What happens to turbulent drag reduction at higher Re ?

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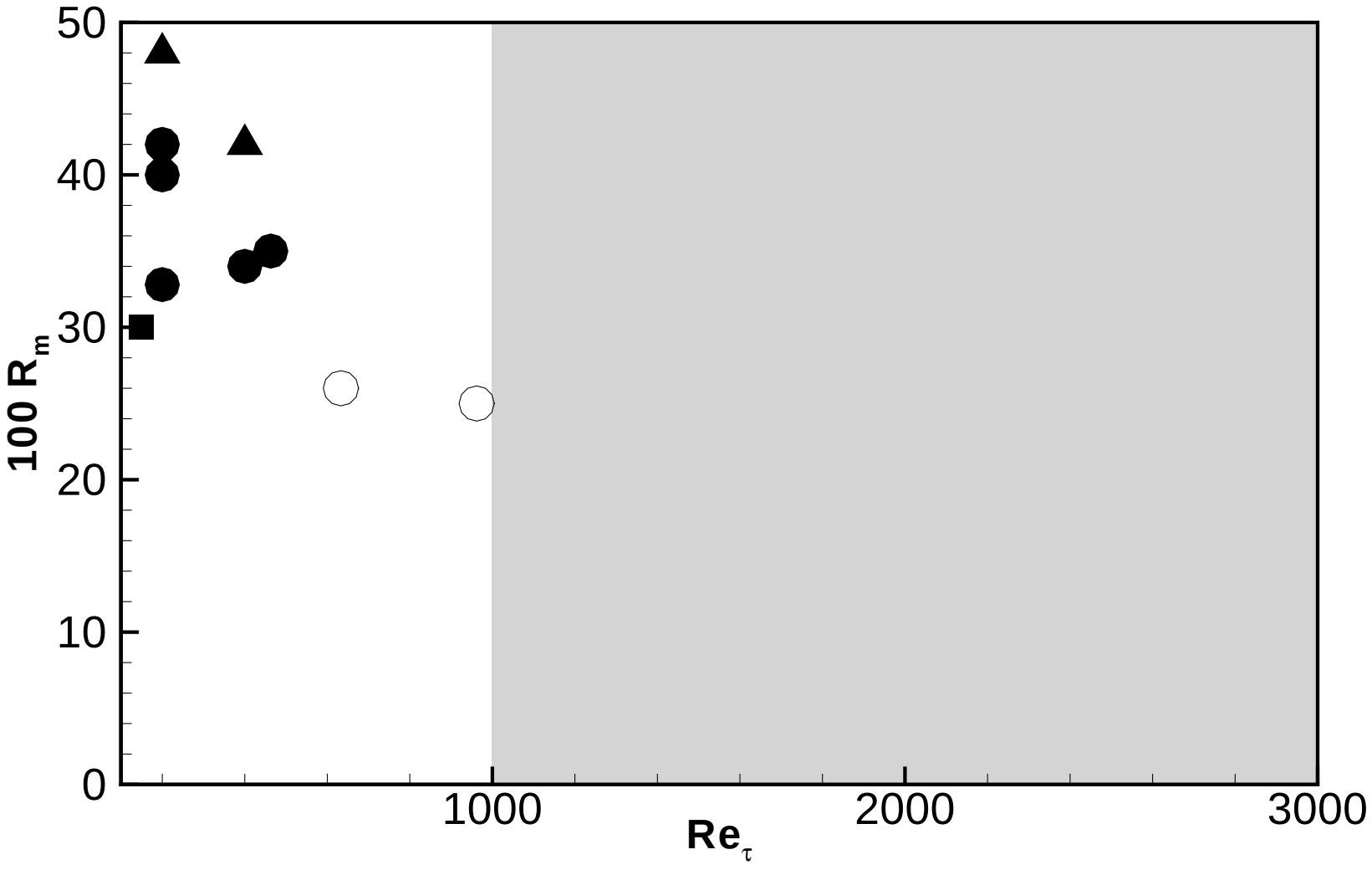
Skin-friction drag reduction and high Re

- Several techniques are under development
- DNS and experiments at low Re, applications at high Re
- Focus on active techniques, spanwise forcing
- Drop of max. drag reduction R_m as Re grows (data for $200 < Re_\tau < 1000$)
- Literature (Choi AIAA J. 02, Touber JFM12) suggests

$$\boxed{R_m \sim Re_\tau^{-0.20}}$$

What happens at high Re?

Numerical / experimental information for spanwise forcing



What happens at high Re?

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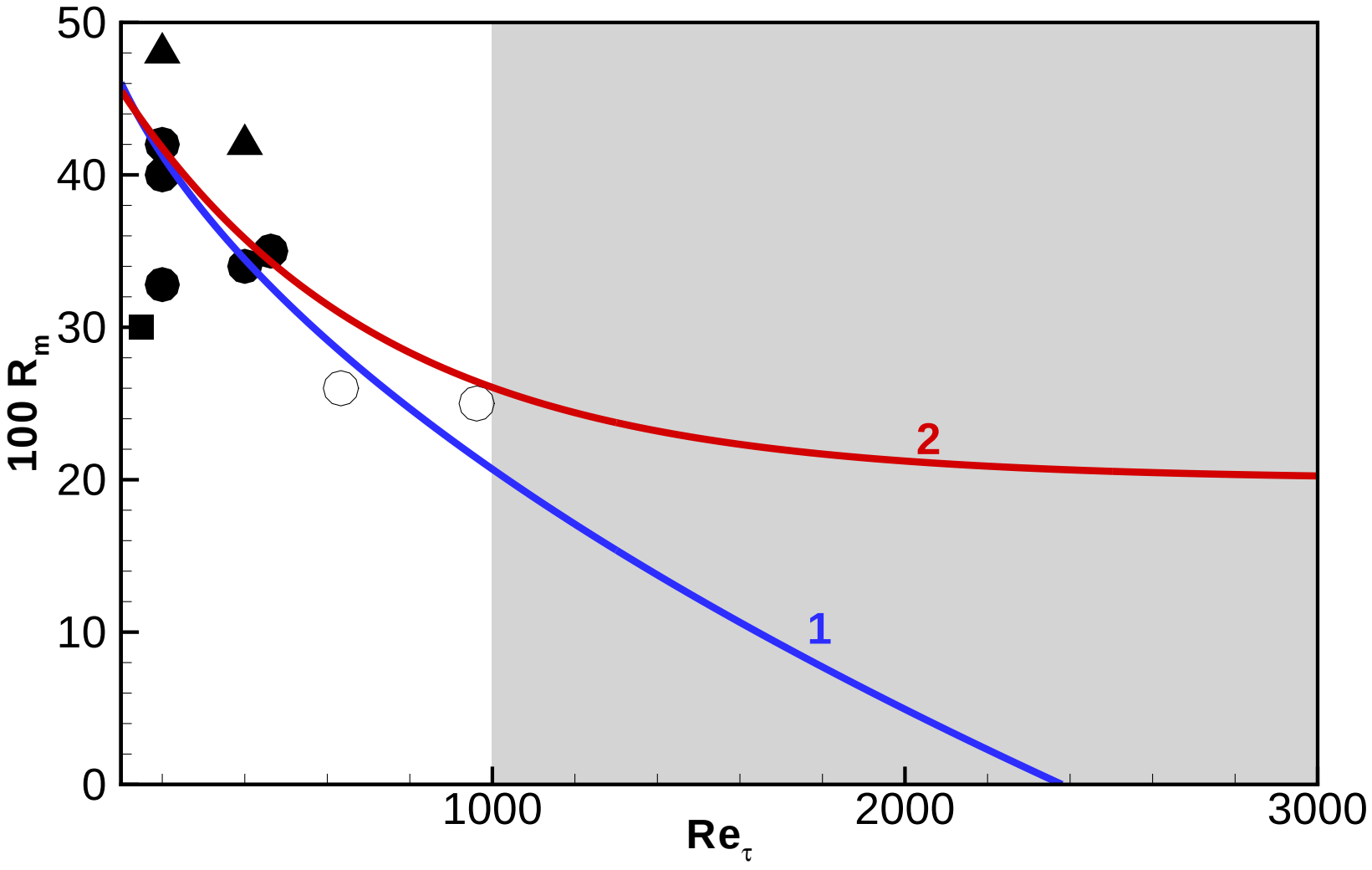
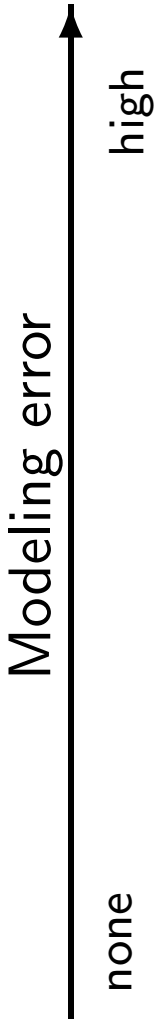


