Large Scale Structures based on Pressure in High Reynolds Number Turbulent Boundary Layer.

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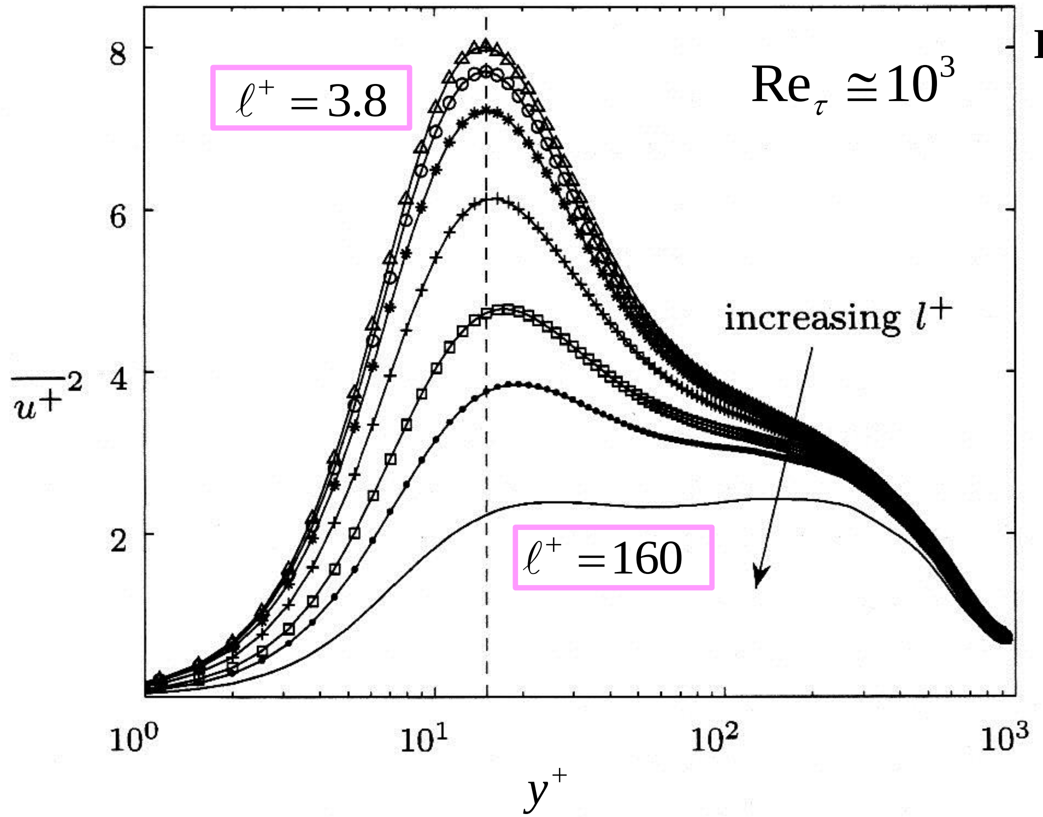
Purpose of present study

Present the correction of pressure data measured near the wall in high Re number turbulent boundary layers.

From the correction of measured data, we think about the large scale motions in turbulent boundary layers.

