Reynolds Number Scaling of Turbulent Channel Flow

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Outline

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- Results
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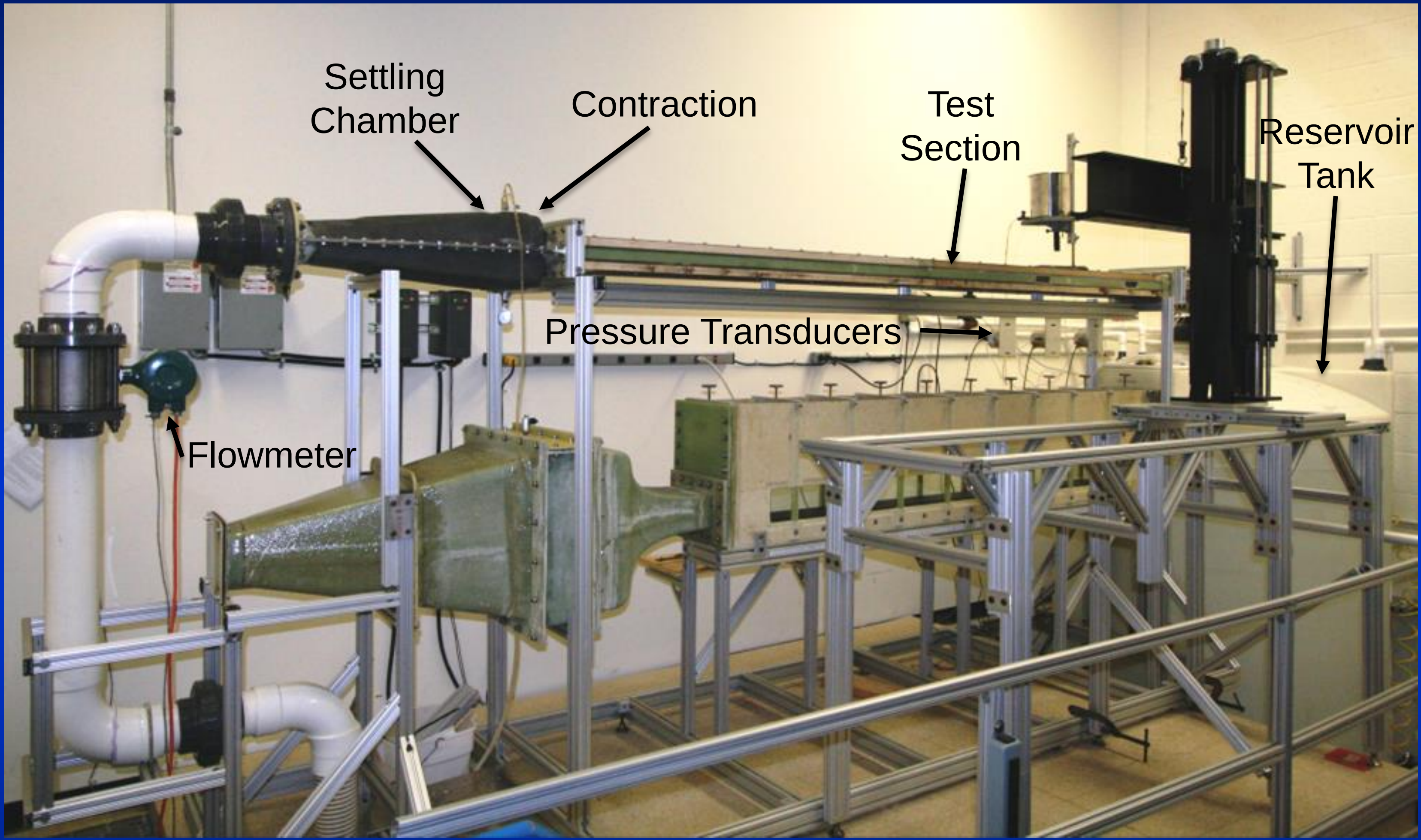
  - Mean Flow
  - Reynolds Stresses
- Conclusions

Motivation

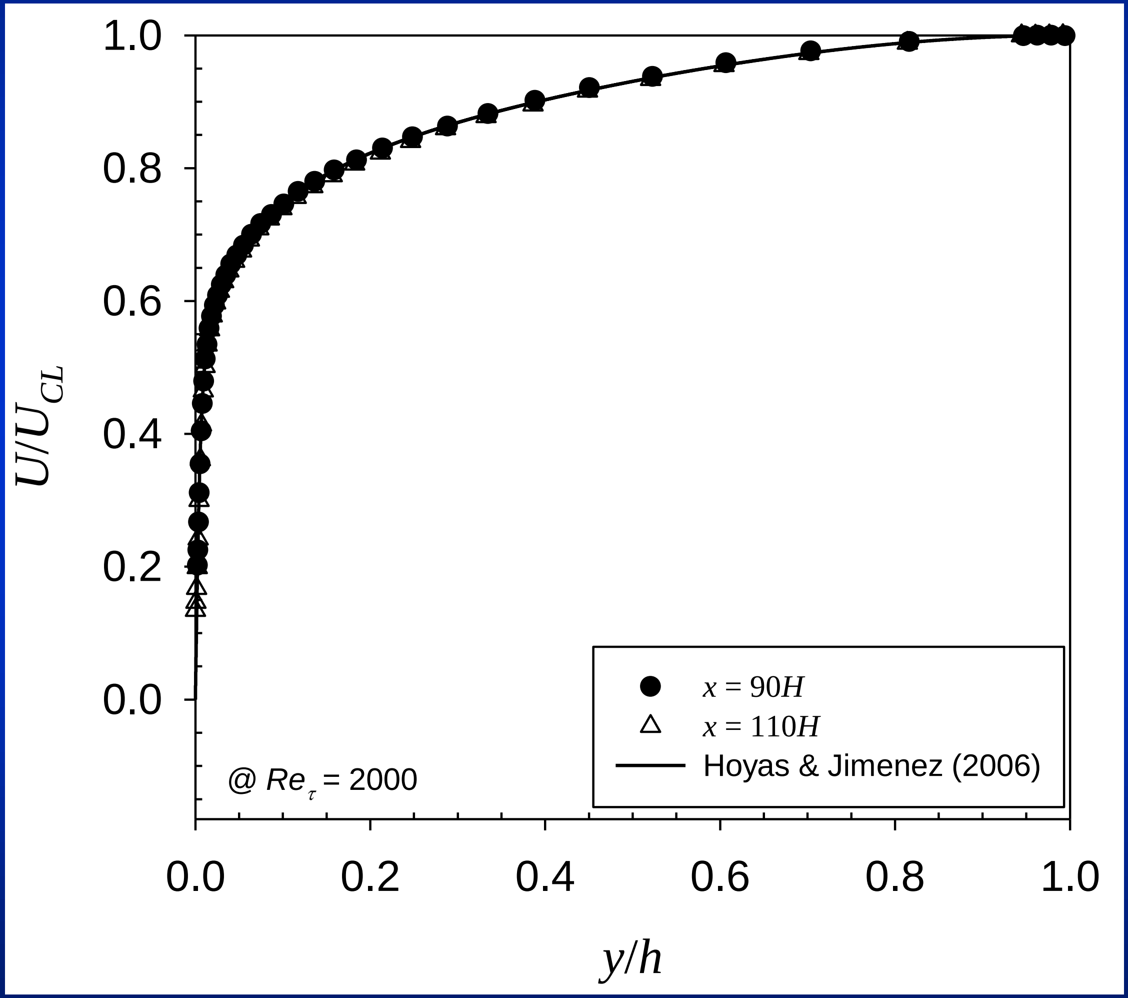
- Reynolds number dependence in wall-bounded turbulent flows is of significant interest
  - Prediction of frictional drag of vehicles
  - Calculation of pressure drop in piping systems
  - Modeling of turbulent flows
- Fully-developed turbulent channel flow is the most studied wall-bounded flow via DNS
  - Investigating scaling is difficult due to limited *Re* ($Re_\tau < 2000$)
  - There is a relative lack of experimental turbulence data for fully-developed channel flow at high Reynolds number
- What is the behavior of the scaling of the mean and turbulence quantities as *Re* increases?

