Karlsruher Institut für Technologie

Global power budgets in turbulent Couette and Poiseuille flows

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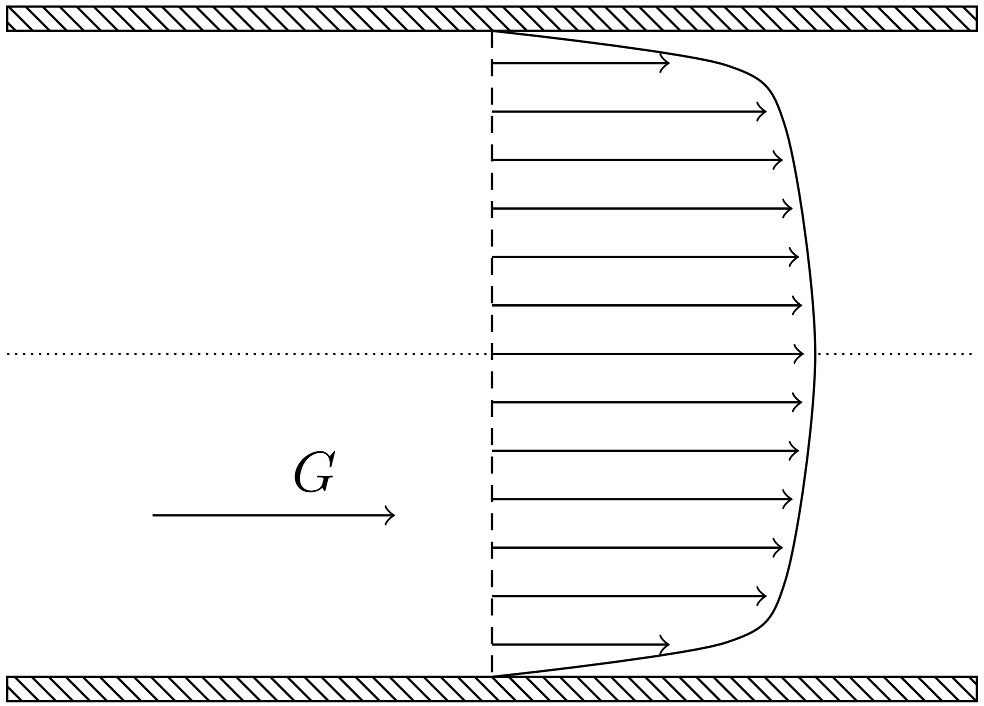
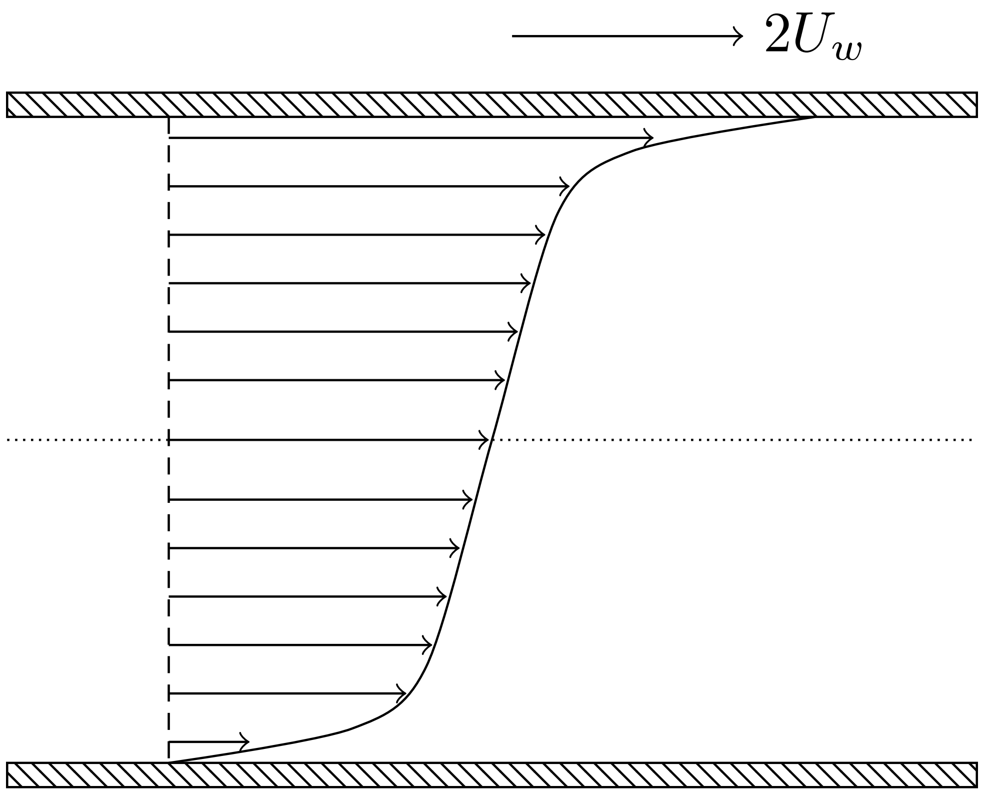




