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Session AA. Turbulent Boundary Layers I (AA.06)

New Values for Logarithmic Layer Parameters Revealed by Two Experiments in High Reynolds Number Boundary Layers.

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Background

- Alternative Theories for Turbulent BL:
  - log- or power-law overlap regions
  - Re dependence of the overlap region
- Measurements in the MTL and NDF wind tunnels at KTH and IIT
  - Large span in Re
  - Independent measurements of the skin-friction

Classical Theory of Boundary Layers

Inner scaling

$$\frac{\overline{U}}{u_\tau} = f\left(\frac{y u_\tau}{\nu}\right) \tag{1}$$

Outer scaling

$$\frac{U_\infty - \overline{U}}{u_\tau} = F\left(\frac{y}{\delta}\right) \tag{2}$$

High Re $\Rightarrow$ Overlap region: $\nu/u_\tau \ll y \ll \delta$

Matching $\Rightarrow$

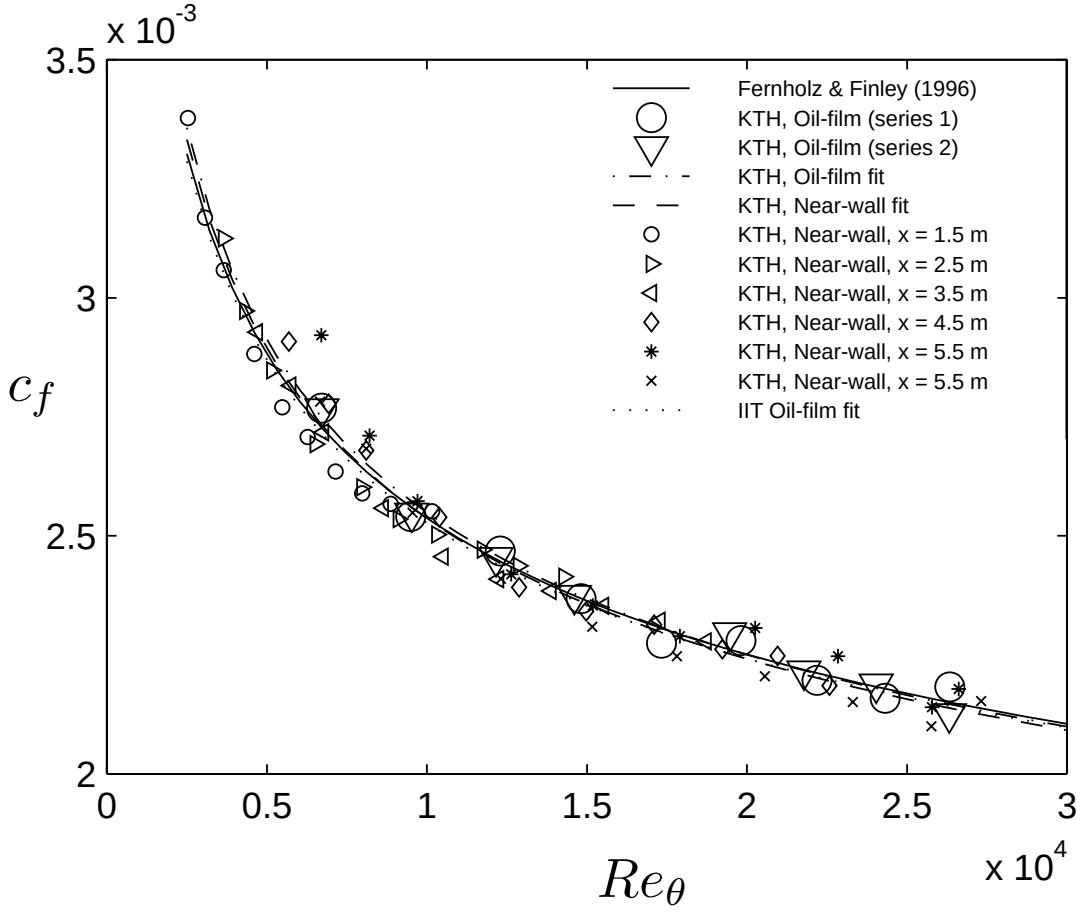
$$\frac{\overline{U}}{u_\tau} = \frac{1}{\kappa}\ln\left(\frac{y u_\tau}{\nu}\right) + B \tag{3}$$

$$\frac{U_\infty - \overline{U}}{u_\tau} = -\frac{1}{\kappa}\ln\left(\frac{y}{\delta}\right) + B_1 \tag{4}$$