Several attack strategies



RANS — exceeds present modeling skills

LES — we did non succeed with standard models

Touber JFM 2012 :
high computational cost

DNS — prohibitive computational costs
for a parametric study

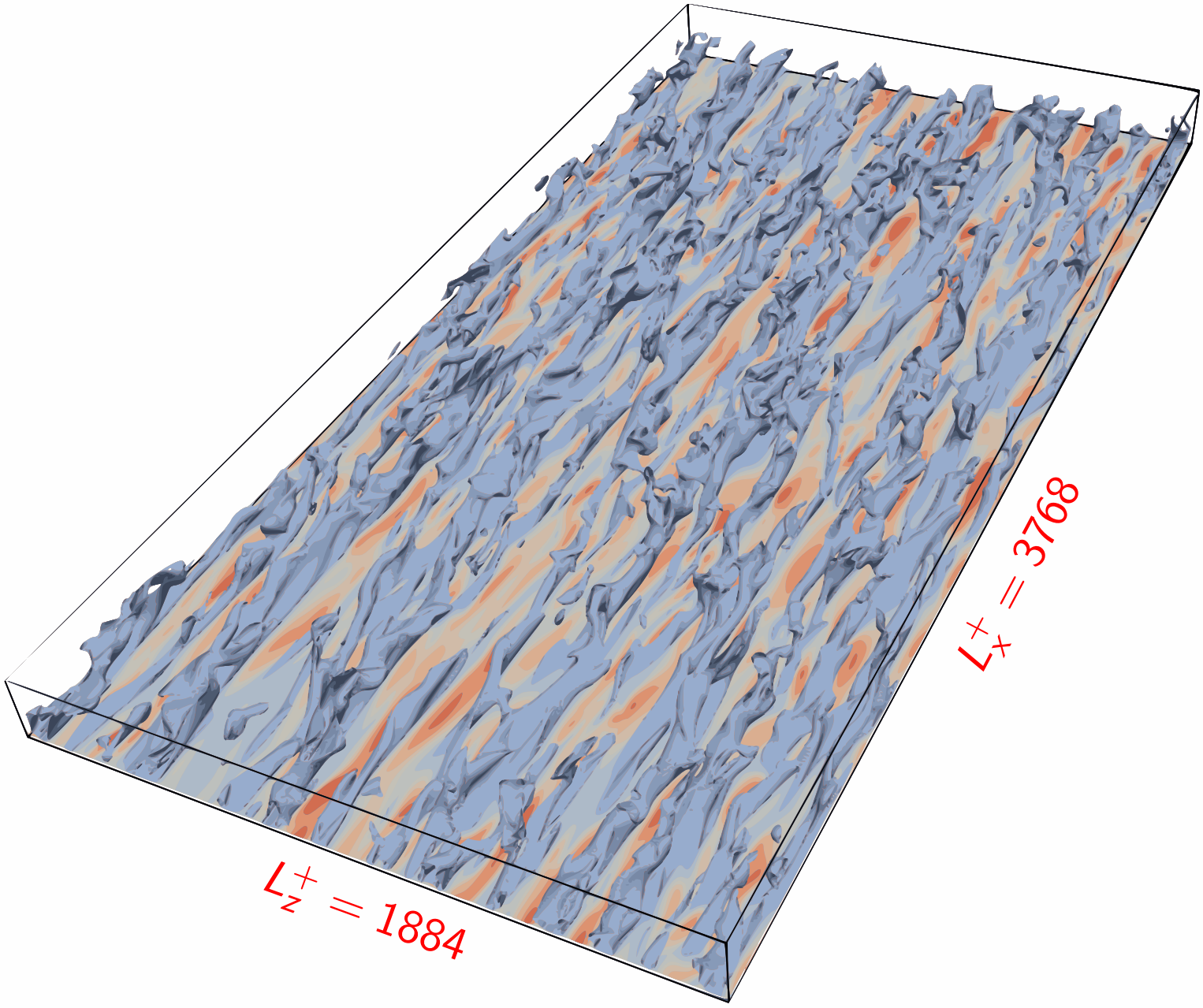
Experiments — difficulties measuring drag, spatial transient

Our workaround

DNS of turbulence in channels of reduced size

- No modeling errors (like in full DNS)
- Discretization errors like in full DNS, but...
- ...truncation of large scales is potentially larger!