Experimental Facility



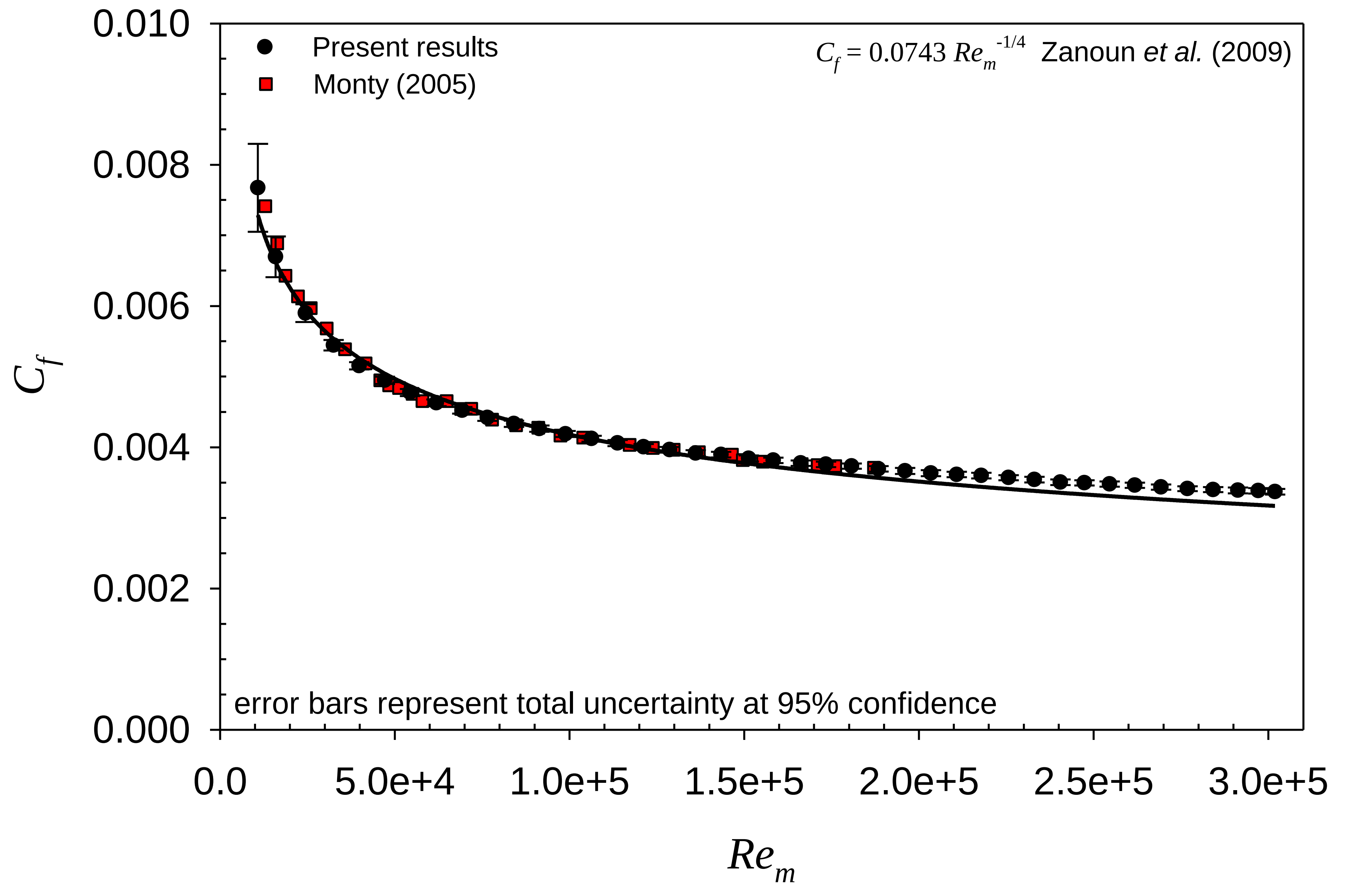
- L = 3.1 m, H = 25 mm, W = 200 mm
- 9 - static pressure taps
- 3 - GE/Druck pressure transducers
  (accuracy +/- 0.1% of full scale)
- Yokogawa magnetic flowmeter
  (accuracy +/- 0.2% of reading)
- Filtered, deaerated water (T +/- 0.25º C)
- $Re_m = U_b H/\nu$ = 10,000 – 300,000
  $Re_\tau = u_\tau H/\nu$ = 350 – 6100

Fully-Developed Flow Check

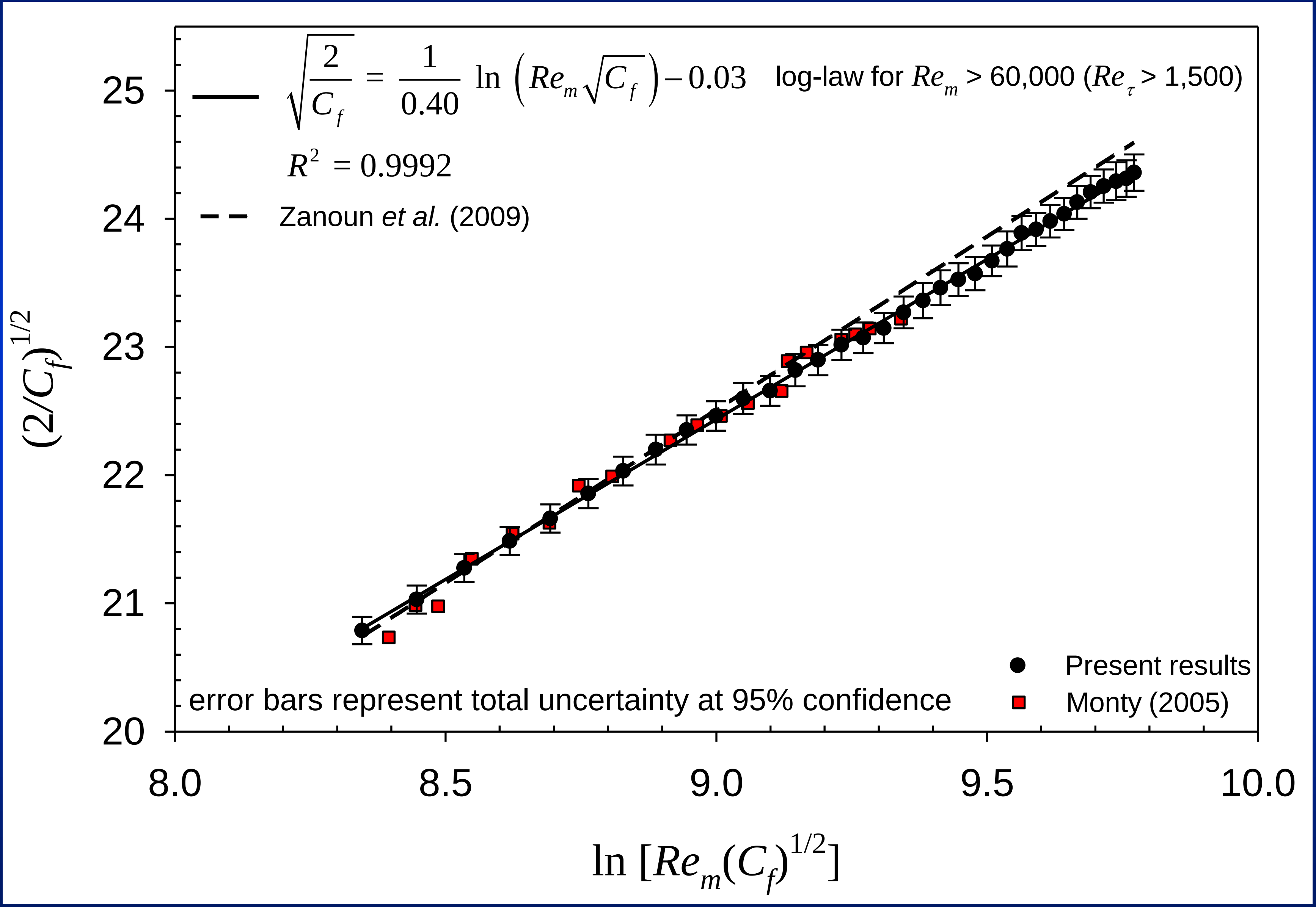


- Two-component, fiber optic LDV
- Four beam arrangement with beam expansion and displacer
- 50,000 samples in coincidence mode
- Flow seeded with 2 μm silver-coated glass spheres
- 45 μm probe volume diameter ($d^+ = 3.6$ @ $Re_\tau = 1000$; $d^+ = 21$ @ $Re_\tau = 6000$)
- *u*' measurements corrected for velocity gradient bias according to Durst *et al.* (1998)