Logarithmic skin friction law

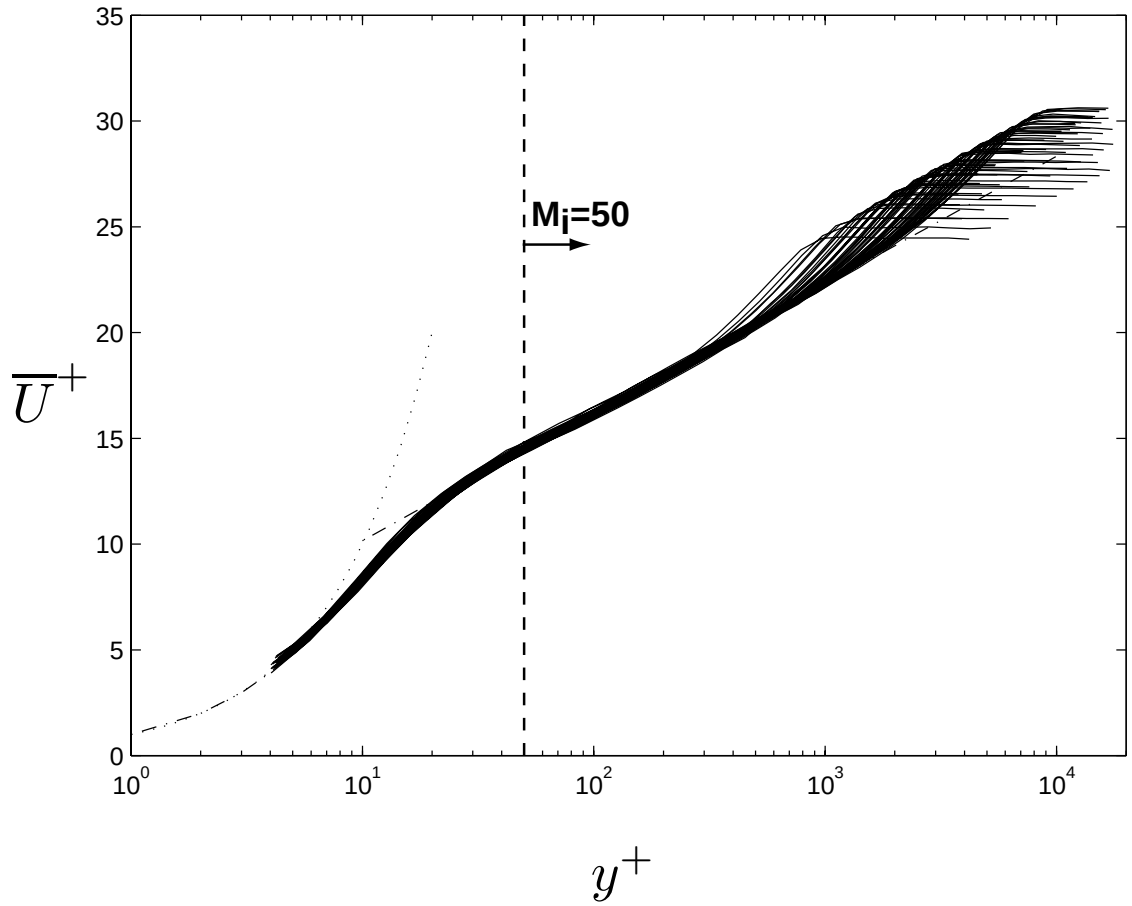
$$\frac{U_\infty}{u_\tau} = \frac{1}{\kappa}\ln\left(\frac{\delta u_\tau}{\nu}\right) + B + B_1 \tag{5}$$