Neither minimal nor full



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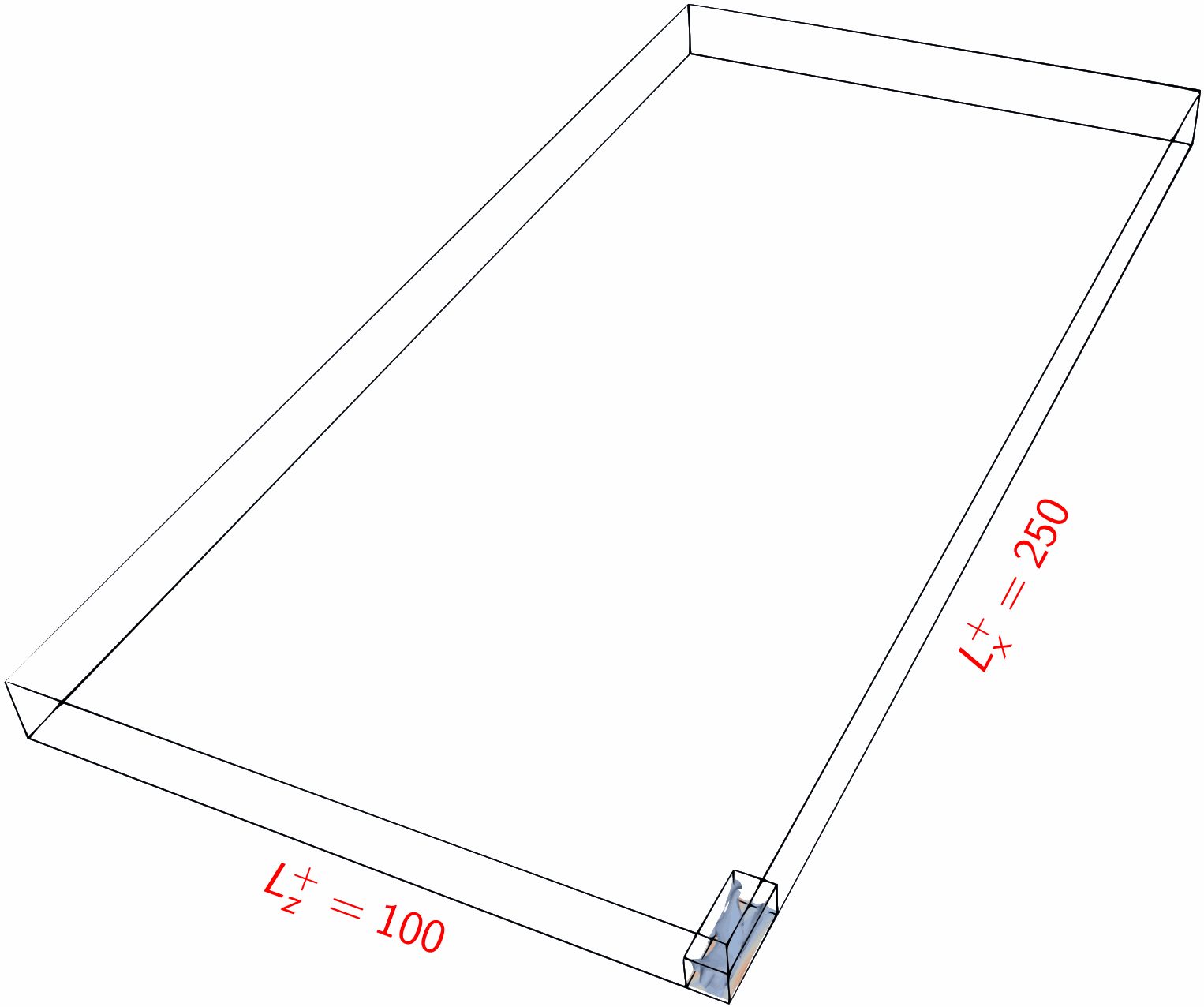

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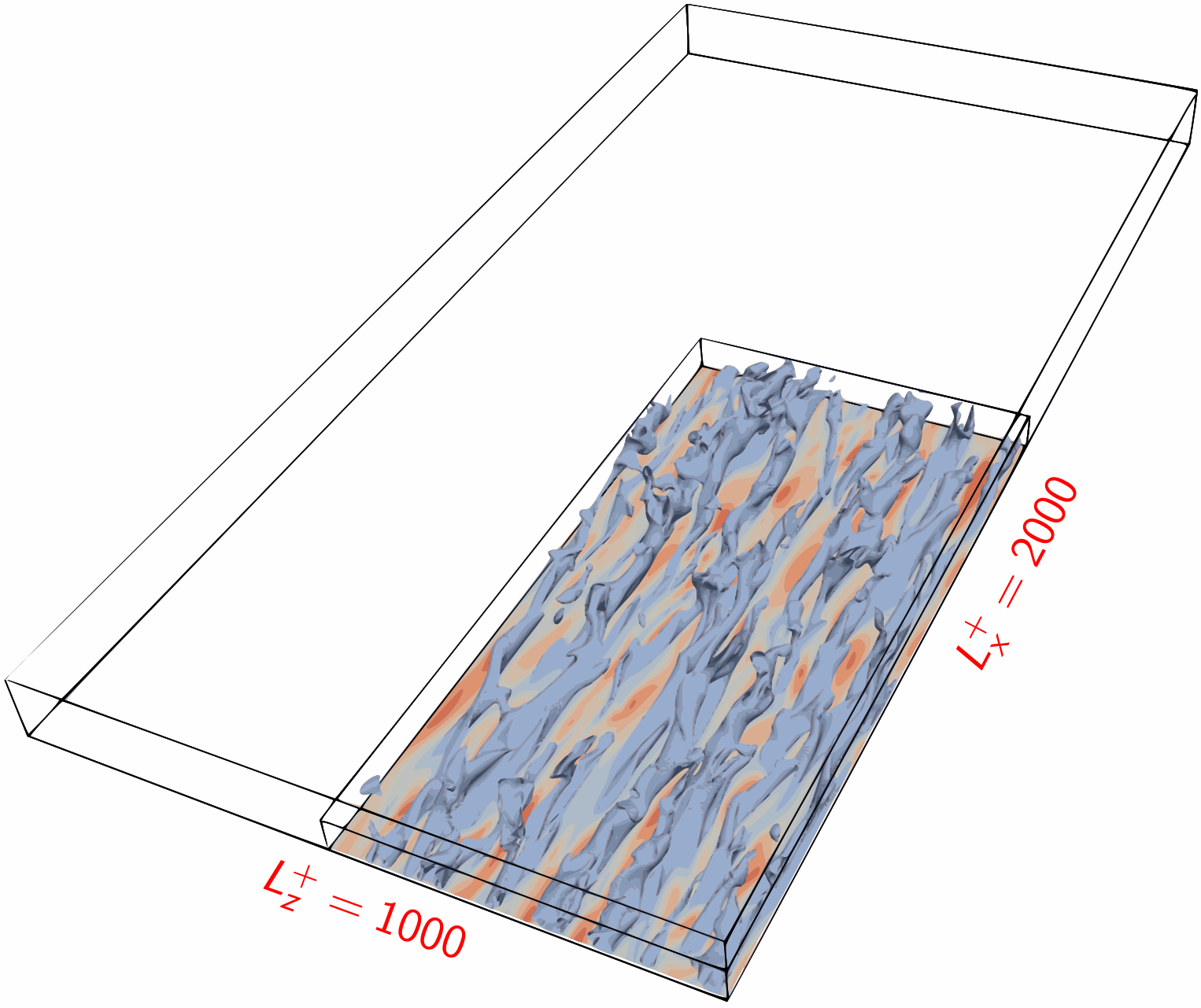
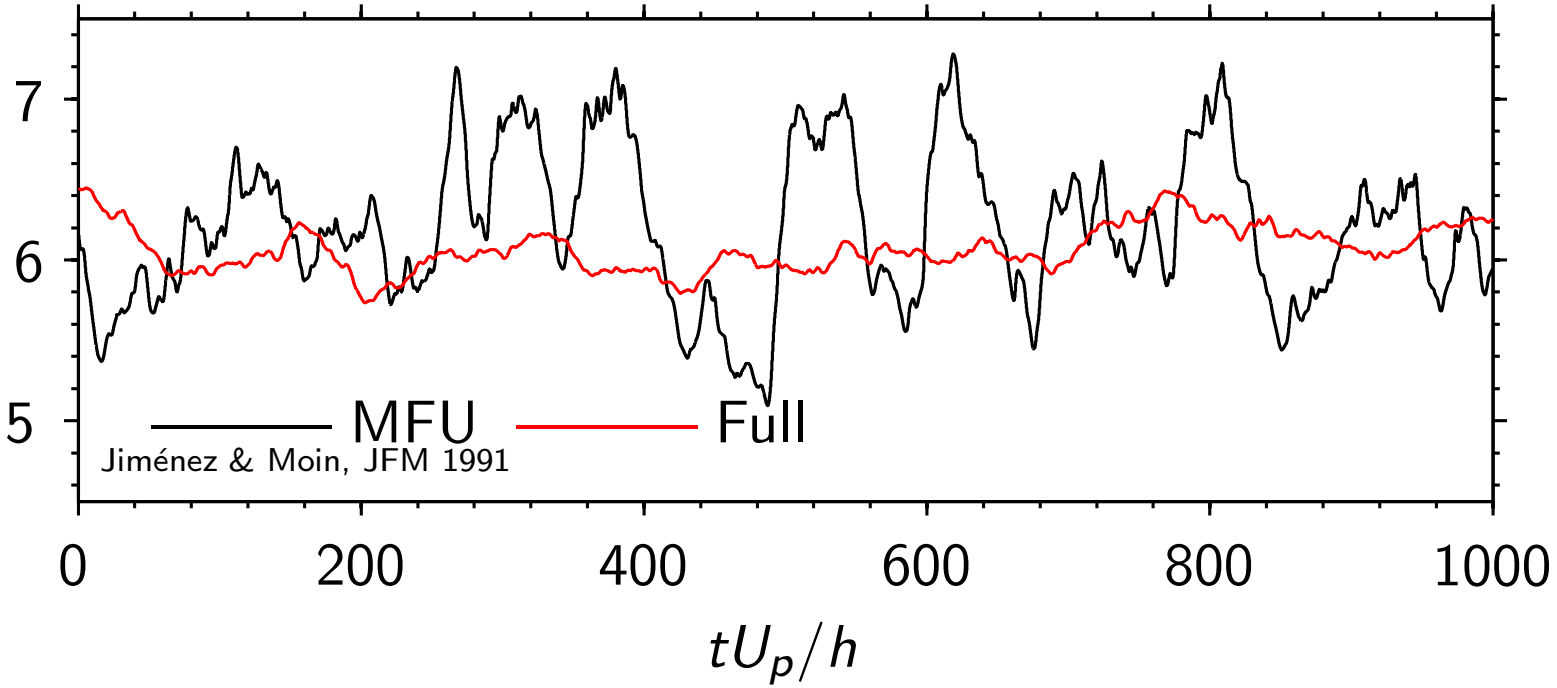