Skin-Friction Results

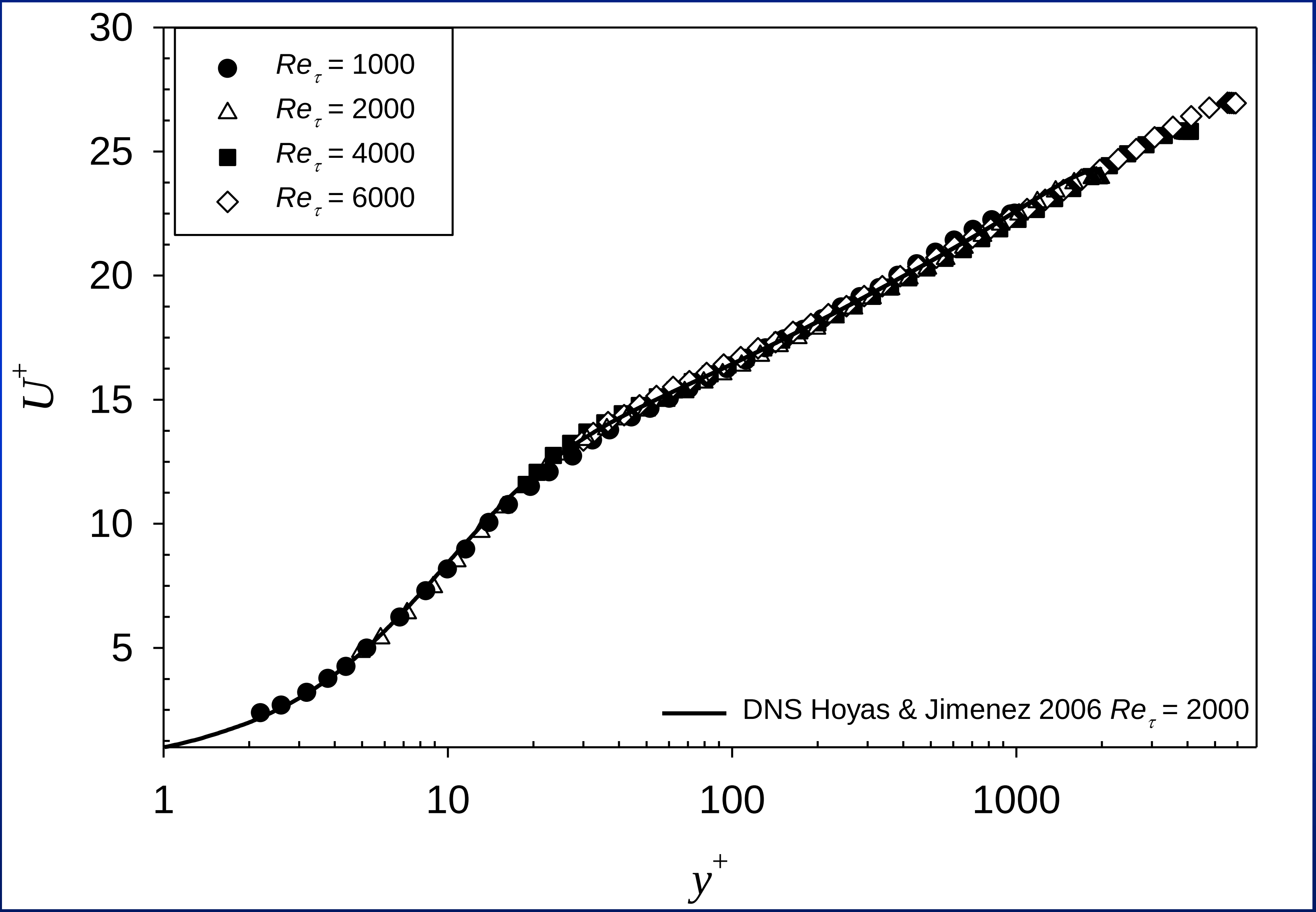


Skin-Friction Results



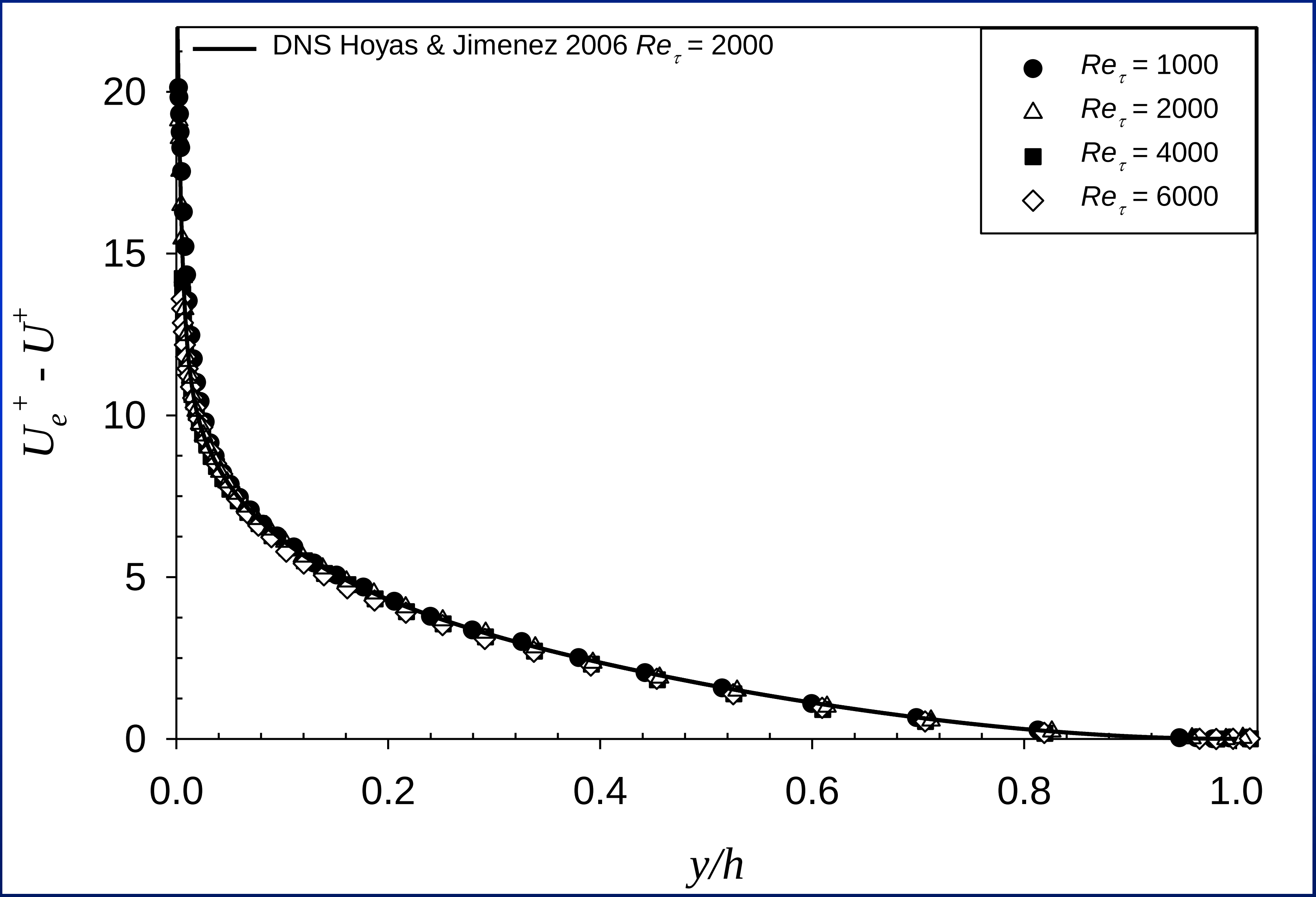
Mean Flow

Inner Scaling



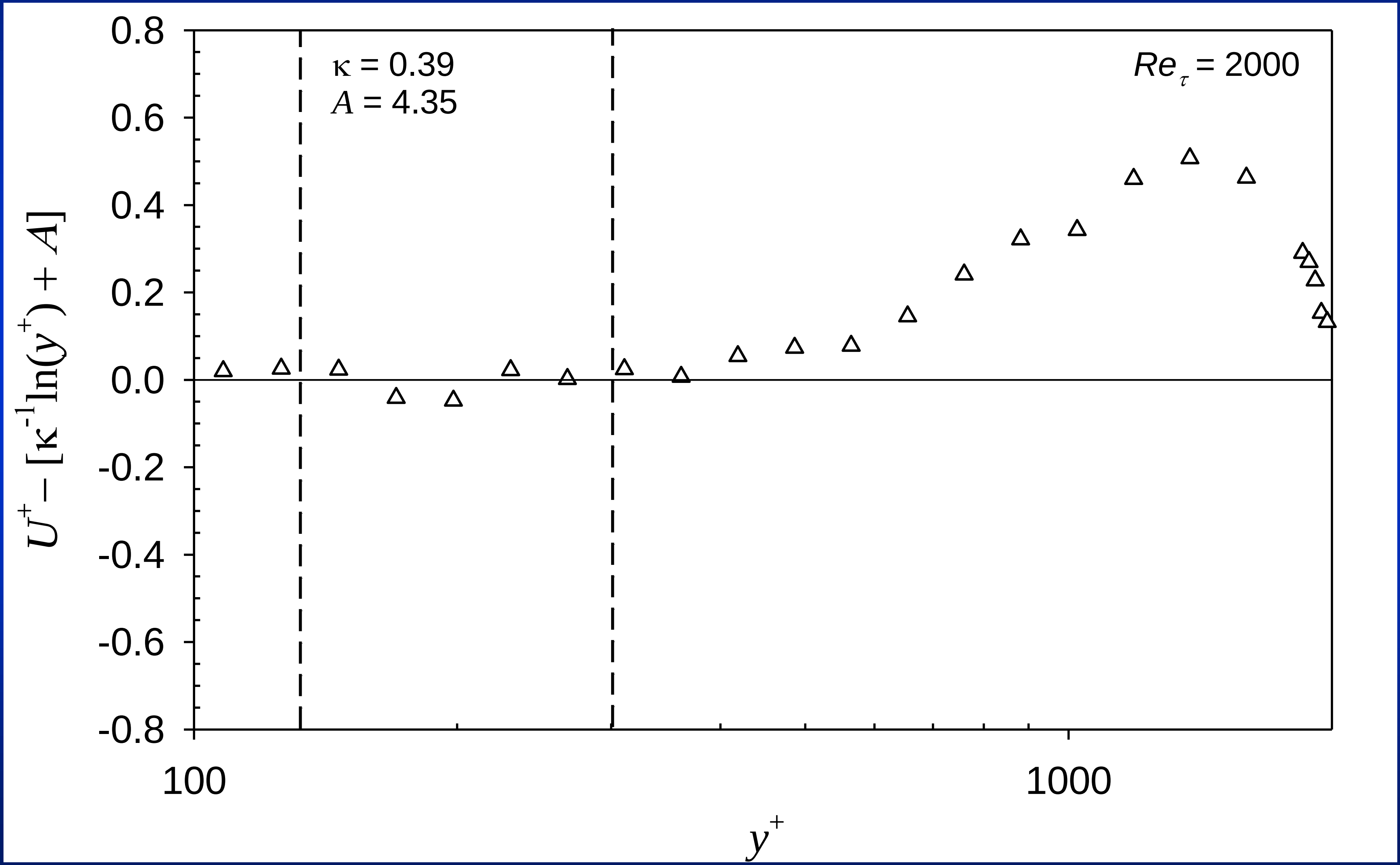
