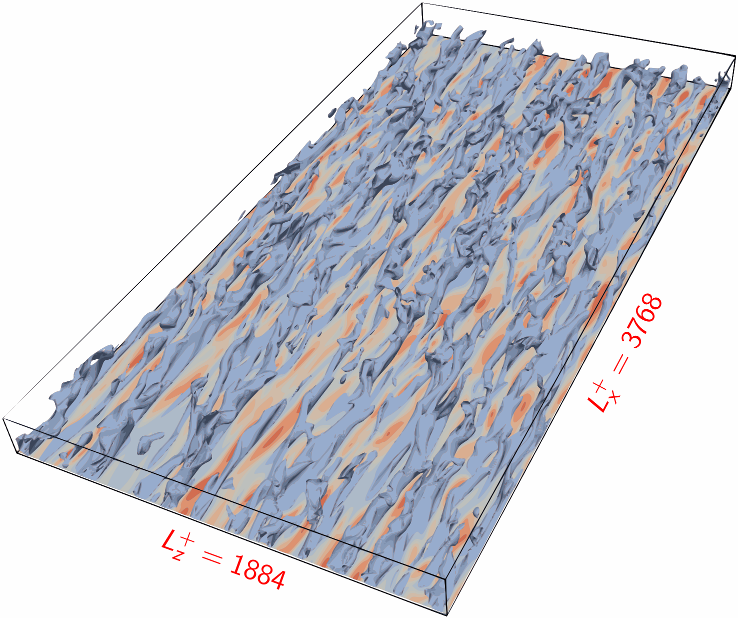
Cons

- Discretization errors at the large scales

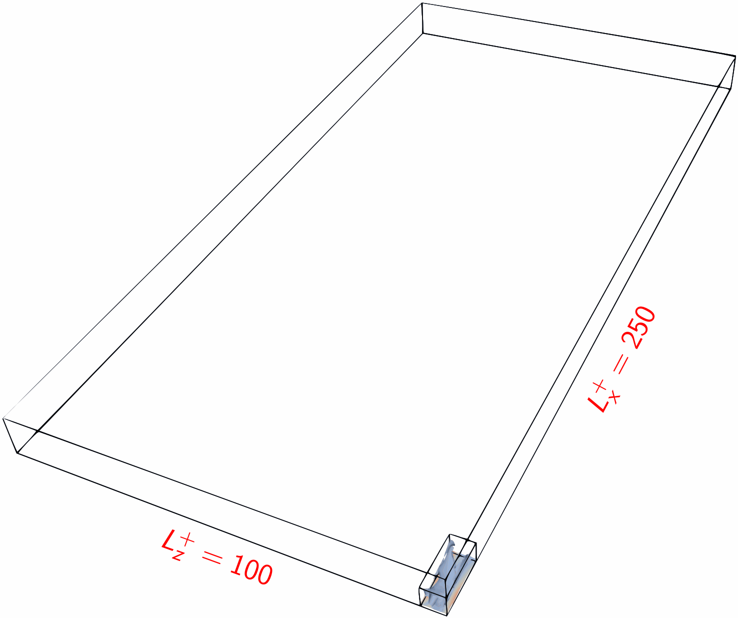
Neither minimal nor full



Neither minimal nor full



Neither minimal nor full

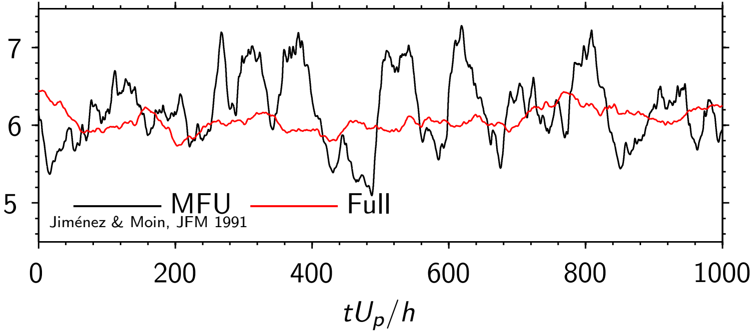


Simulation time

Larger fluctuations of the space-averaged wall shear (Ω)