Choosing the simulation time

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

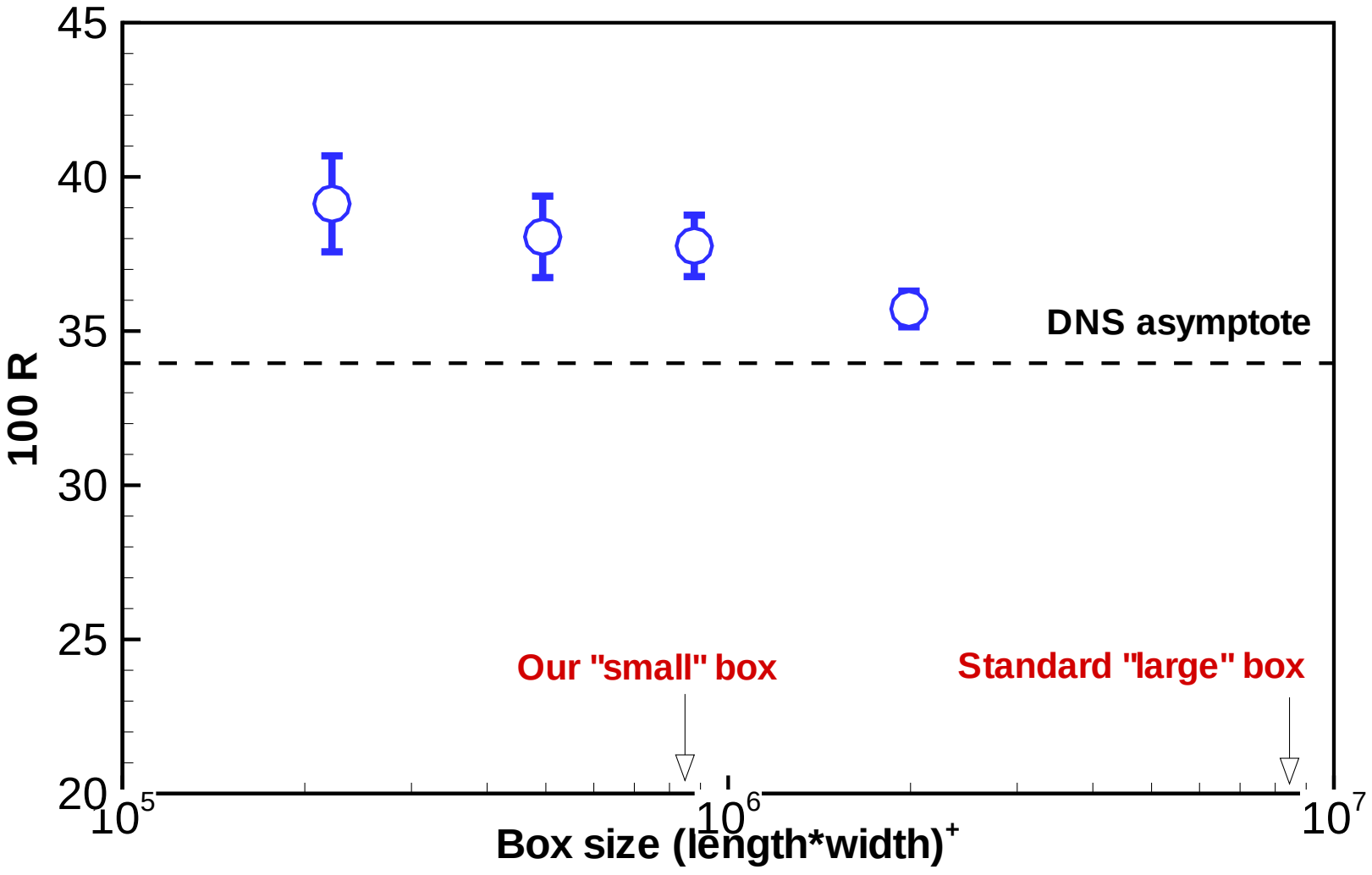


Need to compromise between space and time average

$$\sigma_{\overline{\Omega}} = C \frac{\sigma_\Omega}{\sqrt{T_{sim}}}$$