Motivations & Background

Stream-wise turbulence intensity profiles



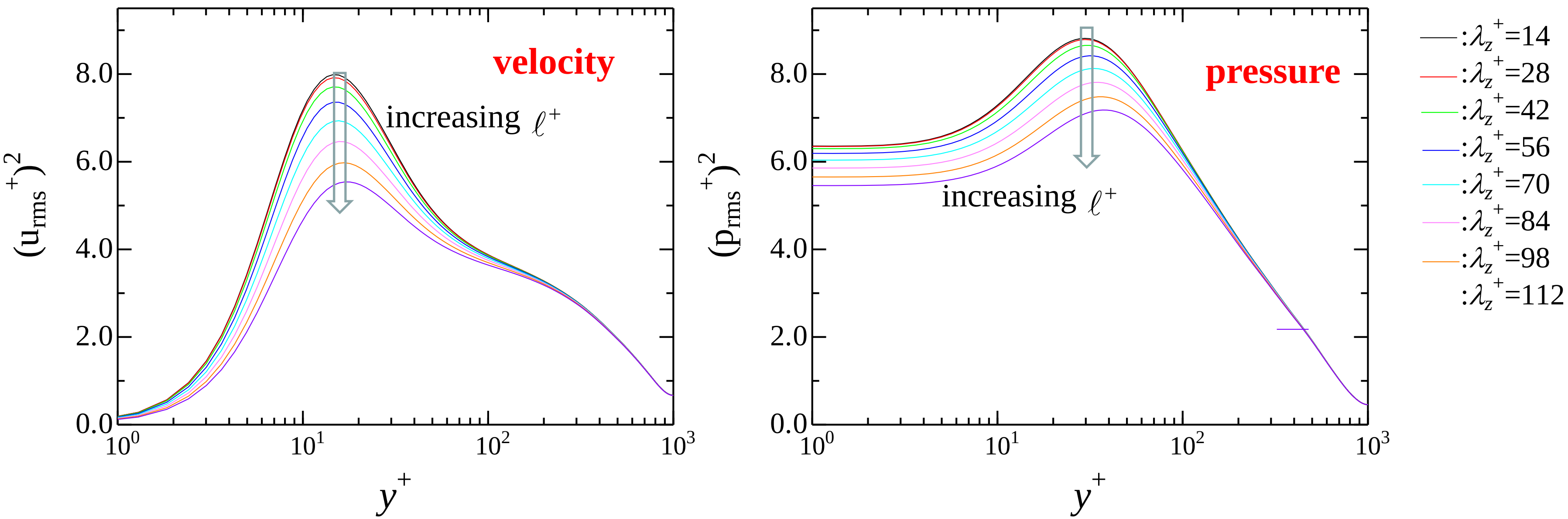
DNS Channel Flow

A significant effect of special resolution on the near-wall peak of the stream-wise turbulence intensity profile has been studied for three decades.

C. Chin et al., Exp. Fluids, vol.50, 1443 (2011) A. Segalini et al., Exp. Fluids, vol.51, 693 (2011)
P.A . Monkewitz et al., Physics of Fluids, vol. 22, 701, (2010)

Objectives 1

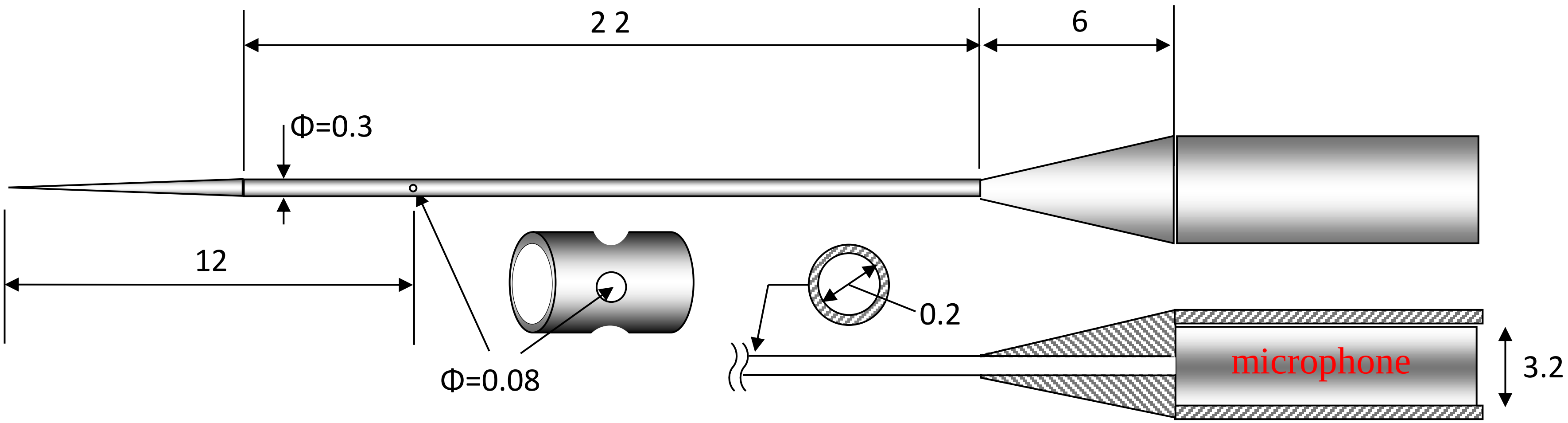
Channel flow DNS results ($\mathrm{Re}_\tau \cong 10^3$)