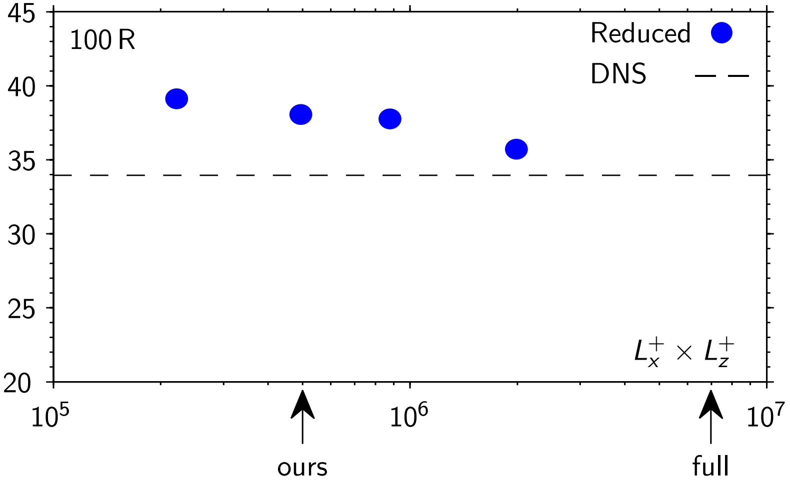
Ω treated as a measure: $\sigma_{\overline{\Omega}} = C \frac{\sigma_\Omega}{\sqrt{T_{sim}}}$

optimal compromise between space and time average



Effects on drag reduction

$\kappa_x = 0$ (oscillating wall)



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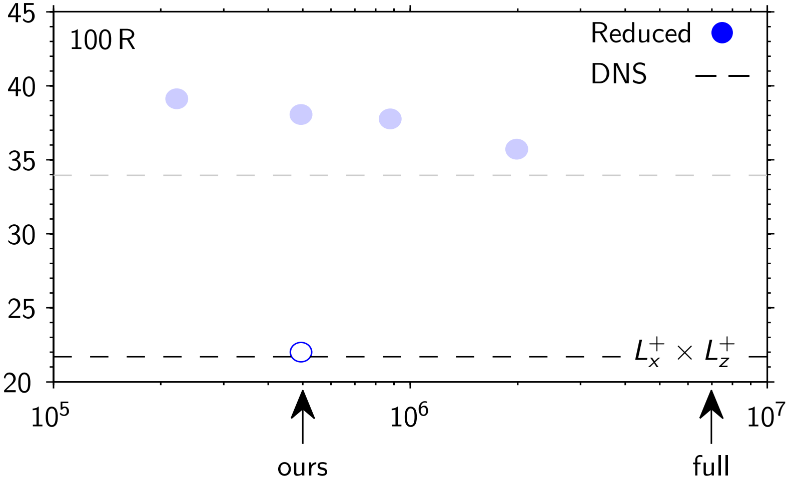
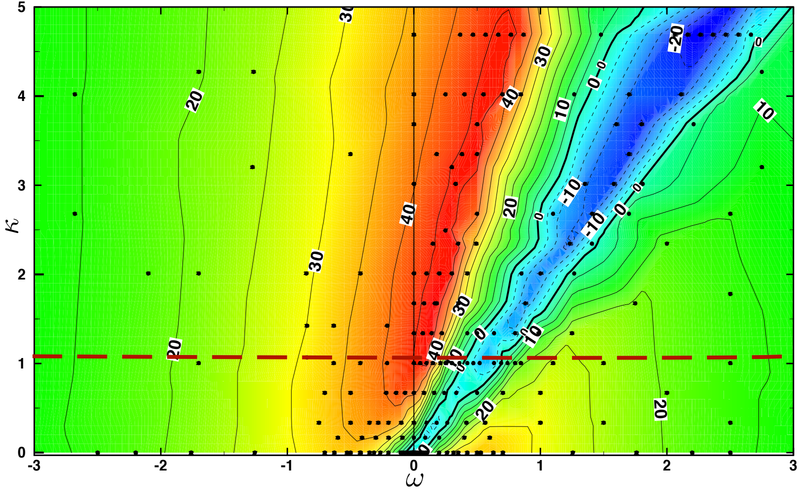