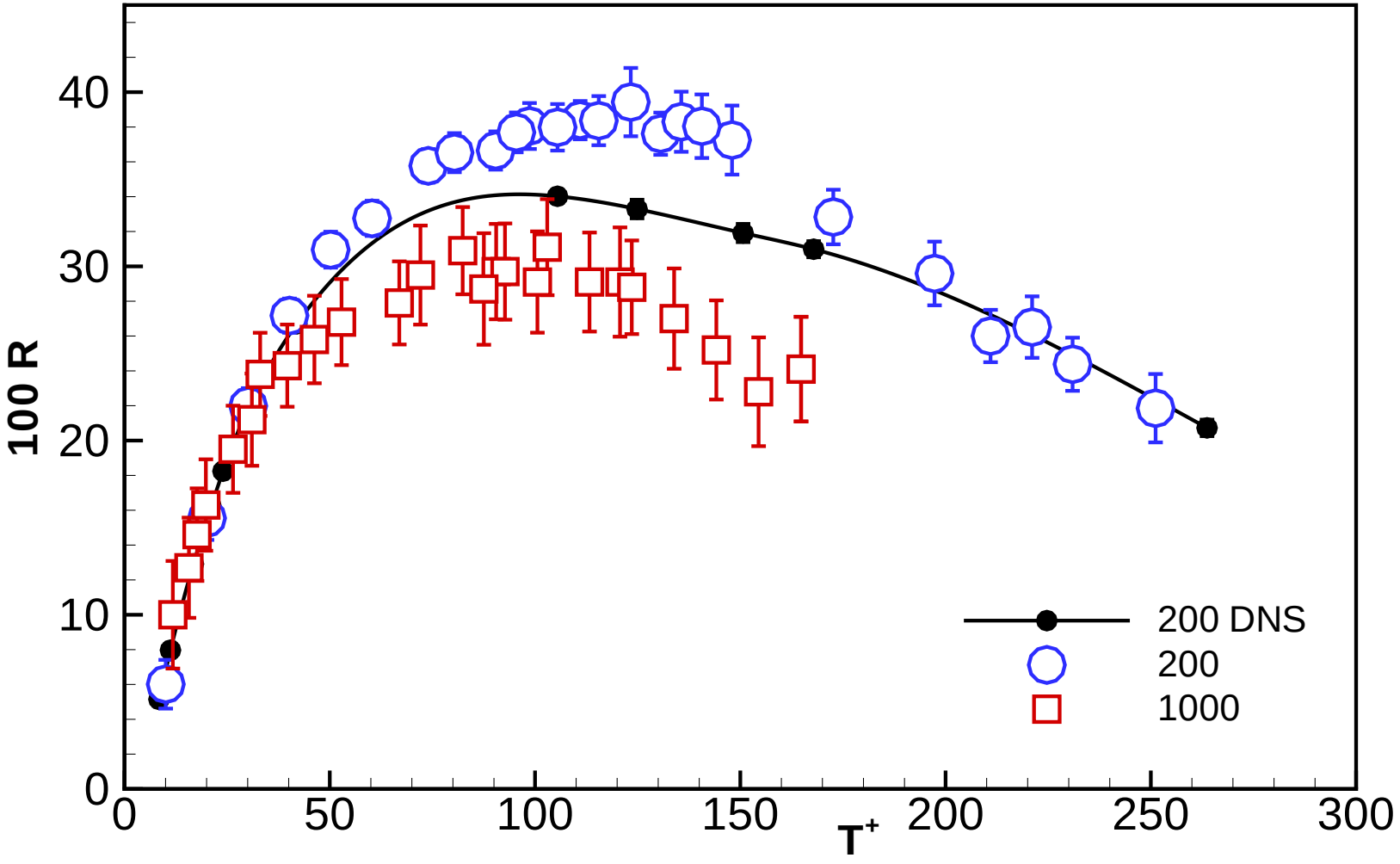
Drag reduction with error bars

(oscillating wall, $A^+ = 12$, $T^+ = 125$)



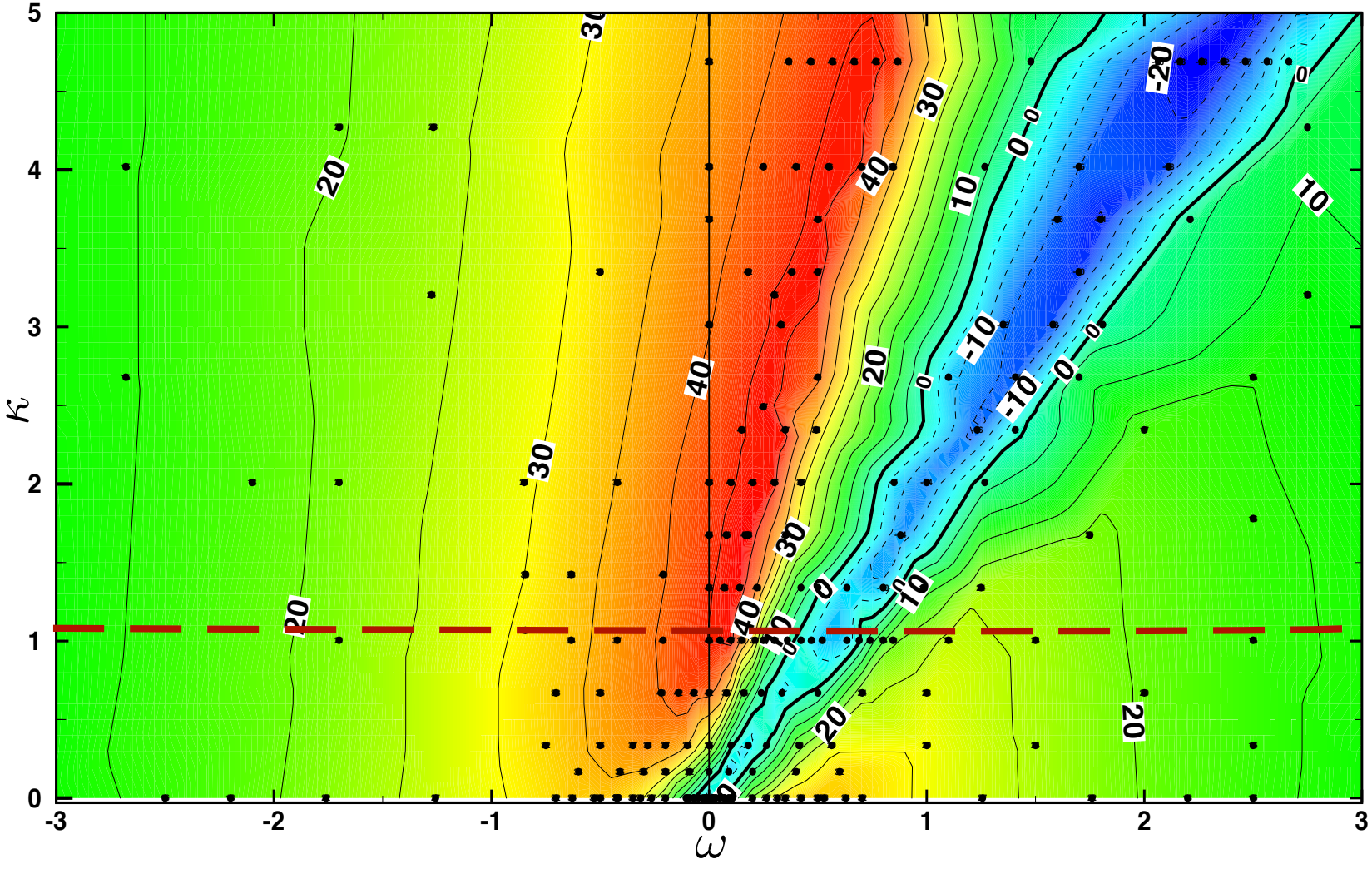
The oscillating wall, up to $Re_\tau = 1000$