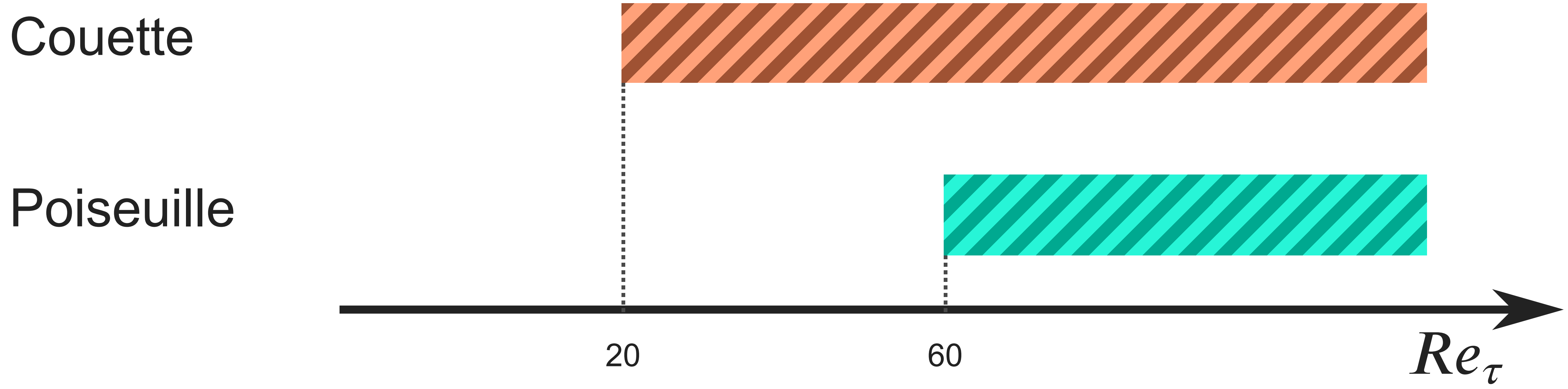
Poiseuille

Couette

FURTHER DIFFERENCES...

Self-sustained turbulence

Source: *Orlandi et al., Poiseuille and Couette flows in the transitional and fully turbulent regime. JFM 2015*



FURTHER DIFFERENCES...

Presence of very-large-scale structures

Source: *Lee, Moser, Extreme-scale motions in turbulent plane Couette flows. JFM 2018*

“Turbulence develops faster with Re_τ in Couette flows”

ISSUES

- Better quantification?
- Comparison at same Re_τ: not really sensible

EFFICIENCY & OVERHEAD

See Gatti et al., Global energy fluxes in fully-developed turbulent channels with flow control. JFM 2018

Objective

CREATE FLOW RATE

Ideal solution

(best cost-effectiveness)

LAMINAR SOLUTION

EFFICIENCY

Or, *laminar dissipation*

$$\Phi^L = \frac{\Pi^L}{\Pi}$$

TURBULENT OVERHEAD

Or, *laminar production*

$$\mathcal{P}^L = 1 - \Phi^L = \frac{\Pi - \Pi^L}{\Pi}$$

Fraction of power that is not strictly necessary to produce a flow rate, but is wasted due to presence of turbulence