Spatial resolution problem is also confirmed in pressure fluctuation close to the wall. We think about this problem with the help of DNS data, and suggest the method to correct the experimental data.

Static pressure probe

Kolmogorov length scale is $\eta = 0.19mm$ for $R_\lambda = 700$.



Microphone: $2 \times 10^{-4} < \tilde{p} < 3.2 \times 10^{3}$ [Pa] $2 \times 10^{1} < f < 7.0 \times 10^{4}$ [Hz]

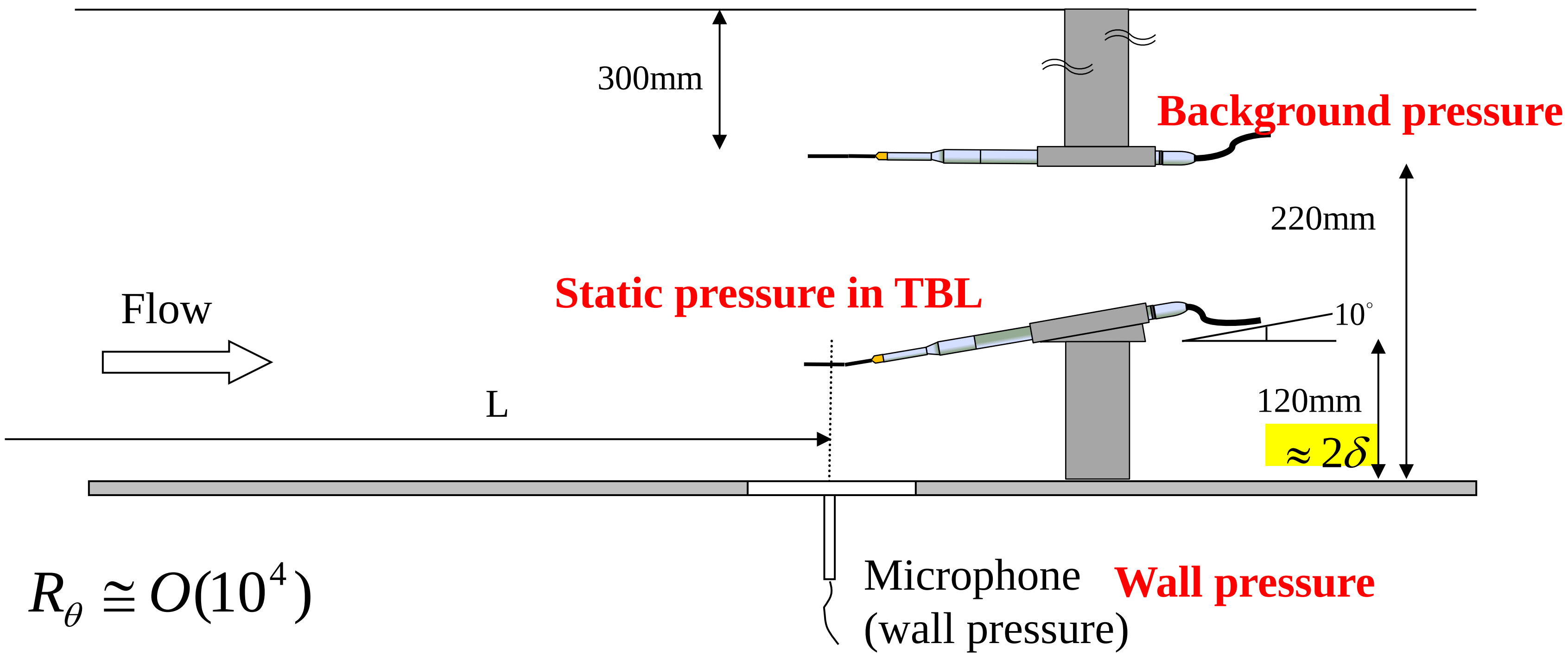
1/8 inch $d = 3.2$ [mm]