$A^+ = 12$



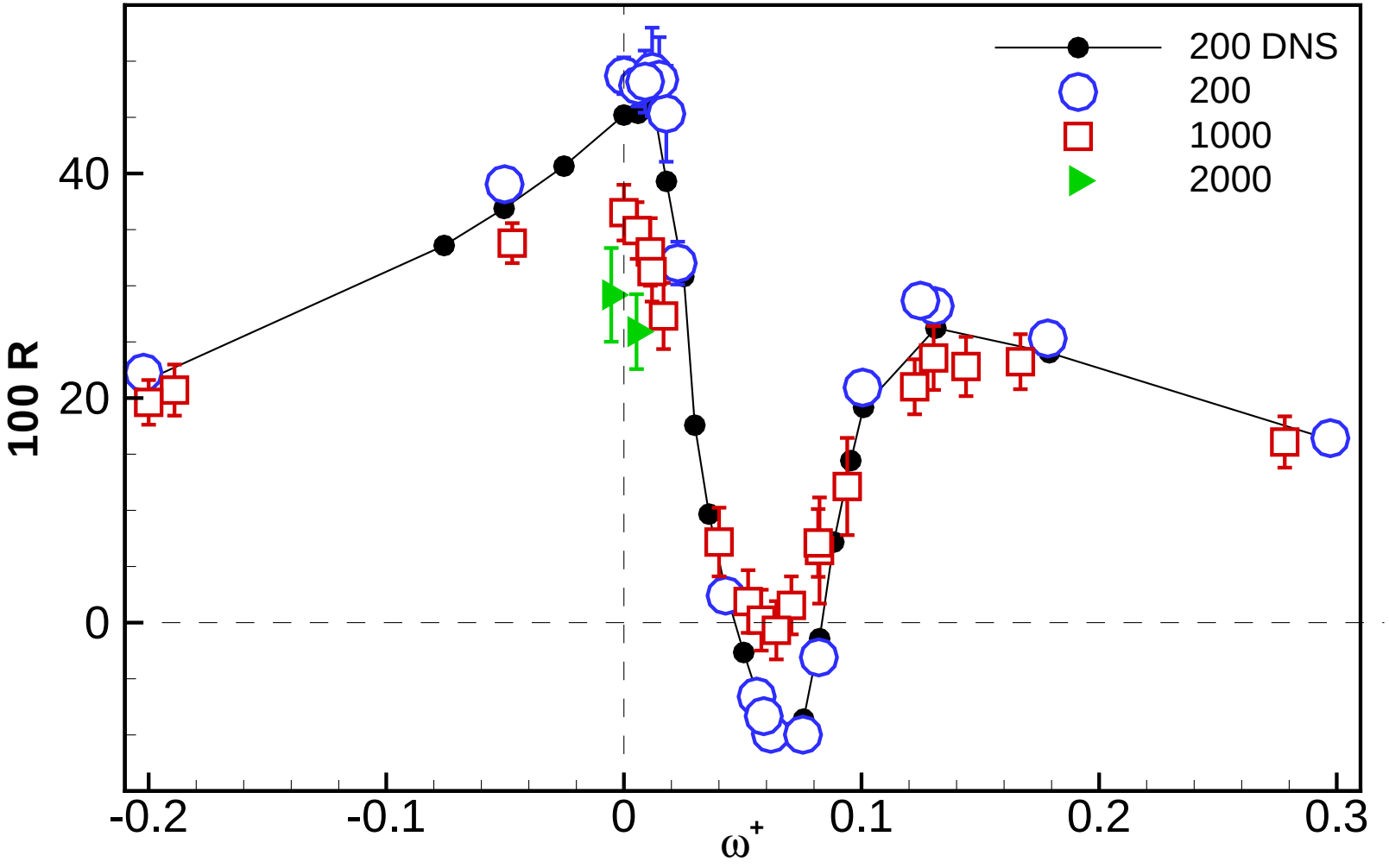
The travelling wave

$A^+ = 12, \lambda_x^+ = 1256$

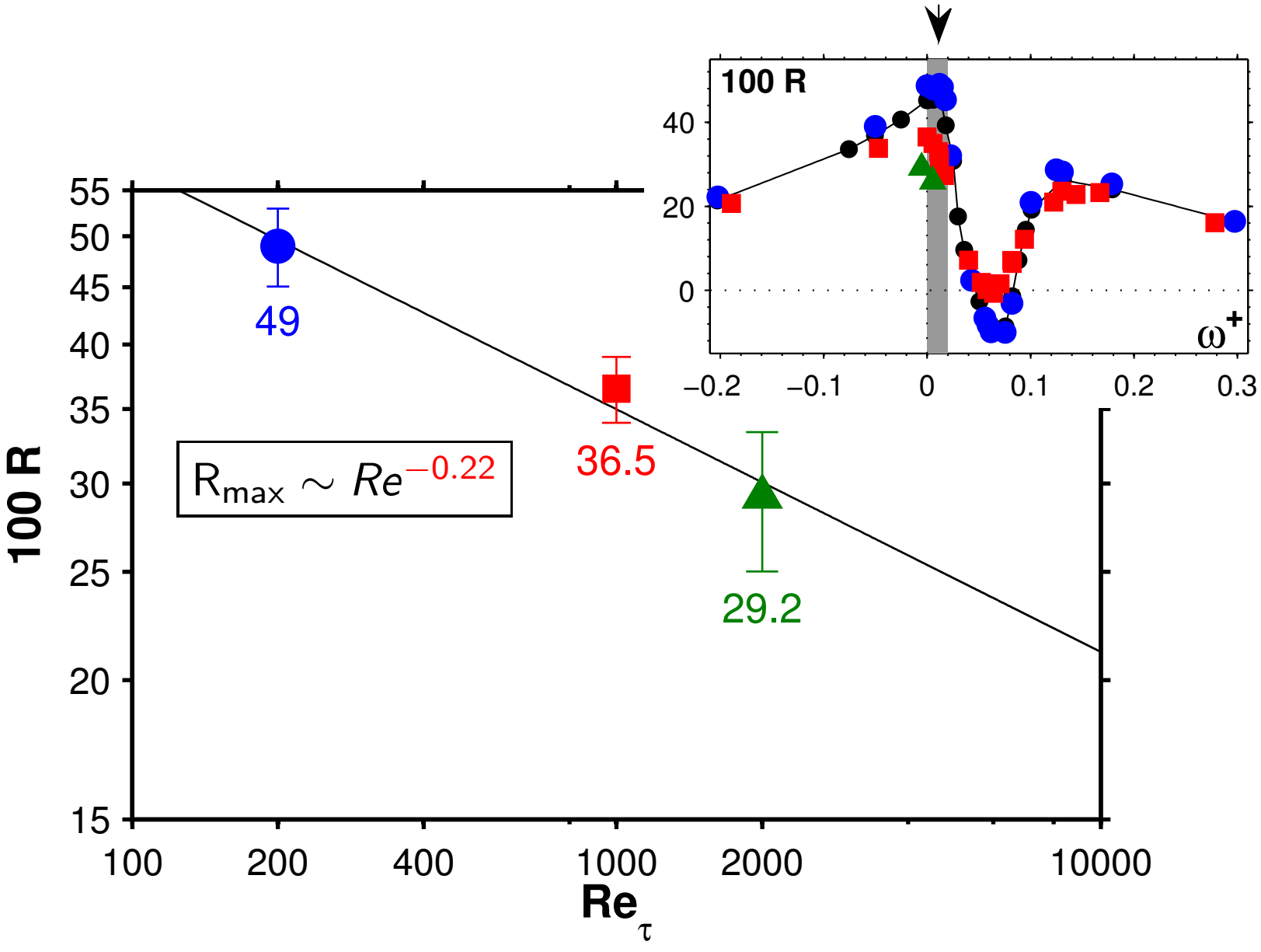


The travelling wave, up to $Re_\tau = 2000$

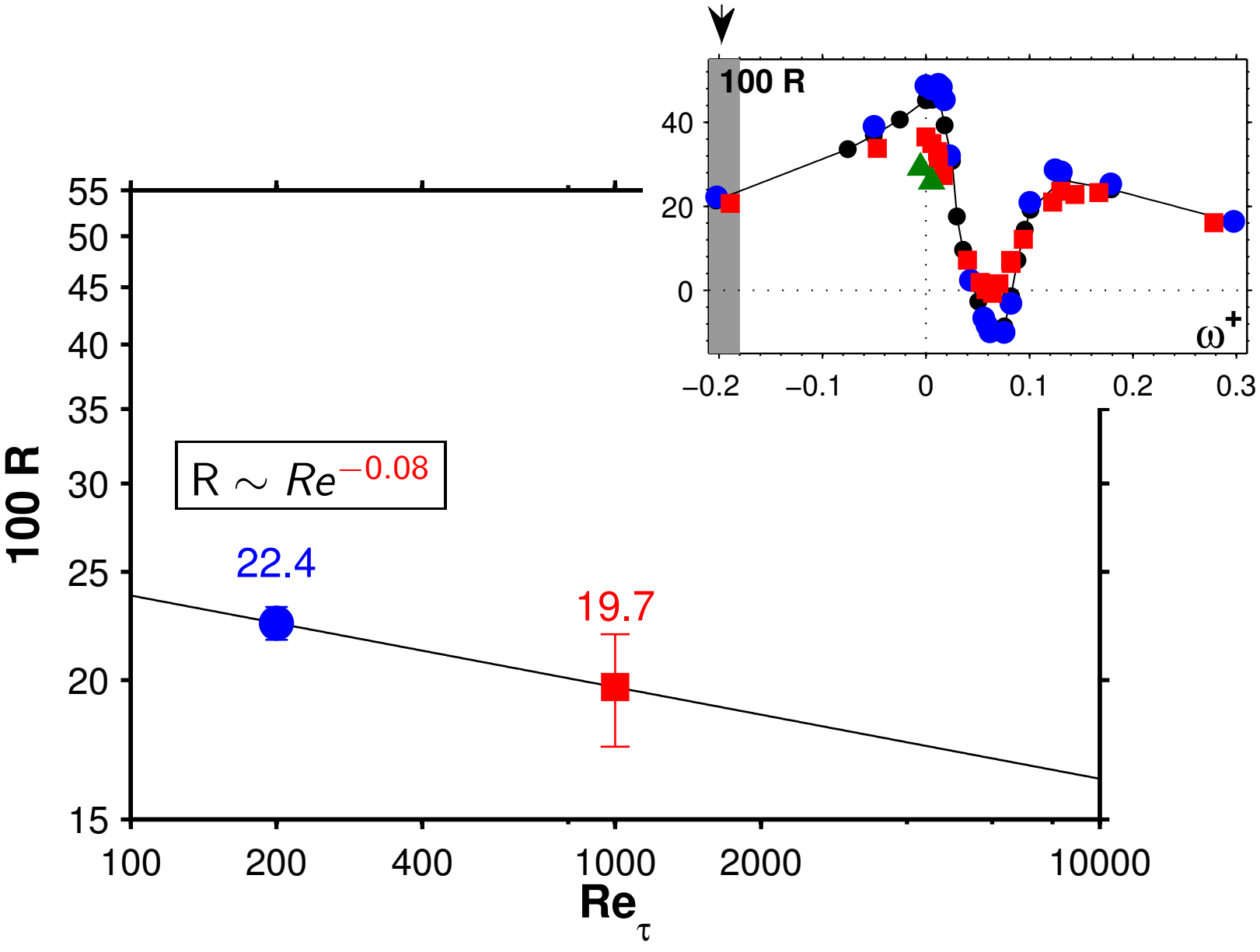
$A^+ = 12, \lambda_x^+ = 1256$



Effect of Re: maximum R



Effect of Re: region at high-ω

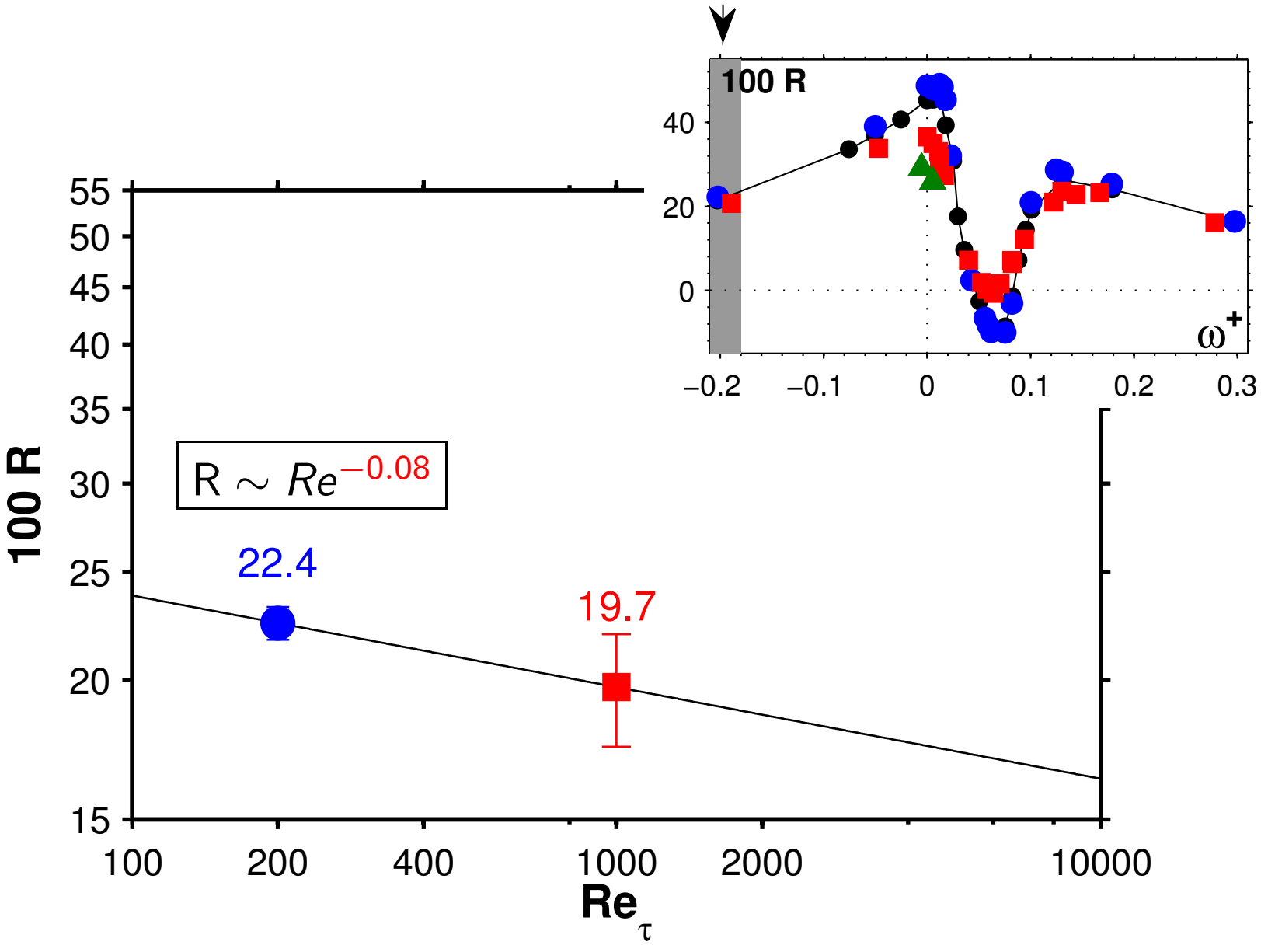