Skin friction coefficient



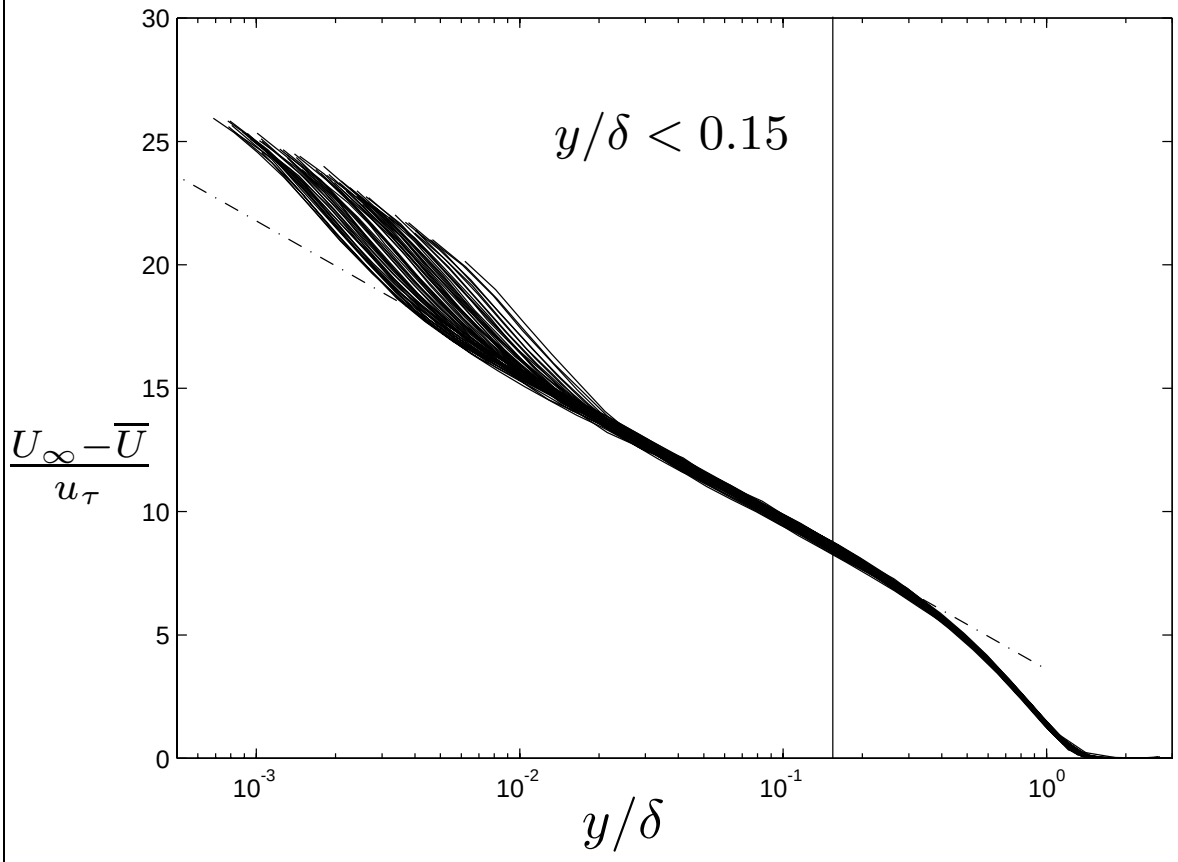
$$c_f = 2\left[\frac{1}{\kappa}\ln(Re_\theta) + C\right]^{-2} \qquad (6)$$