Mean Flow

Outer Scaling



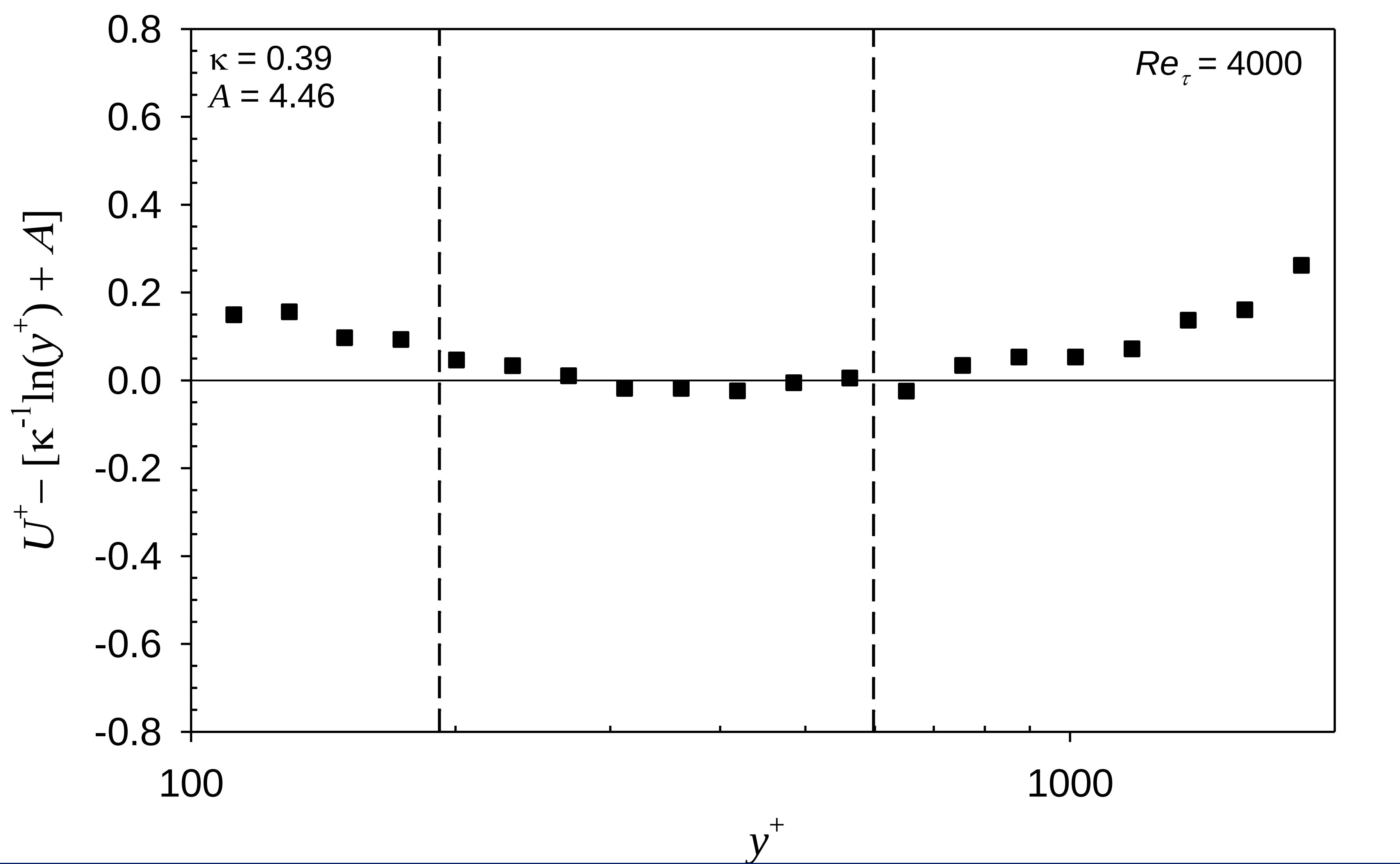
Mean Flow

Log-Law Scaling



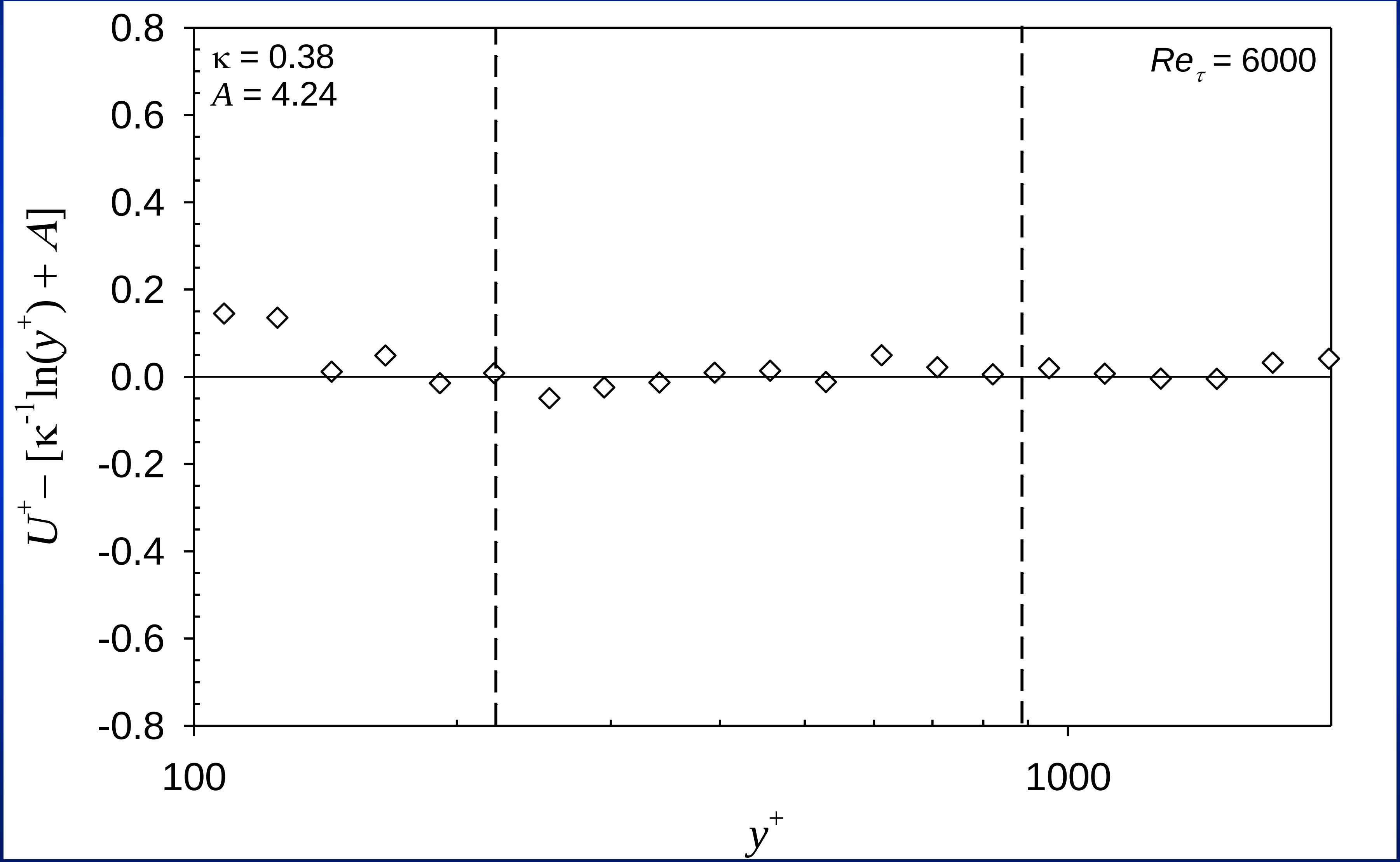
Mean Flow

Log-Law Scaling