Conclusions

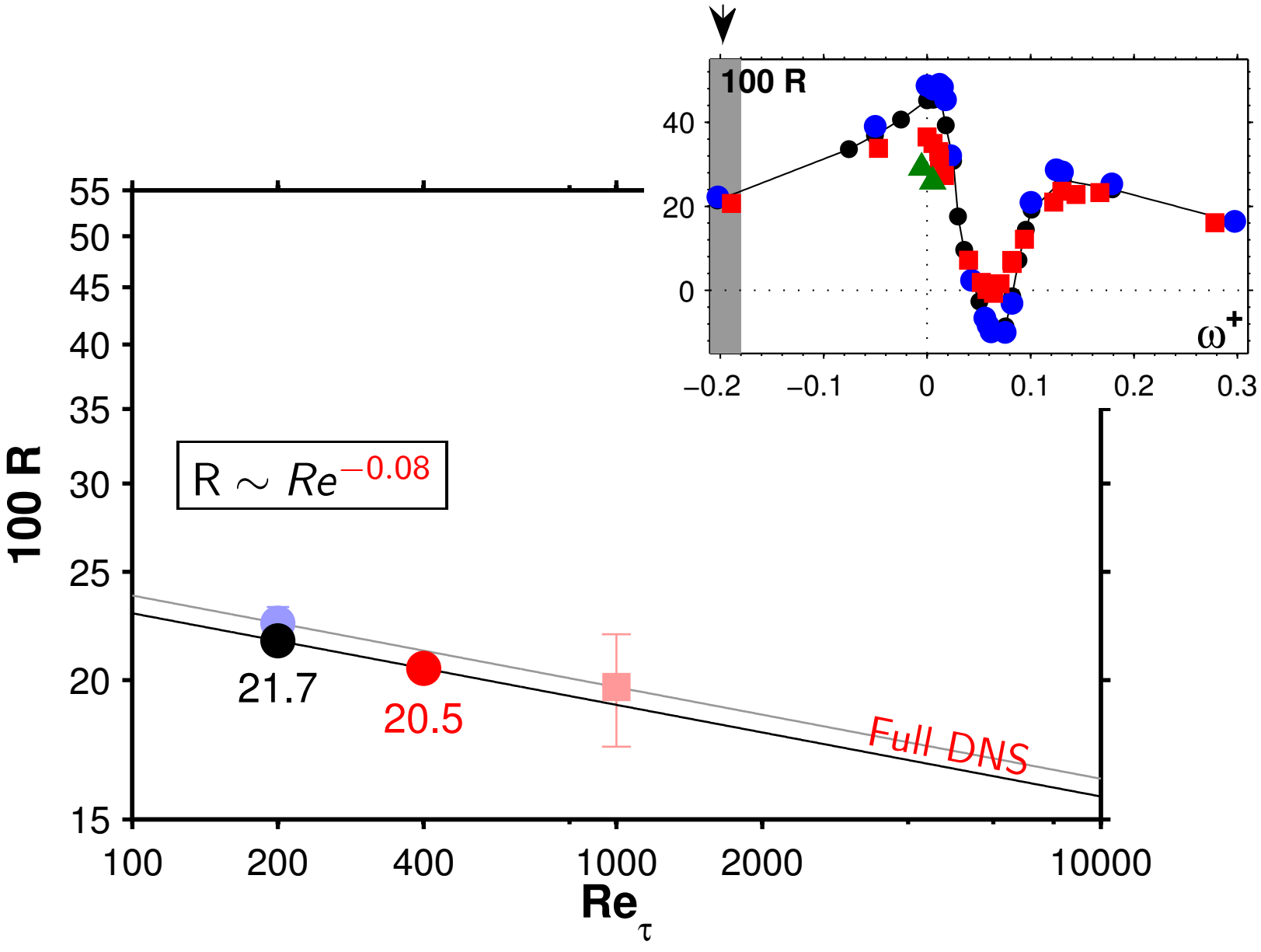
... of suggestive nature!

- Doable strategy for higher-Re parametric studies
- Decreasing trend of max R confirmed: $R \sim Re_\tau^{-0.22}$
- Low-Re effects identified
- More optimistic view: $R \sim Re_\tau^{-0.08}$

Effect of Re: region at high-ω



Full DNS confirms the slow decrease!



Open questions