Mean Velocity
Inner Scaling



$2500 < Re_\theta < 27000.$

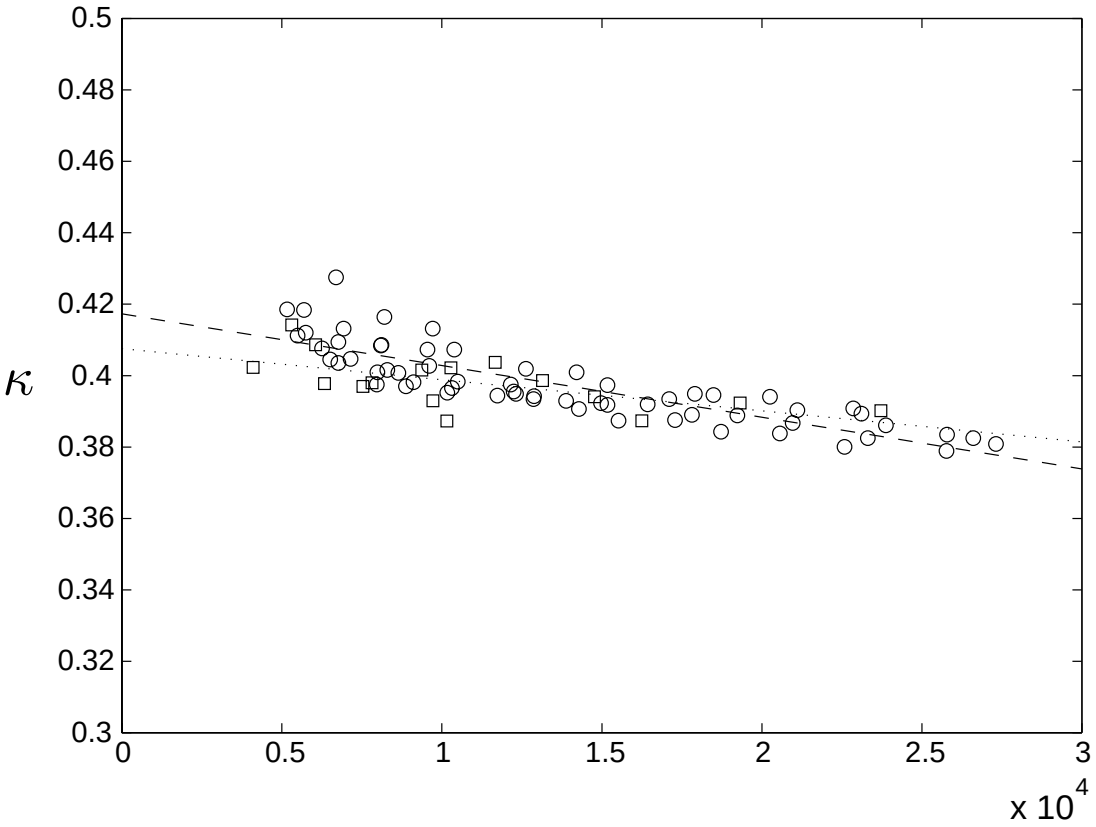
Mean Velocity
Outer Scaling



$2500 < Re_\theta < 27000.$

κ from least-squares-fit of mean velocity profiles