TYPES OF OVERHEAD

$$\mathcal{P}^L = \varepsilon + \Phi^\Delta$$

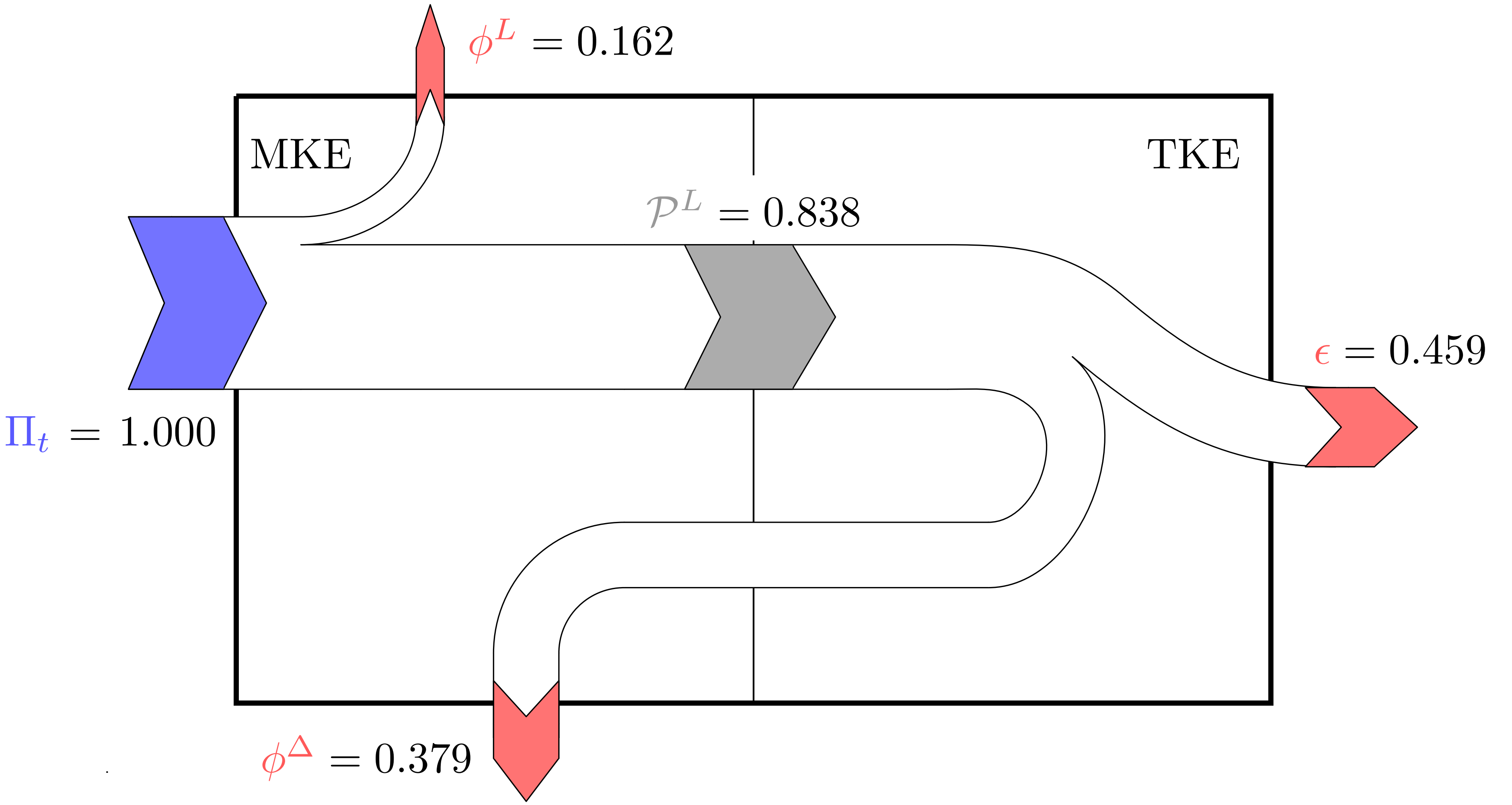
TURBULENT DISSIPATION ε

Directly caused by turbulence

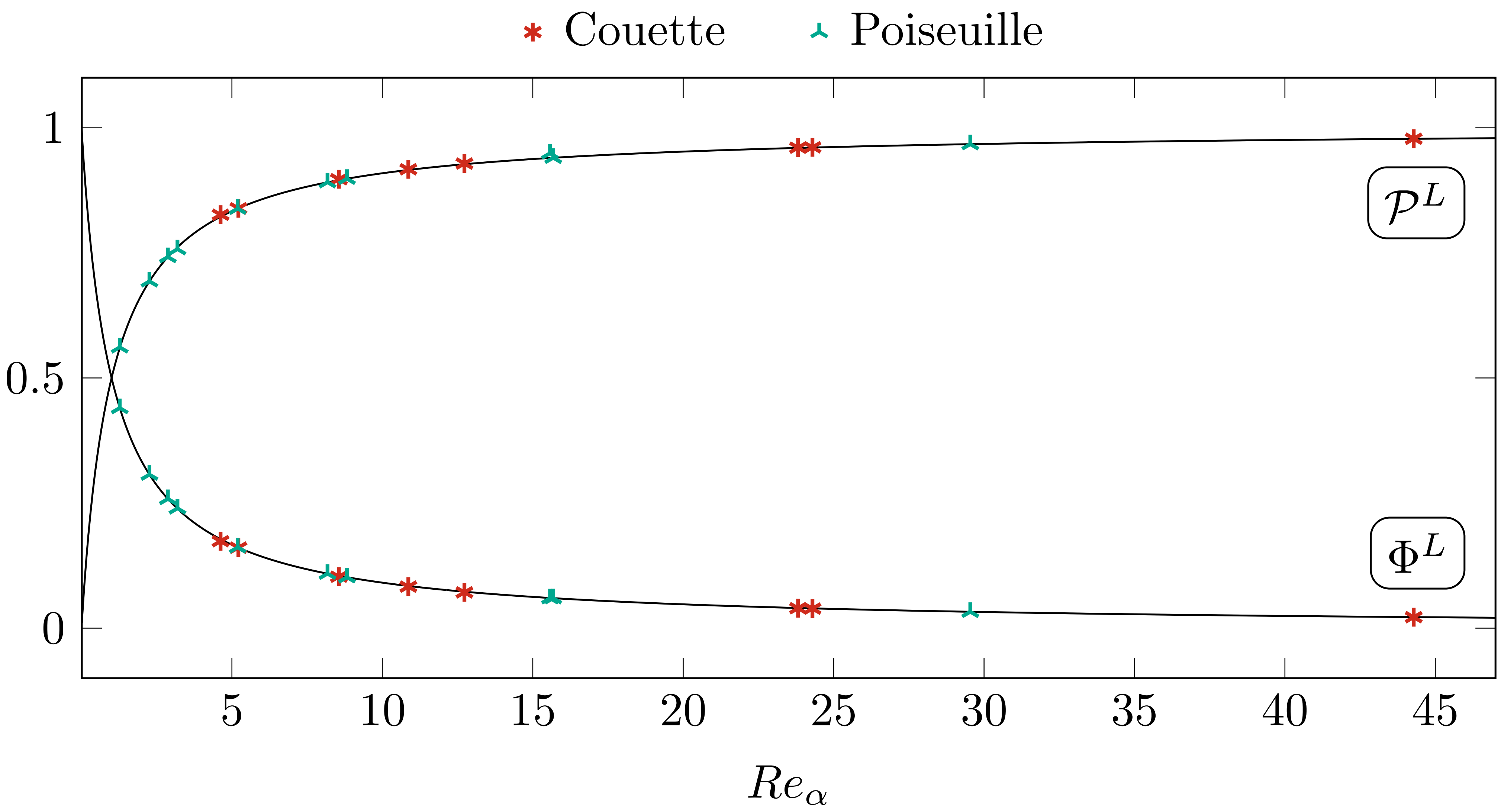
DEVIATION DISSIPATION Φ^Δ

Turbulence **indirectly** induces **deviations in the mean field** from the ideal profile, which cost dissipation

GLOBAL ENERGY BUDGETS



FUNCTIONS OF Re_α



FUNCTIONS OF Re_α

EFFICIENCY

$$\Phi^L = \frac{1}{1+Re_\alpha}$$

OVERHEAD