Pressure measurement in TBL

Static pressure fluctuation inside the boundary layer

Static pressure fluctuation outside the boundary layer ($y > 2\delta$)

Wall pressure fluctuation at the wall

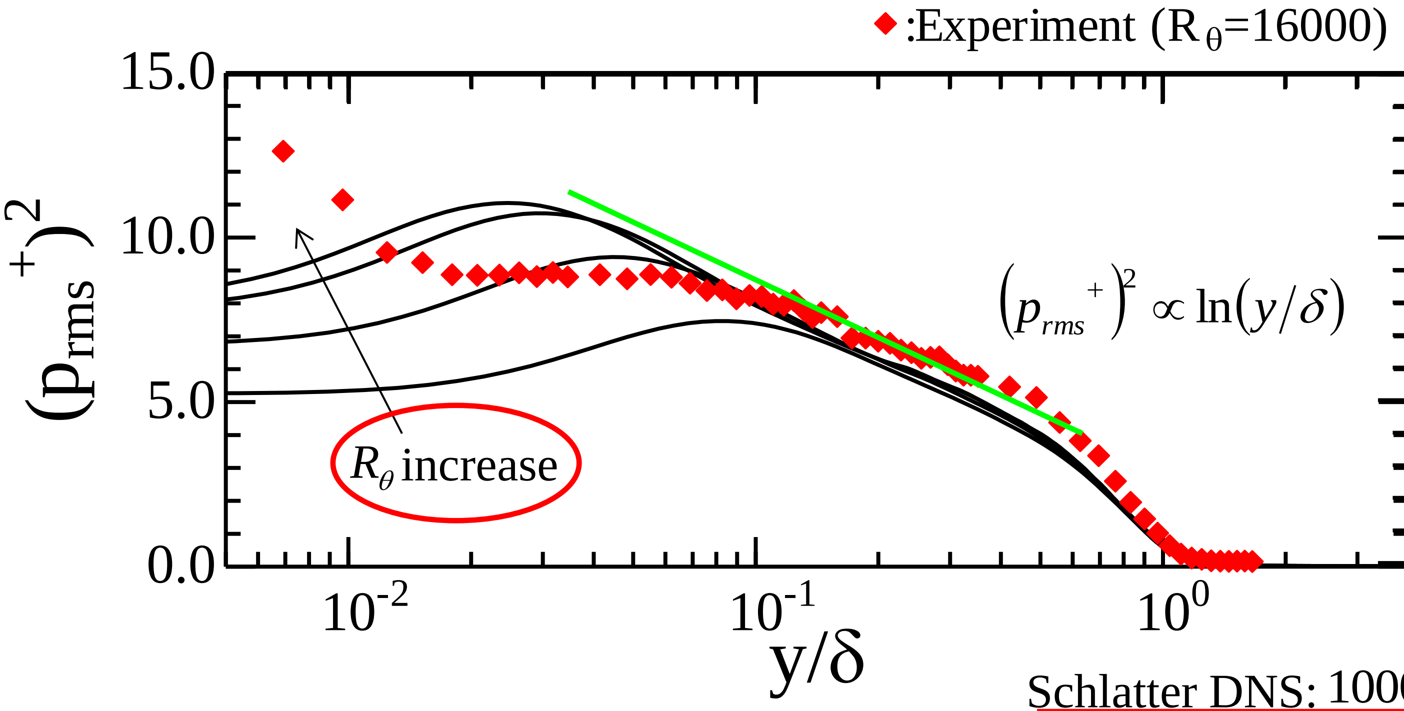


$R_\theta \cong O(10^4)$

Pressure measurement in TBL

Pressure probe setting in KTH wind tunnel

Static pressure r.m.s. in TBL



Schlatter DNS: $1000 \leq R_\theta \leq 4060$

As Reynolds number increases, the overlap region is observed.