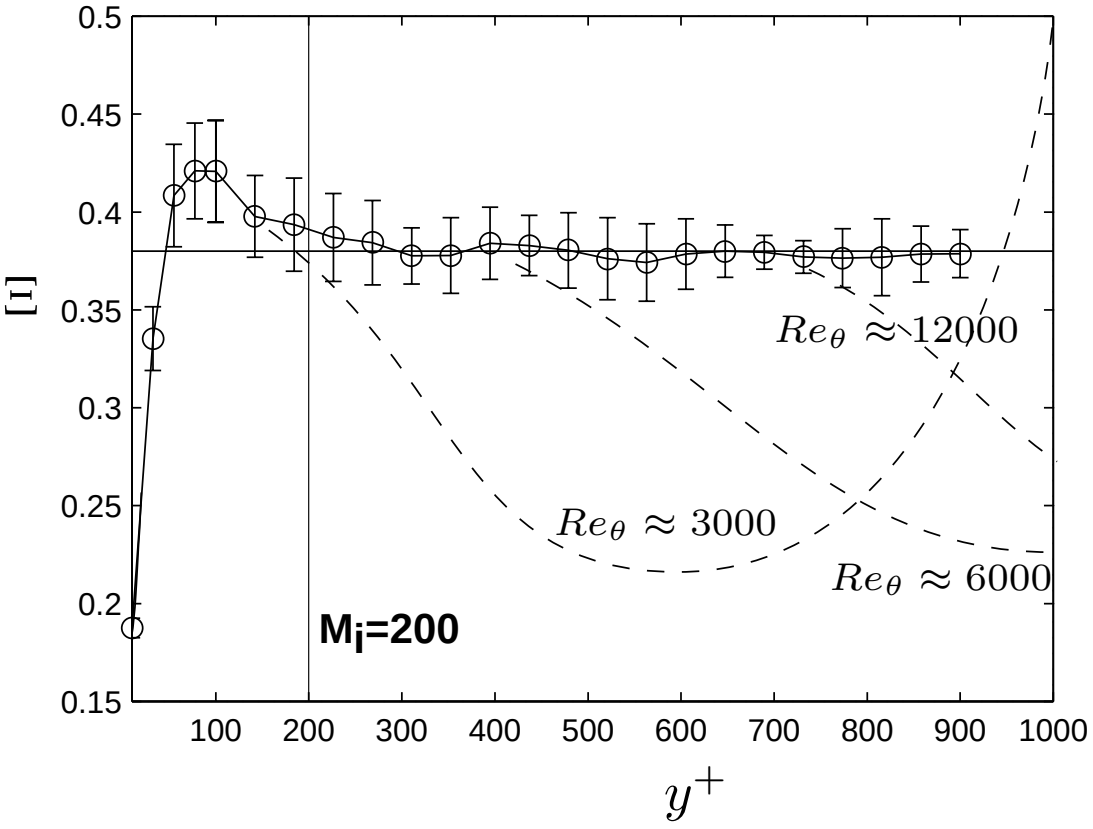
$M_i = 50, \quad M_o = 0.15$



○: KTH

□: IIT

Diagnostic function Ξ
Inner Scaling



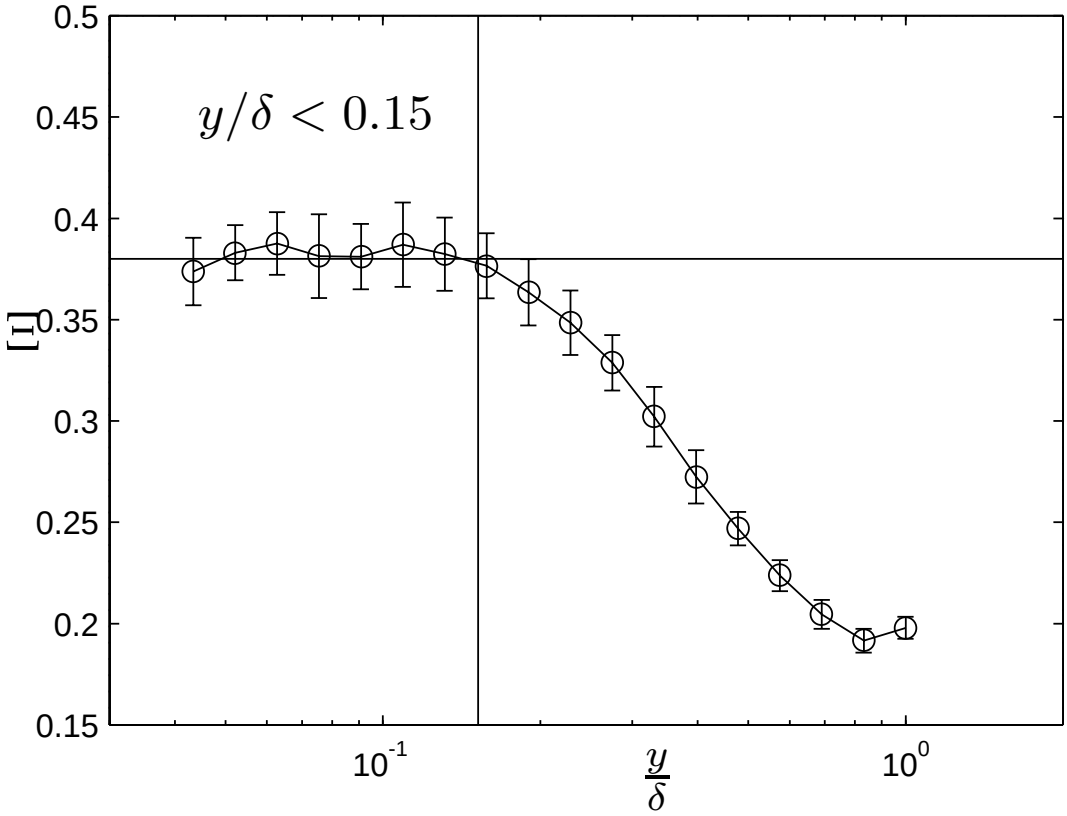
$$\Xi = \left(y^+ \frac{d\overline{U}^+}{dy^+} \right)^{-1} \qquad (7)$$