$$\mathcal{P}^L = \frac{Re_\alpha}{1+Re_\alpha}$$

MORE ABOUT Re_α

$$Re_\alpha = \frac{h}{\nu} \frac{\alpha}{U_b}$$

$$\alpha = \int \psi(y) \, (-\langle uv \rangle) \; dy$$

$$\psi(y) = \frac{dU^L}{dy} \Big/ \left(\frac{dU^L}{dy} \right)_{wall}$$

$$Re_\alpha \implies$$ **EFFICIENCY, OVERHEAD**

$$Re_\alpha \Longrightarrow$$ **TURBULENT ACTIVITY**

CONSTANT POWER INPUT

EFFICIENCY

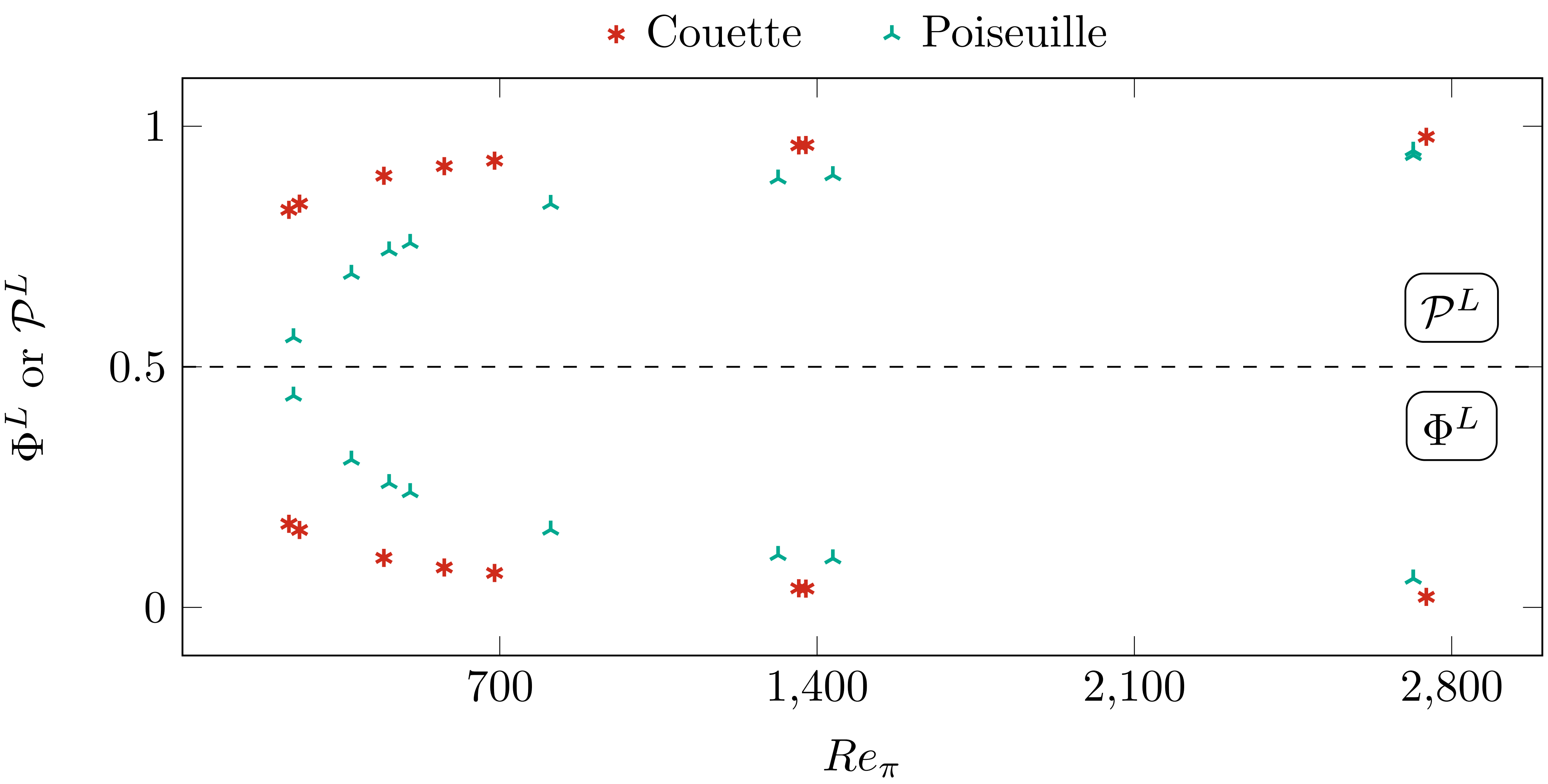
Fraction of power spent in a useful manner.