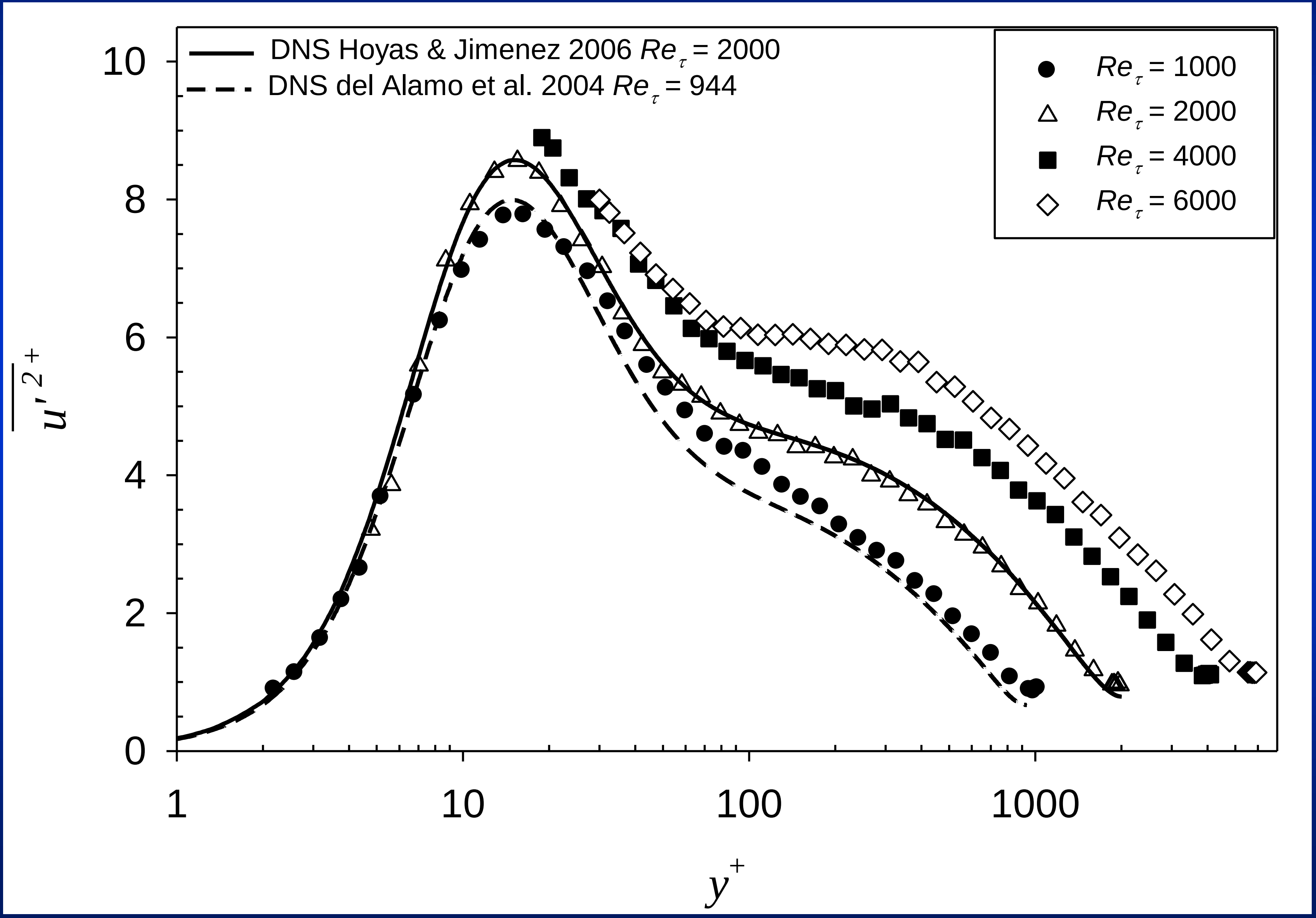
Mean Flow

Log-Law Scaling



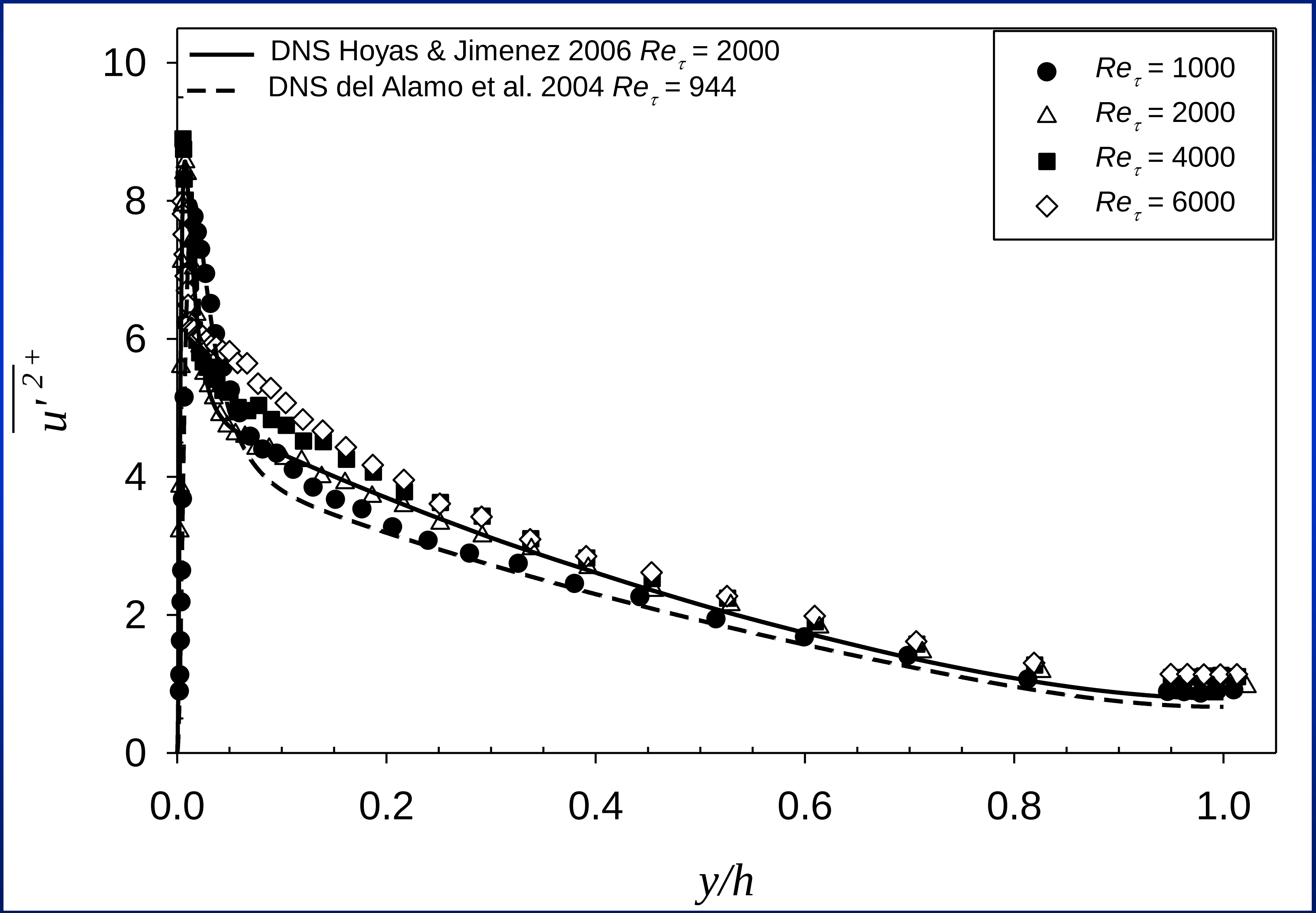
Reynolds Normal Stress

Streamwise Component – Inner Scaling