$2500 < Re_\theta < 27000.$

Errorbars show a 95% confidence interval.

The horizontal line corresponds to $\kappa = 0.38$

Diagnostic function Ξ
Outer Scaling



$2500 < Re_\theta < 27000.$

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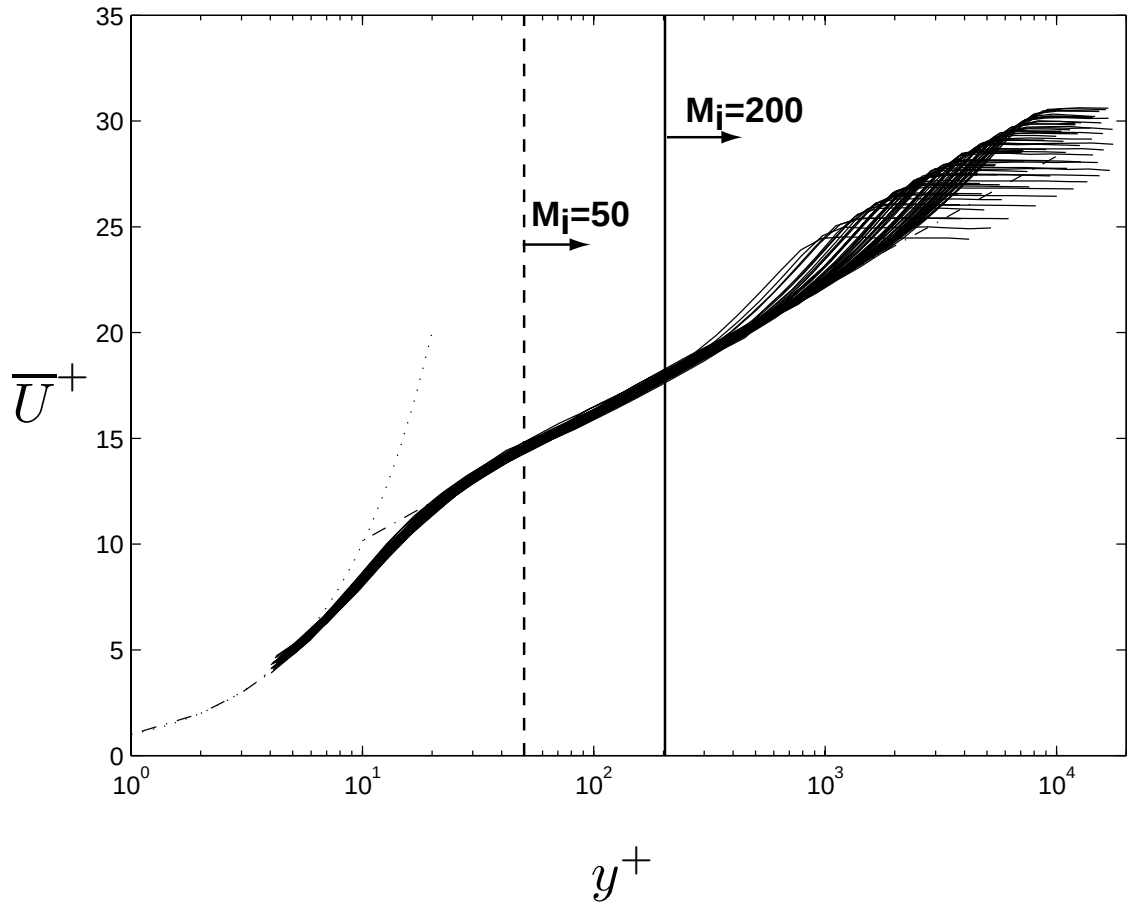
Mean Velocity
Inner Scaling