EFFECTIVENESS

Flow rate produced out of a given power input.

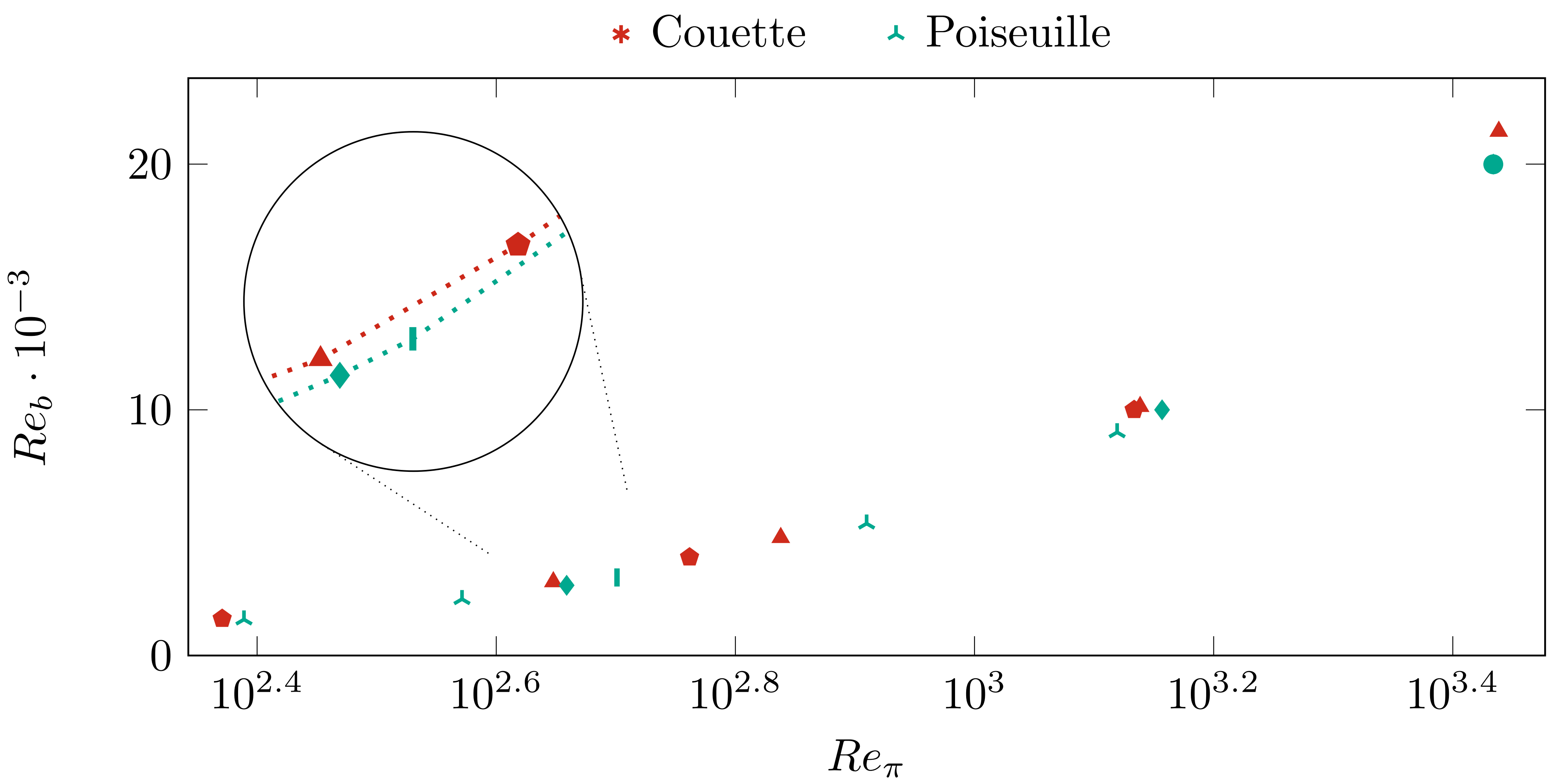
Under **constant power input,**
Couette has **lower efficiency** but **better effectiveness**,
i.e. it produces more flow rate