- Generality?
- What happens at even higher Re?
- How to achieve real (non-suggestive) results?

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

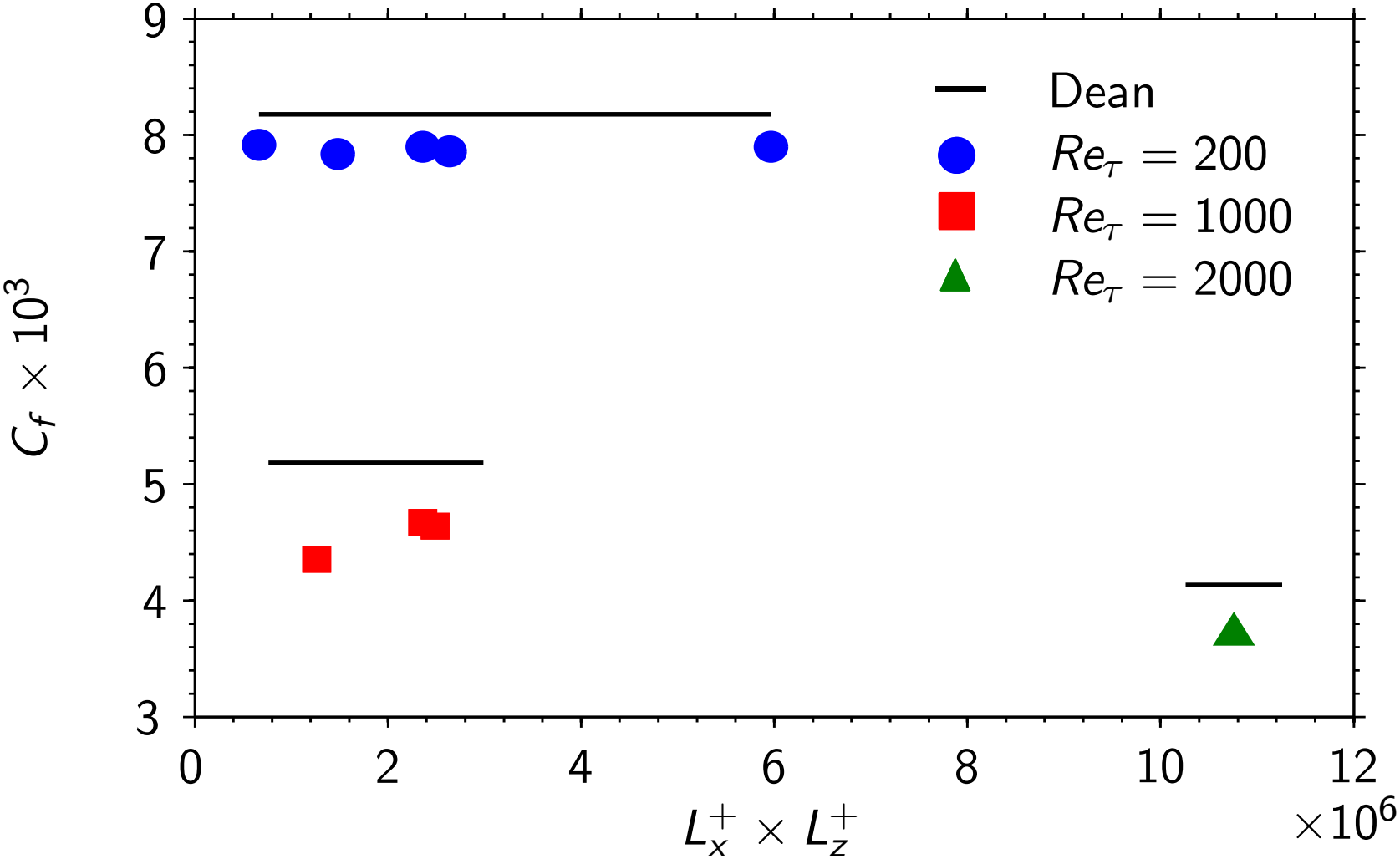
Simulation time: $T^+_{sim} = 12000 \div 24000$

Resolution: $\Delta x^+ = 2\Delta z^+ = 10 \qquad \Delta y^+ < 4$

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

$\kappa_x = 0$