In the overlap region, the following relation is observed.

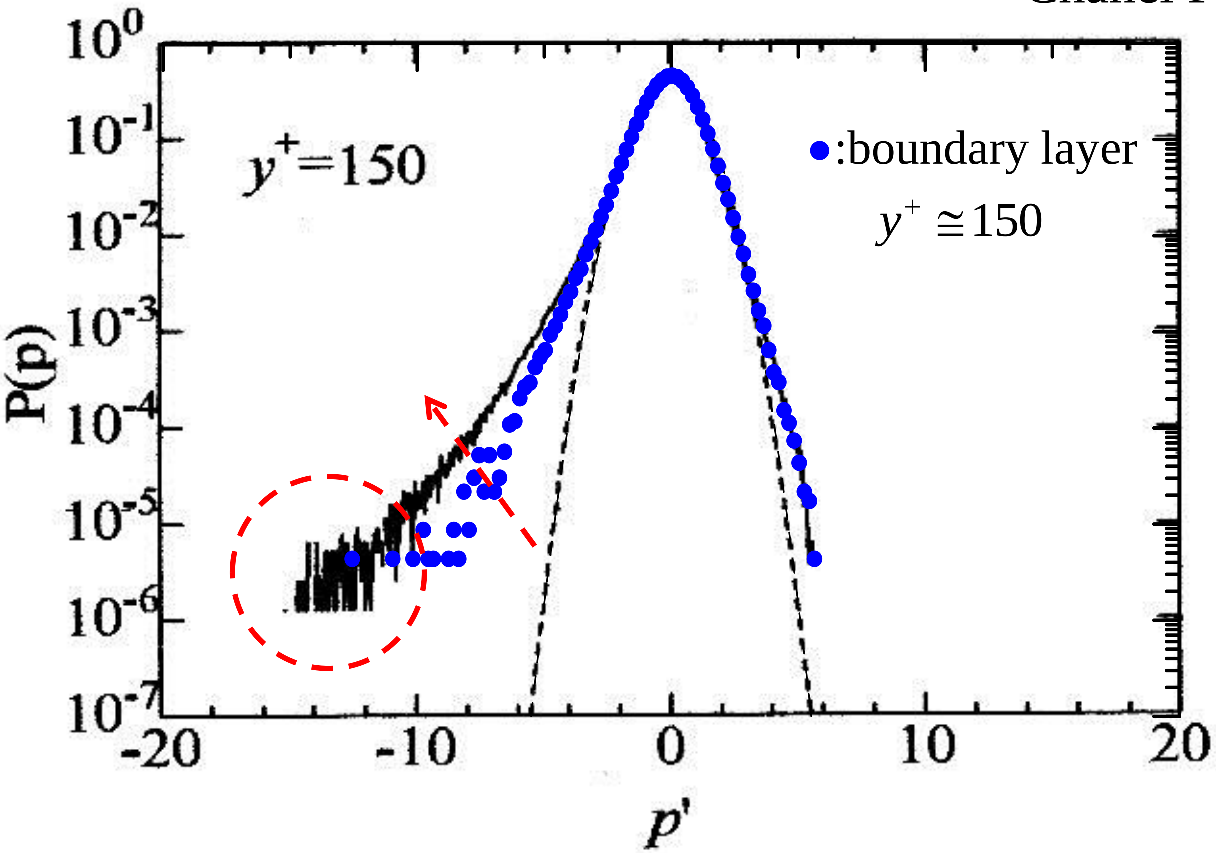
$$\left(p_{rms}^+\right)^2 \propto \ln(y/\delta)$$

Pressure probe attenuation is observed close to the wall.