EFFICIENCY



Couette
Poiseuille
1
0.5
0
700
1,400
2,100
2,800
Φ^L or $\mathcal{P}^L$
Re_π
$\mathcal{P}^L$
Φ^L

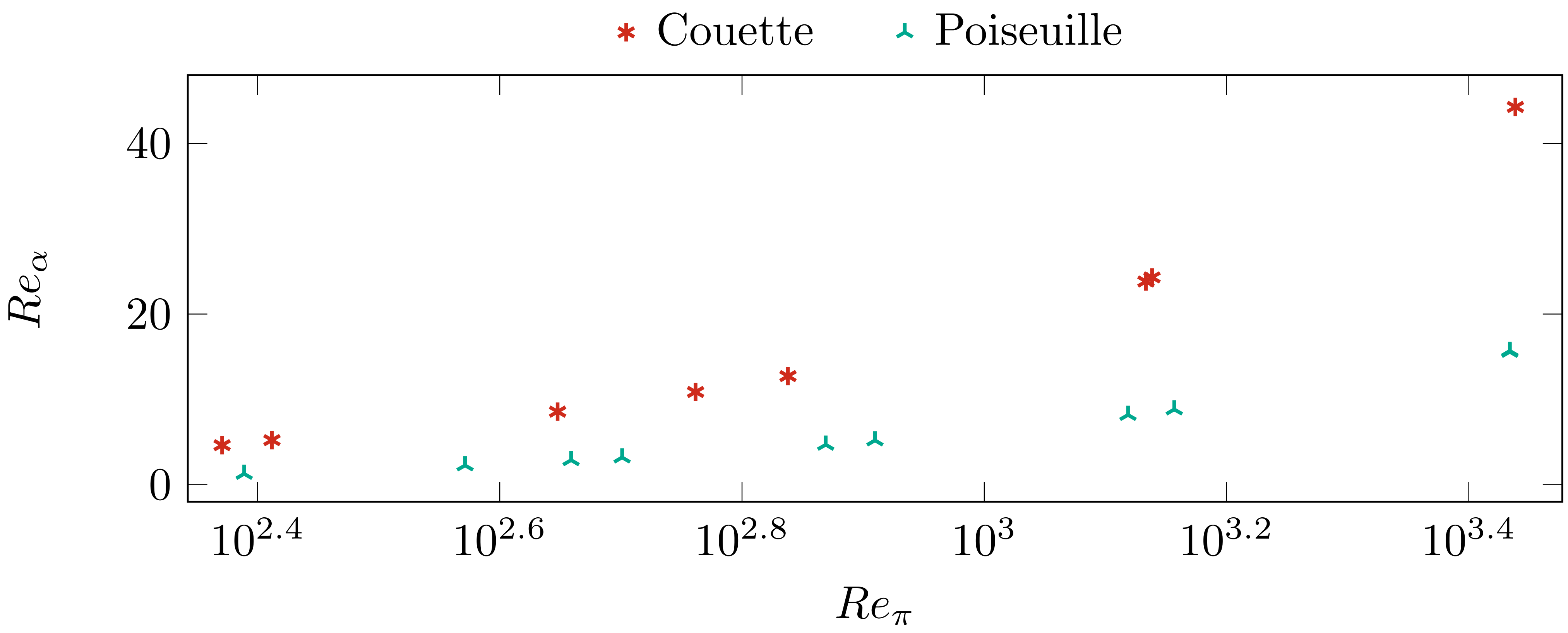
EFFECTIVENESS



WHY?

The **better effectiveness of Couette's laminar solution** compensates for the flow's higher turbulent activity (and consequent wider deviation from the ideal case).