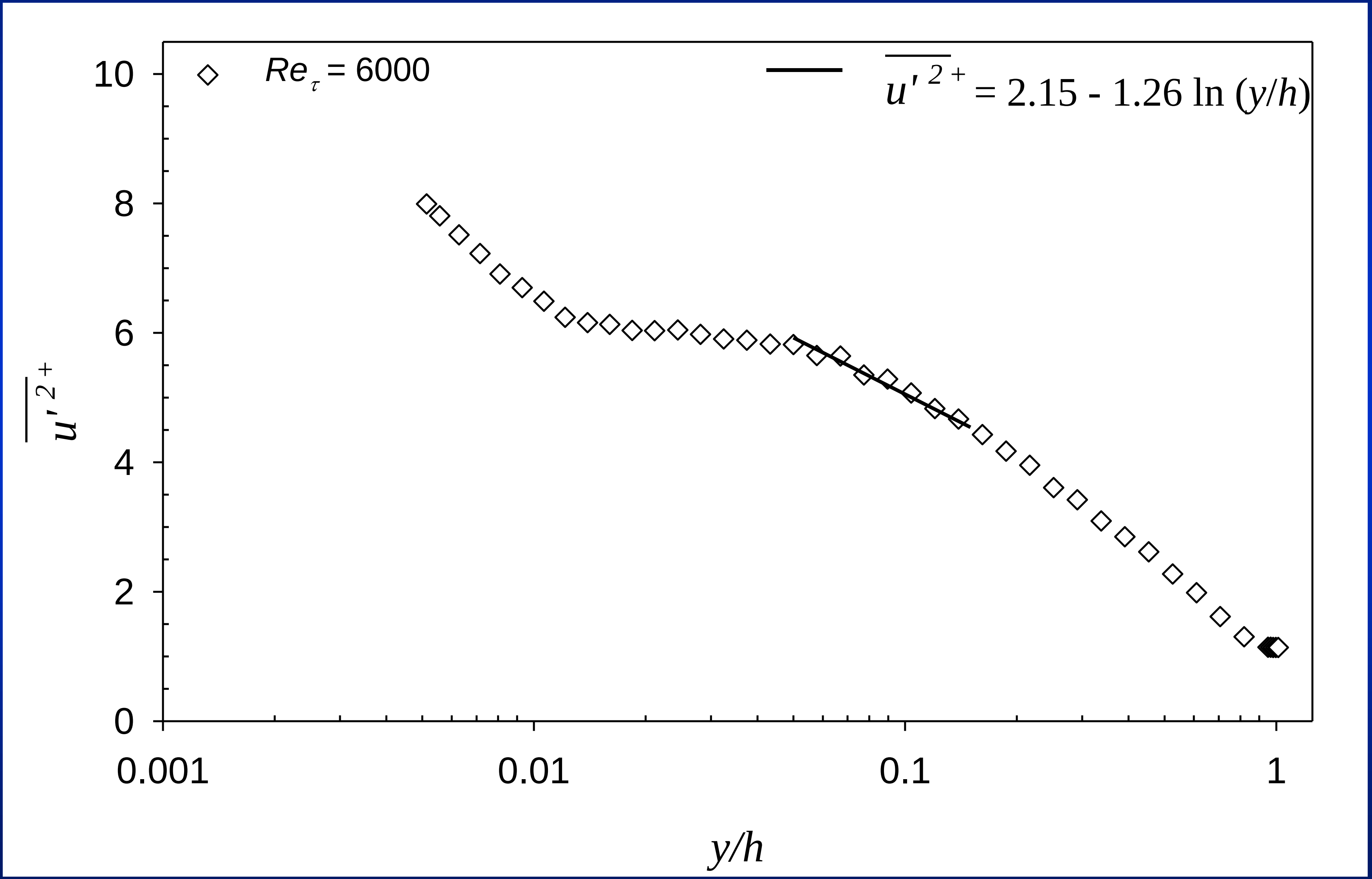
Reynolds Normal Stress

Streamwise Component – Outer Scaling



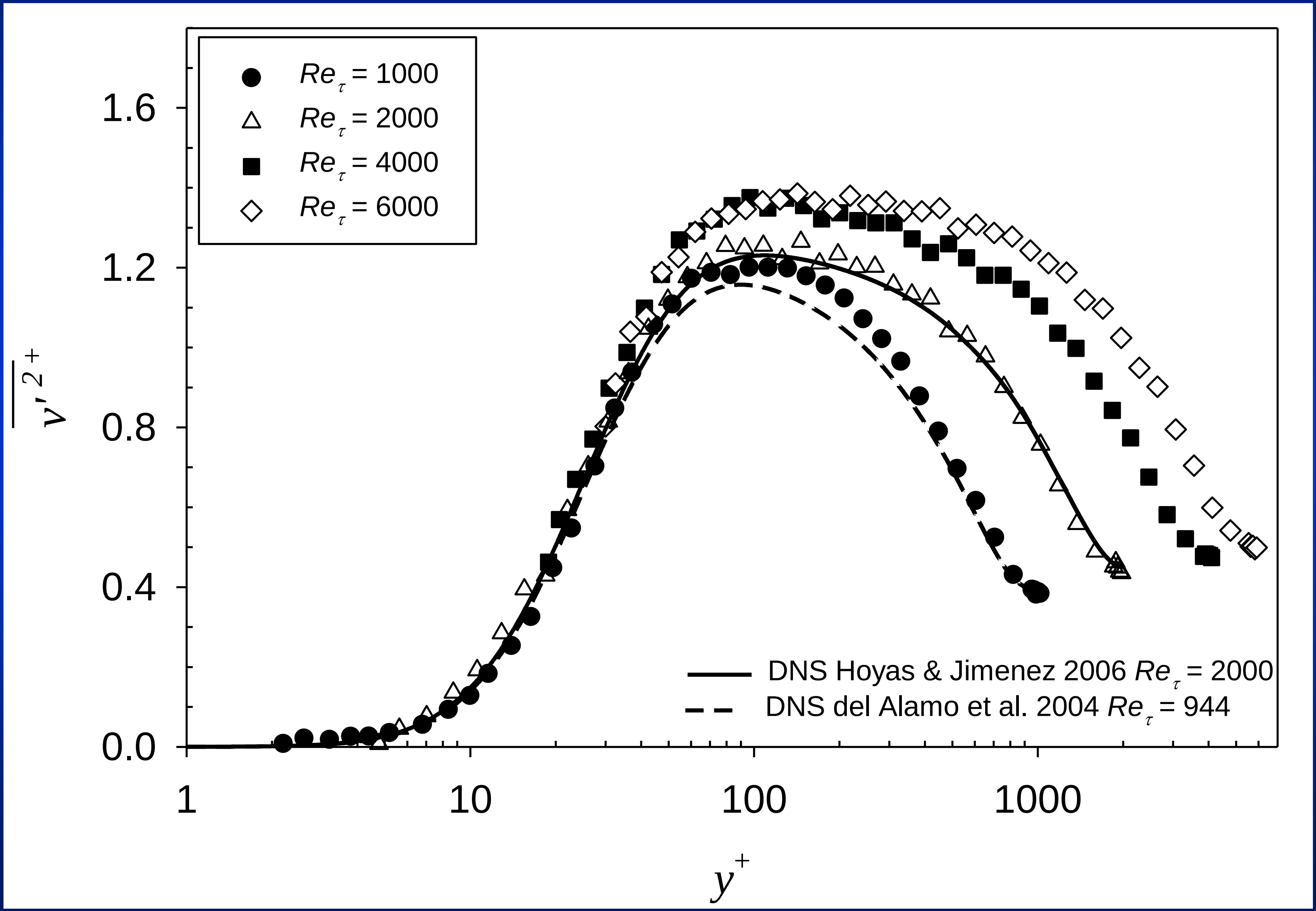
Reynolds Normal Stress

Streamwise Component – Log Scaling?