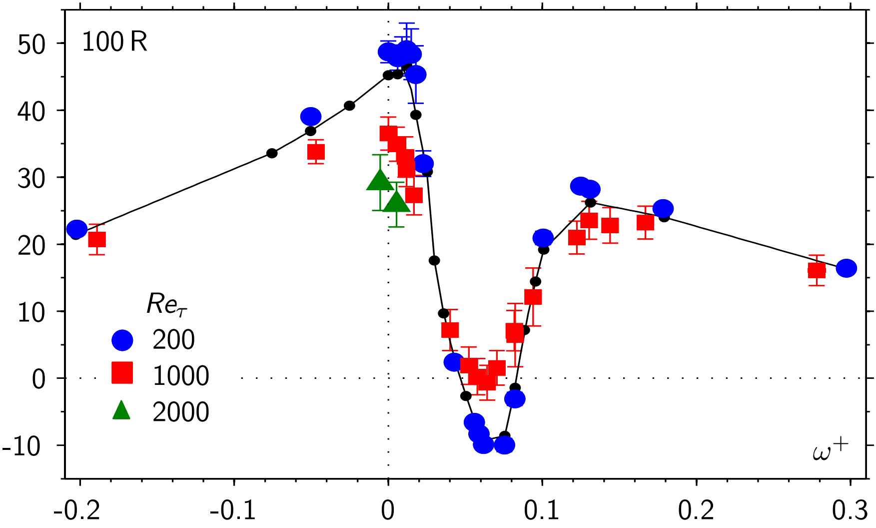
Wave parameters

$\lambda_x^+ = 1256$



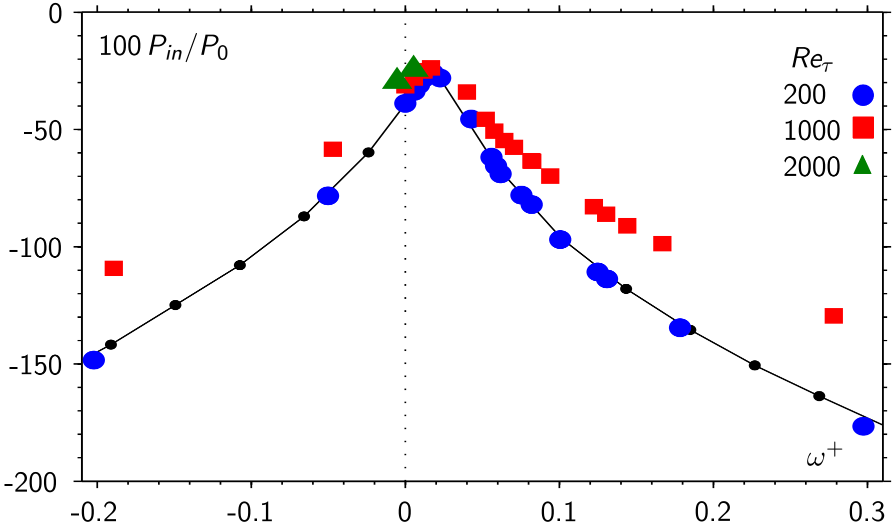
Drag reduction

$\lambda_x^+ = 1256$

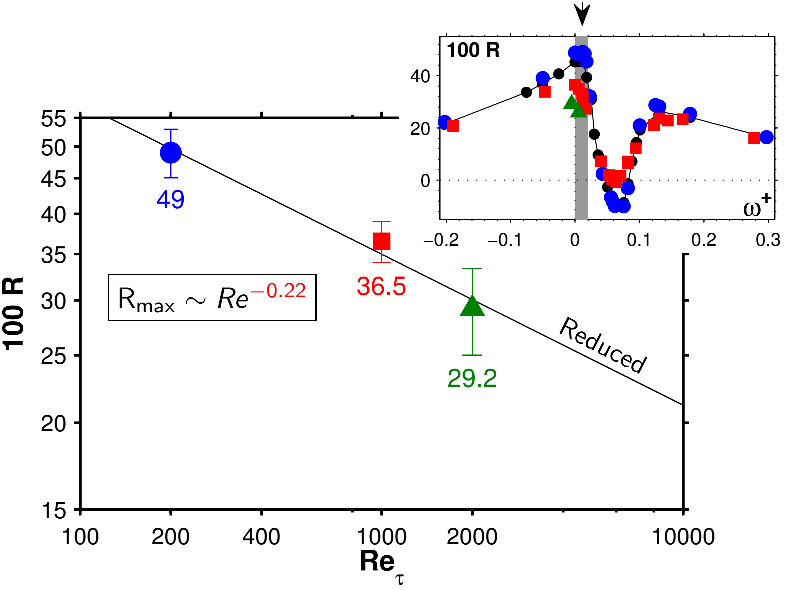


Input power

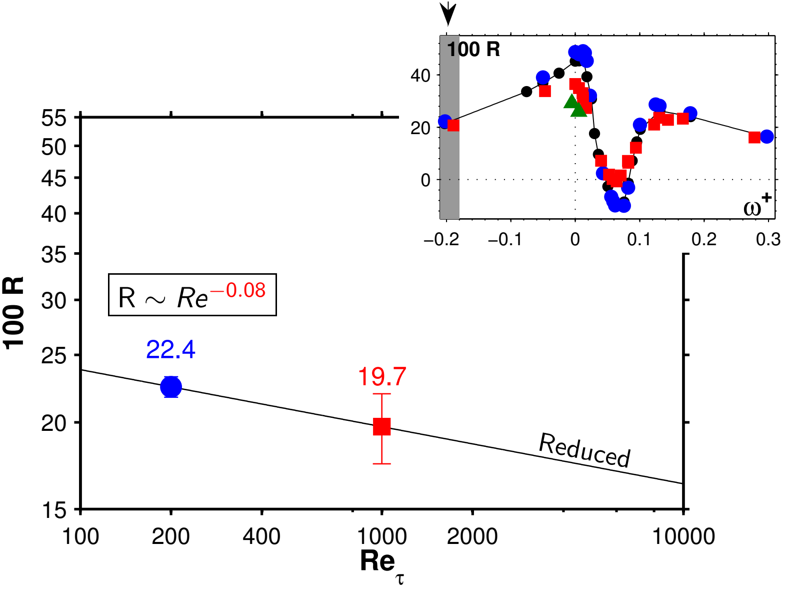
$\lambda_x^+ = 1256$



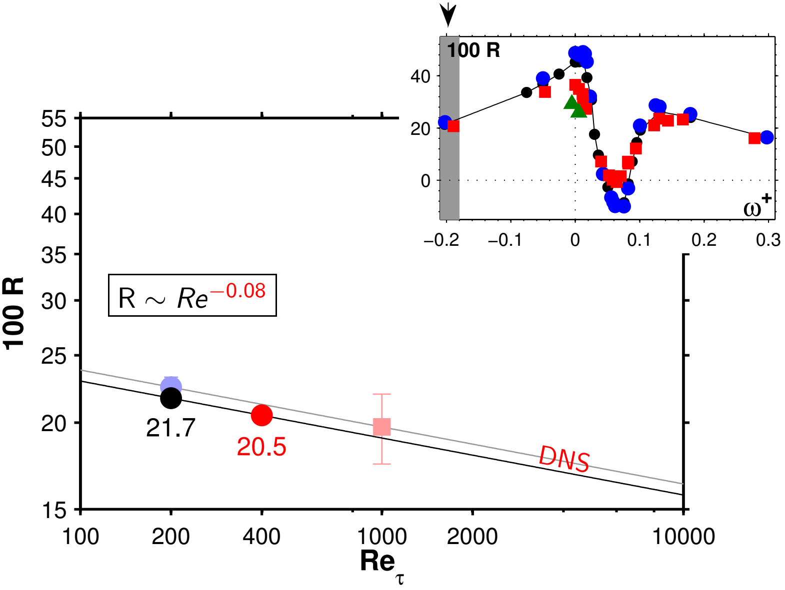
Reynolds effect



Reynolds effect



Reynolds effect



"Conclusions"

$$\mathrm{R} \sim Re_{\tau}^{-0.22}$$

"Conclusions"

...or even better!

$$R \sim Re_{\tau}^{-0.08}$$

S increases with *Re*

A broader result

Need for extensive parametric studies

focusing on optimal parameters gives a limited view!