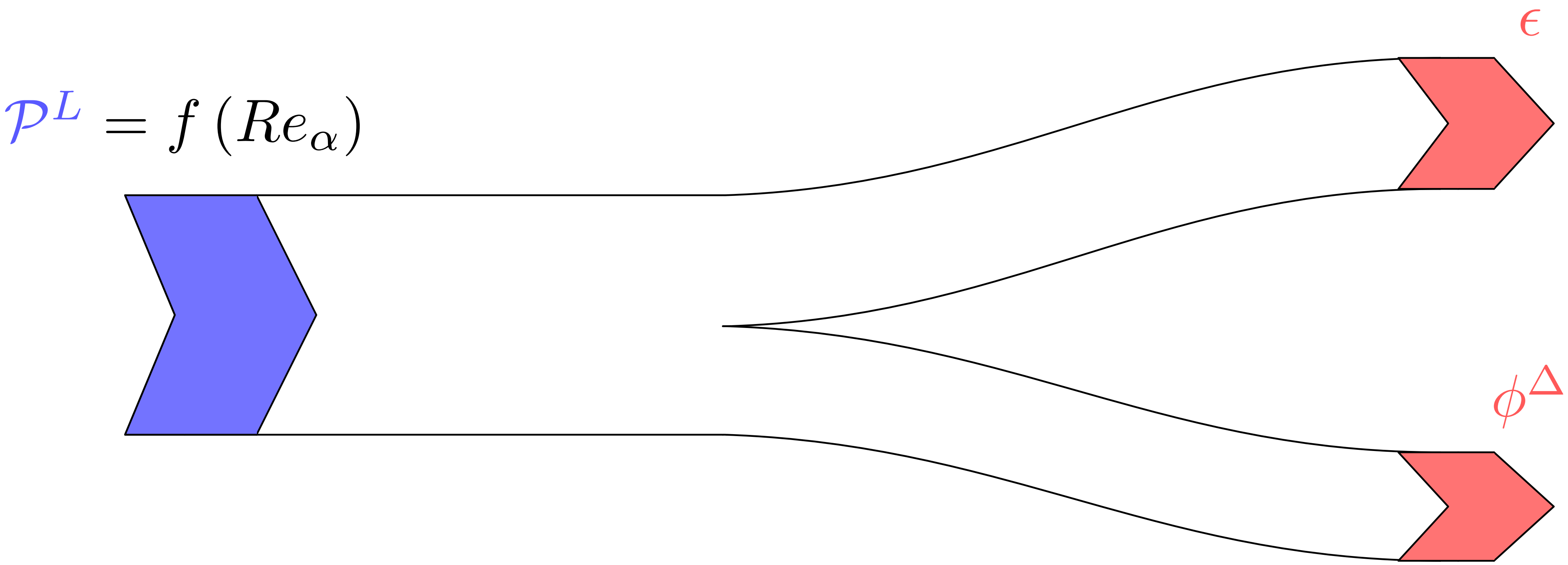
TURBULENT ACTIVITY AT CPI



Similar to comparison at constant Re_τ: different turbulent activity

COMPARISON AT CONSTANT Re_α

PHYSICAL INTERPRETATION



Flows are provided with the same turbulent overhead $\mathcal{P}^L$

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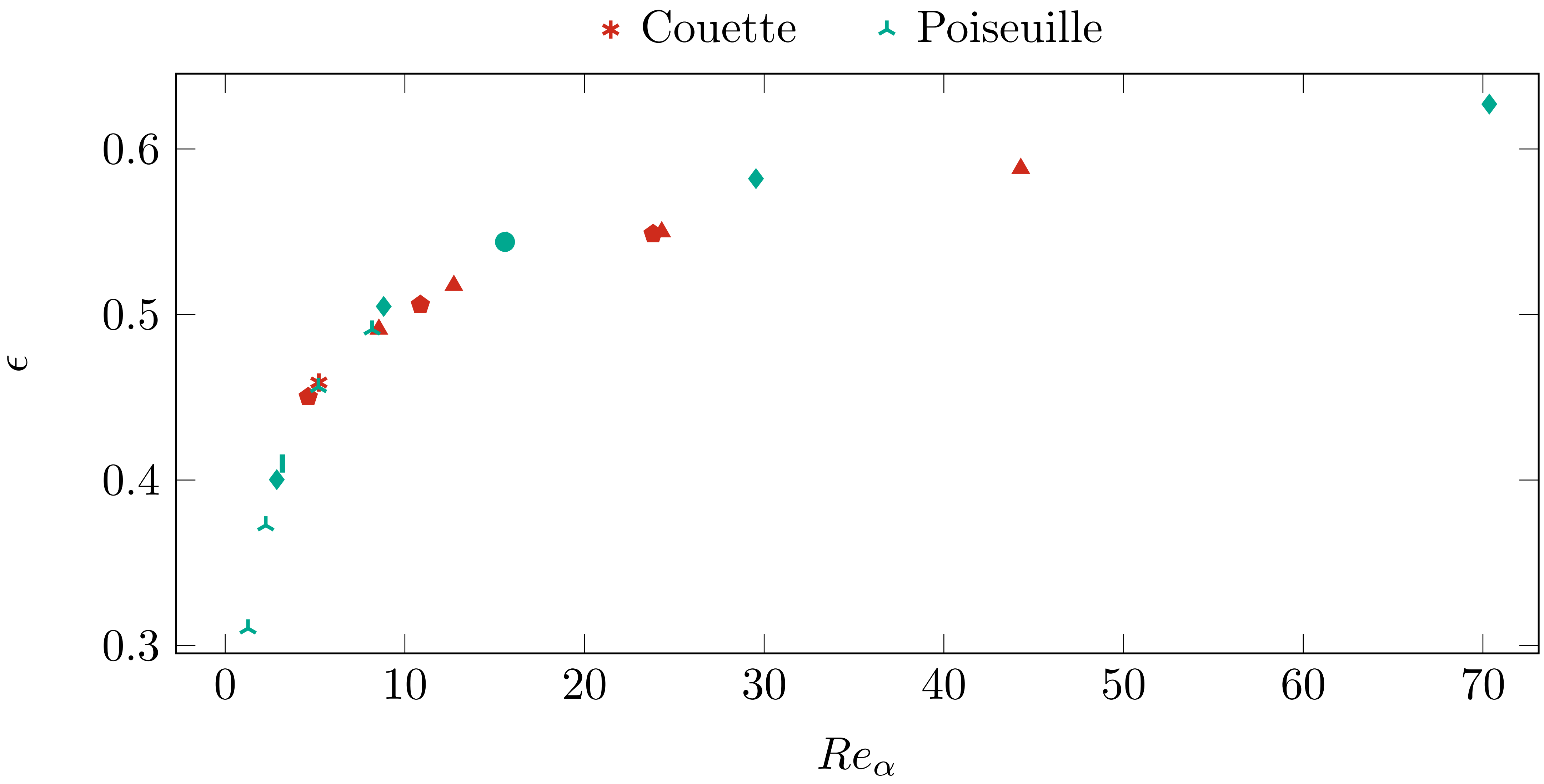
Under **constant turbulent overhead,**
Couette has **lower turbulent dissipation** and
consequently **higher deviation dissipation**.

THE $\epsilon - Re_\alpha$ DIAGRAM



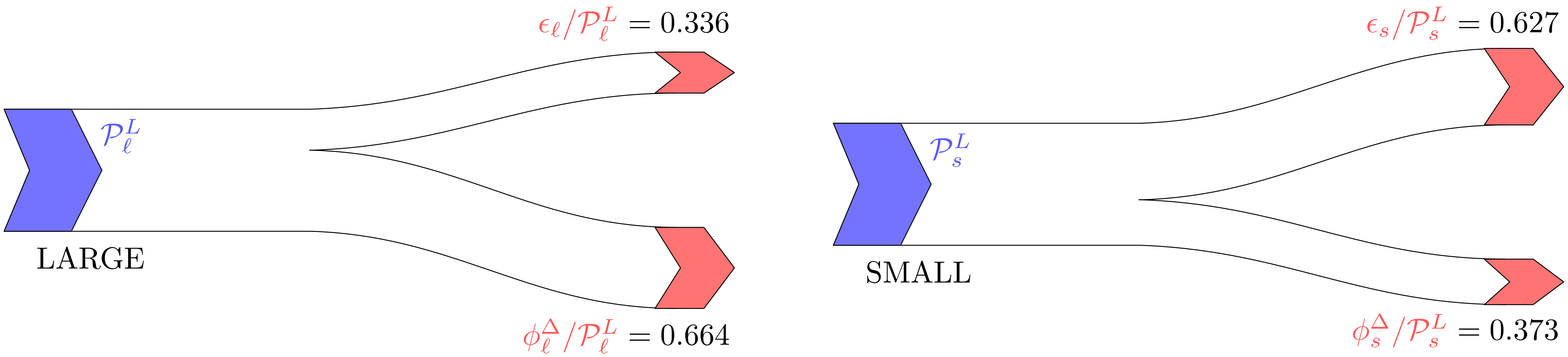
WHY?

Couette develops stronger **large-scale structures**, which:

- provide a low contribution to turbulent dissipation $\Longrightarrow \varepsilon$
- strongly affect the mean field $\Longrightarrow \Phi^{\Delta}$

LARGE-SMALL DECOMPOSITION

Data: Couette, $Re_\tau = 100$



SUMMARISING...

- Re_α quantifies turbulent activity.
- Under CPI, Couette performs better than Poiseuille in absolute terms (thanks to laminar solution), but is less efficient wrt its ideal case (due to higher turbulent activity).
- Large-scale structures in Couette scarcely contribute to turbulent dissipation, but strongly distort the mean field.