$2500 < Re_\theta < 27000.$

κ from least-squares-fit of mean velocity profiles

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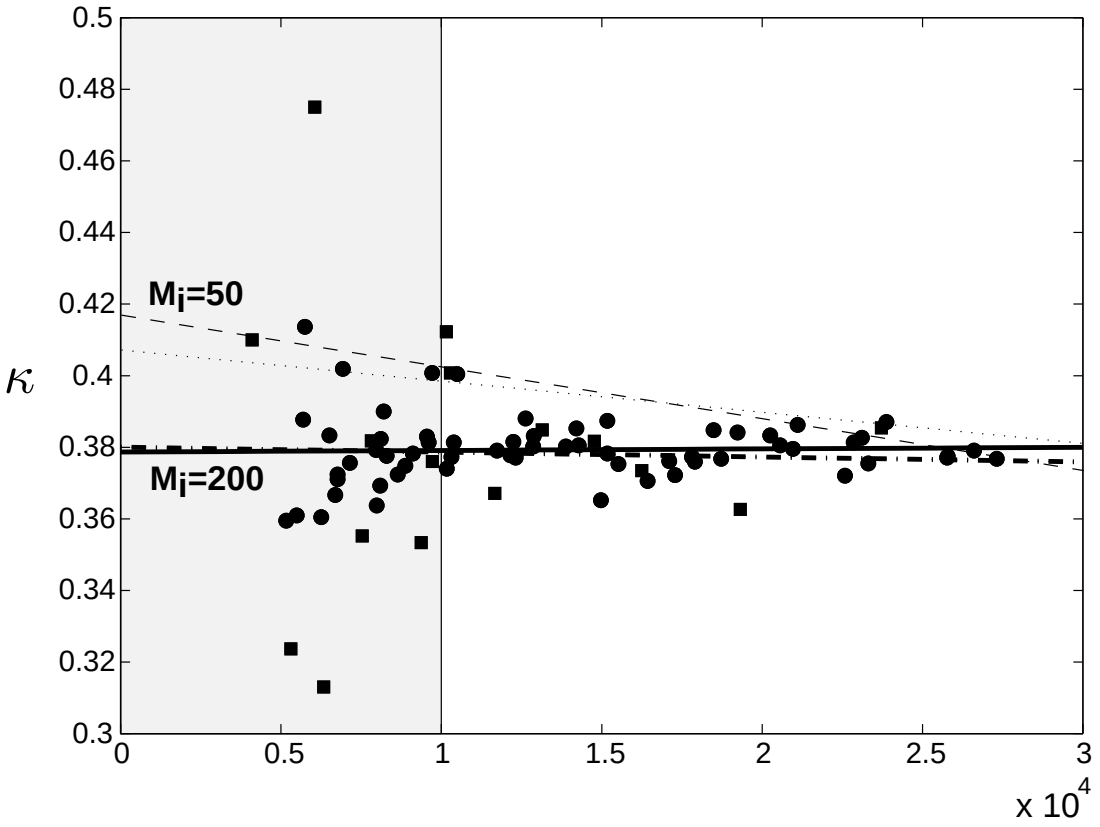
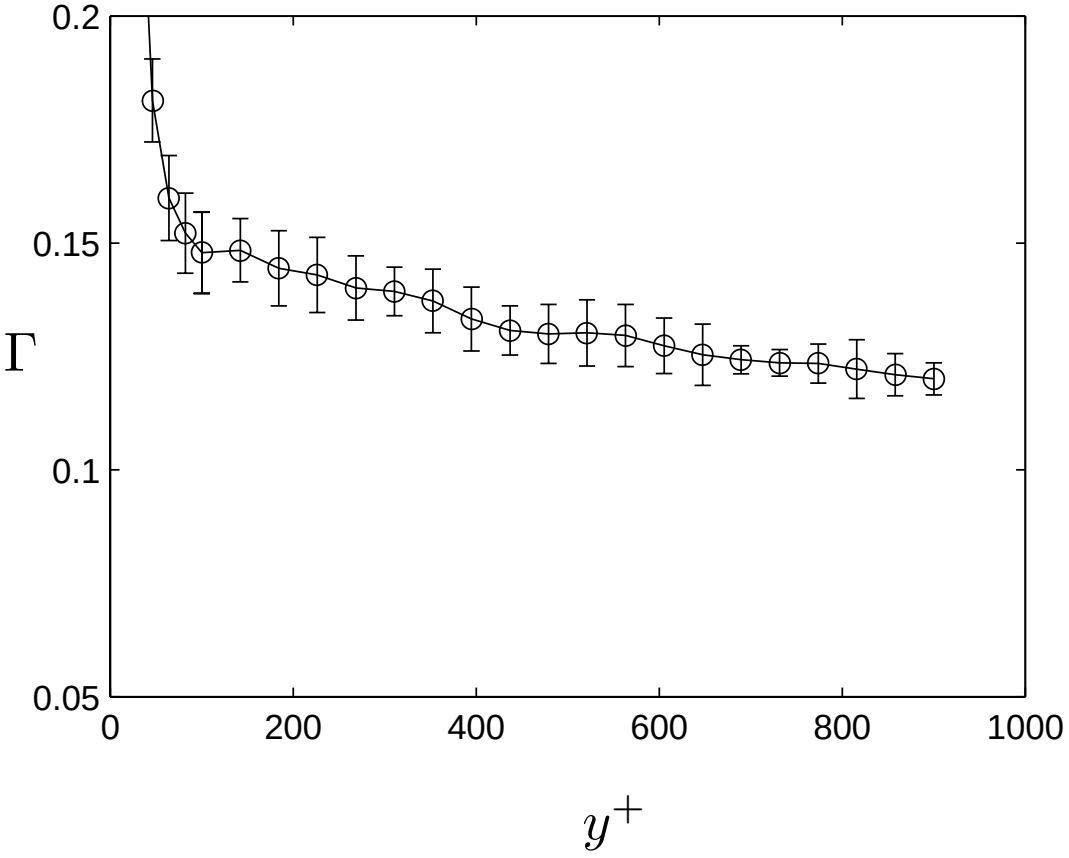


●: KTH

■: IIT

Diagnostic function Γ
Inner Scaling



$$\Gamma = \frac{y^+}{\overline{U}^+} \frac{d\overline{U}^+}{dy^+} \qquad (8)$$

$2500 < Re_\theta < 27000.$

Errorbars show a 95% confidence interval.

Concluding Remarks

- Experimental evidence in favor of the log-law
- New values for the "constants":
  $\kappa = 0.38$
  $B = 4.1$
  $B_1 = 3.6 \quad (\delta = \delta_{95})$
- The overlap region: $200 < y^+ < 0.15\delta^+$
- No overlap for: $Re_\theta < 6000$

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See also:

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Experimental studies of zero pressure-gradient turbulent boundary layer flow

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