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Box size

$$L_x^+ = 1000 \div 2000 \qquad L_z^+ = L_x^+/2$$

Criteria:

- "Healthy" turbulence up to y_d apart from wall
  if $L_z^+ = 3y_d^+$ and $L_x^+ \approx h^+$
  (Florez and Jiménez, PoF 2010)
- At least one wavelength long $L_x = 2\pi/\kappa_x$

Simulation data

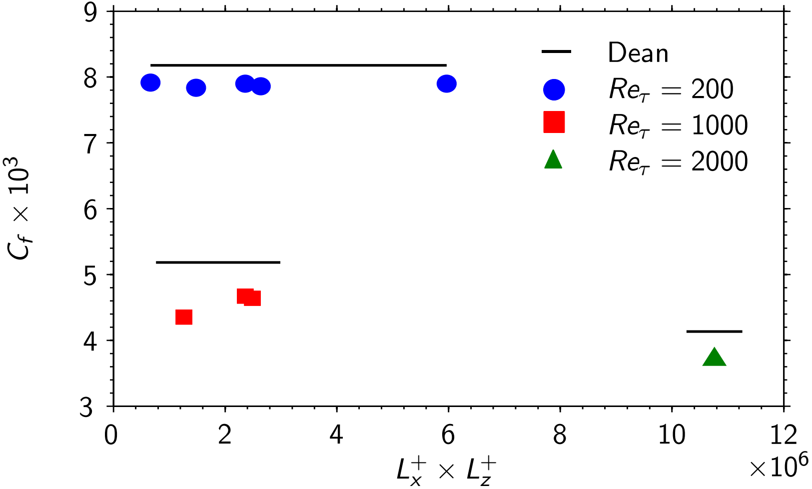
Simulation time: $T^+_{sim} = 12000 \div 24000$

Resolution: $\Delta x^+ = \Delta z^+ = 10 \qquad \Delta y^+ < 4$

Grid points: $128 \times Re_\tau/2 \times 64 \qquad 192 \times Re_\tau/2 \times 96$

Effects on wall skin friction

Fixed wall



Effects on input power

$\kappa_x = 0$