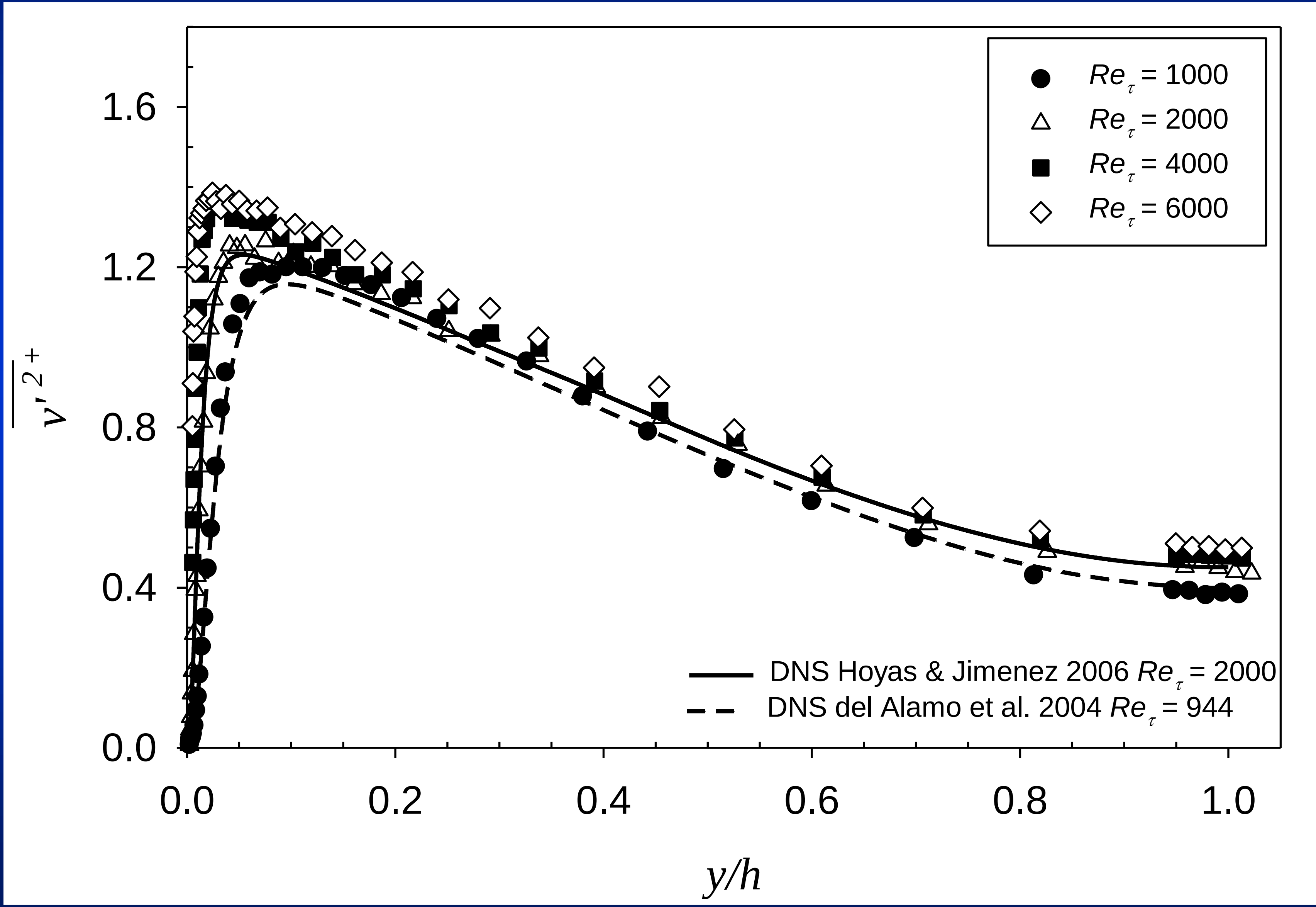
Reynolds Normal Stress

Wall-Normal Component – Inner Scaling



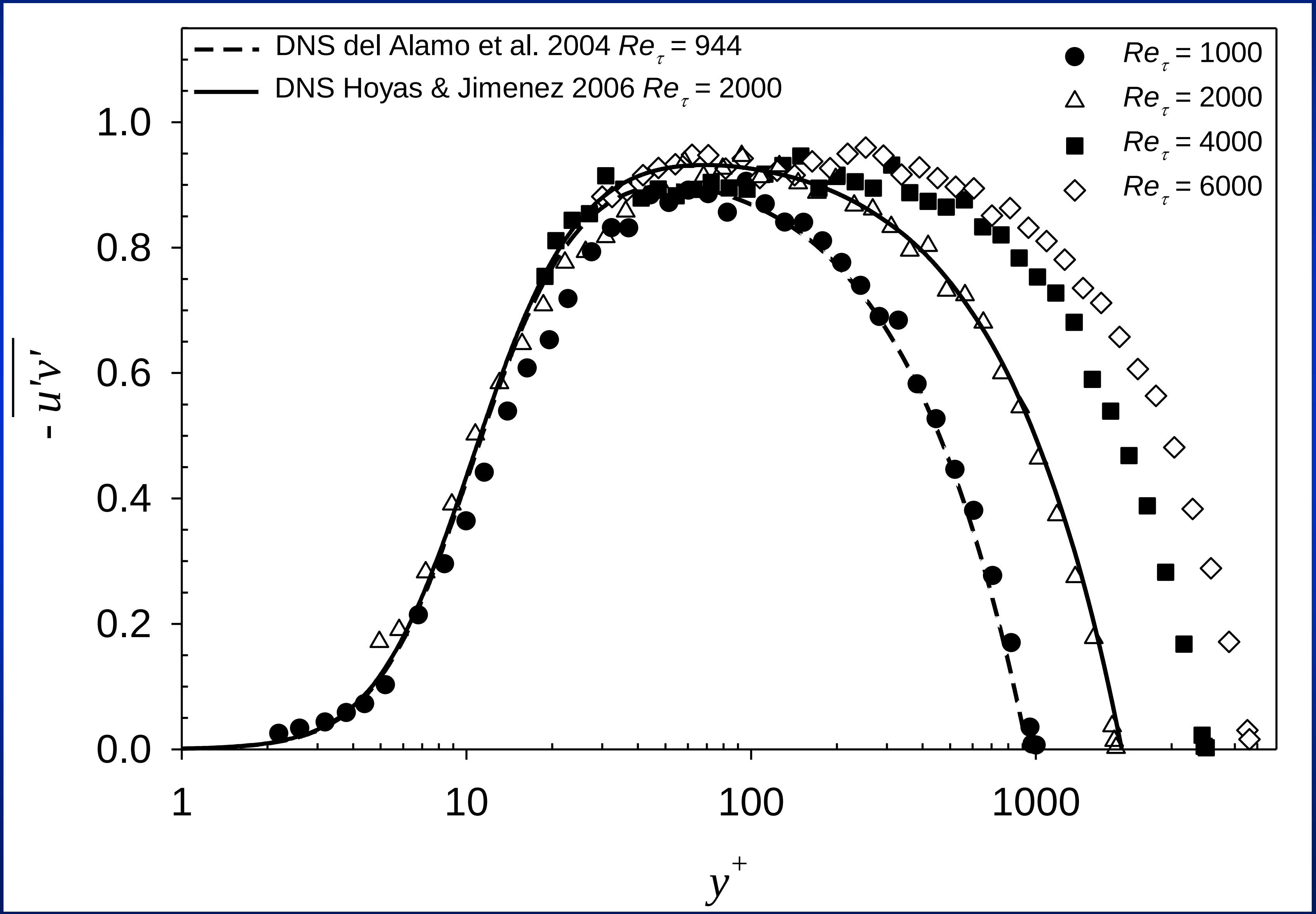
Reynolds Normal Stress

Wall-Normal Component – Outer Scaling



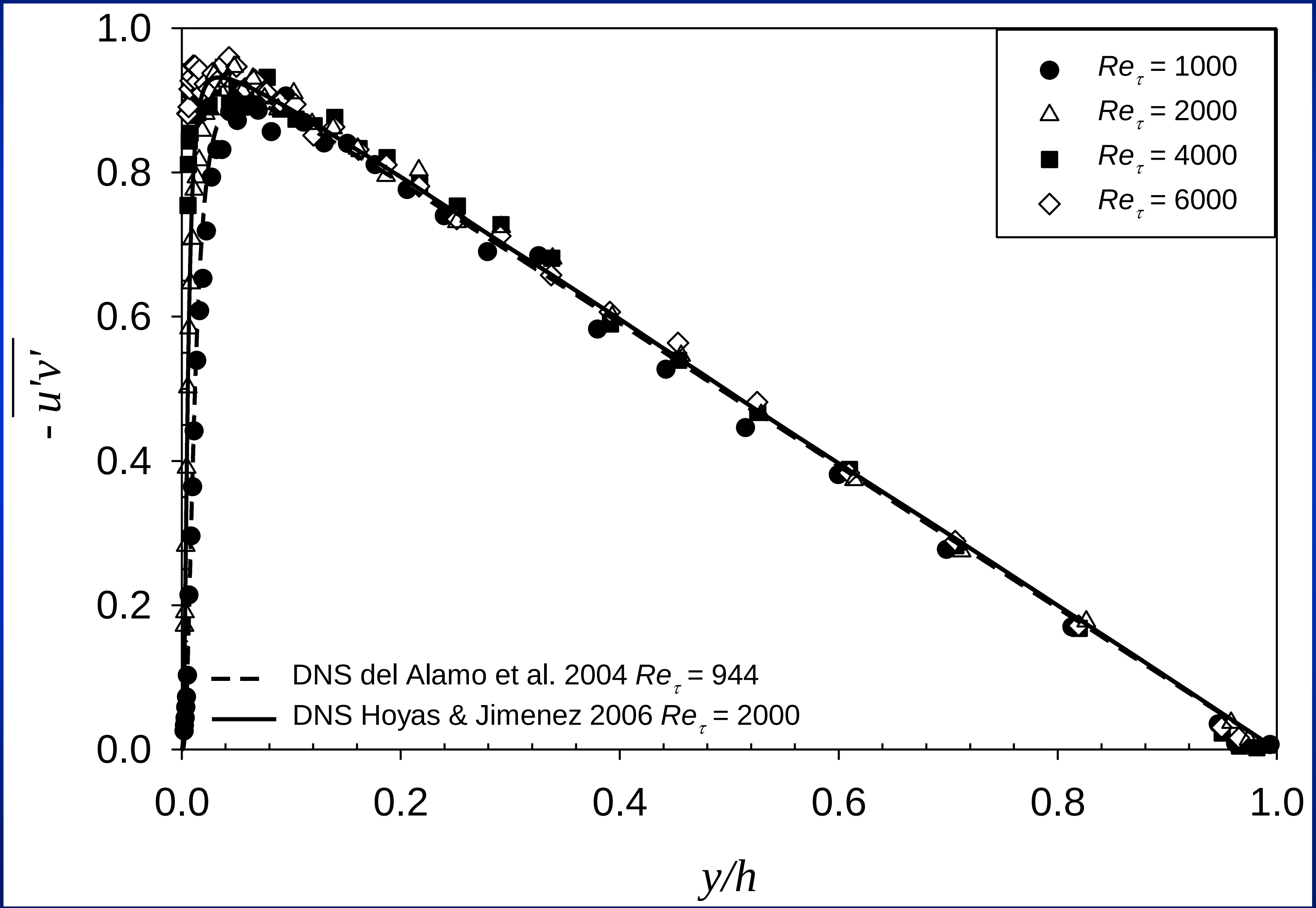
Reynolds Shear Stress

Inner Scaling



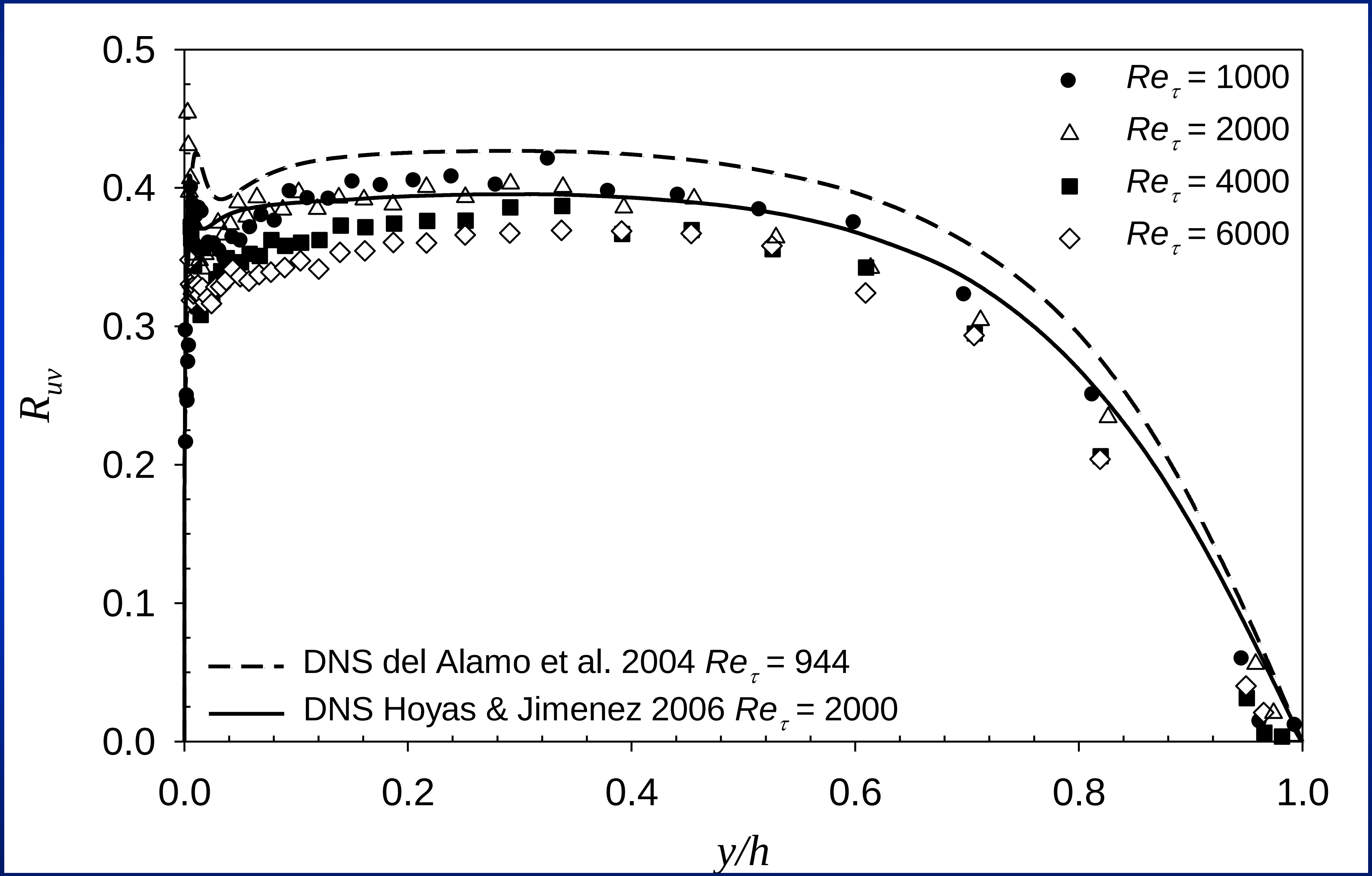
Reynolds Shear Stress

Outer Scaling



Reynolds Shear Stress

Correlation Coefficient



Conclusions

- Skin friction follows a log-law for $Re_m \geq 60{,}000$.
- The mean flow and Reynolds shear stress show little, if any, *Re* dependence for $1000 \leq Re_\tau \leq 6000$.
- The near-wall peak in the streamwise Reynolds normal stress increases with *Re* for $Re_\tau \leq 4000$.
- An increase in the streamwise Reynolds normal stress in the outer layer with *Re* is also observed for all *Re* tested.
- The wall-normal Reynolds normal stress increases with *Re* for $Re_\tau \leq 4000$.

Acknowledgements

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