PDF of pressure fluctuation in shear flow

Shear flow field.

Chanel Flow: $R_{\tau} = 1000$

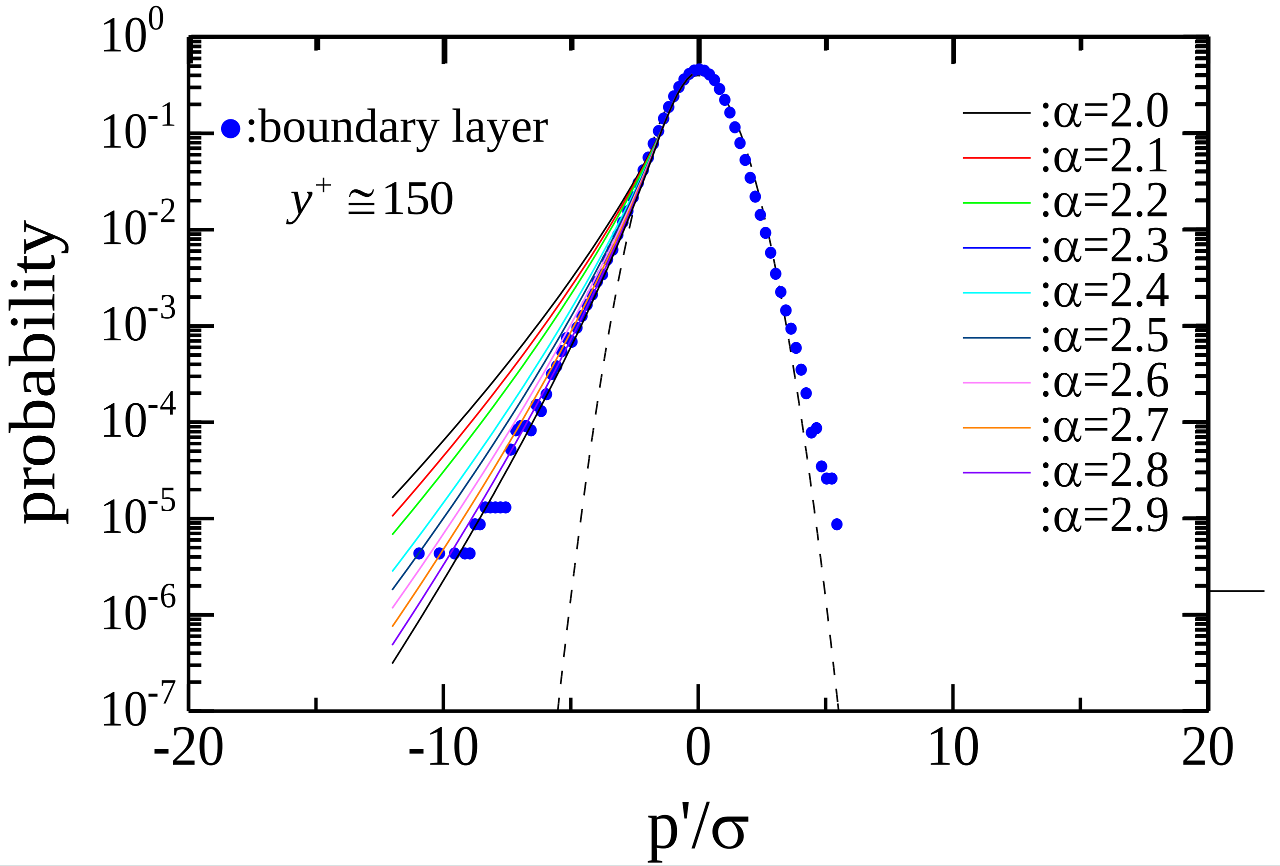


$p' = p/\sigma$

Positive tail shows close to Gaussian profile.

Negative tail shows stretched exponential tail.

Correction of PDF negative tail

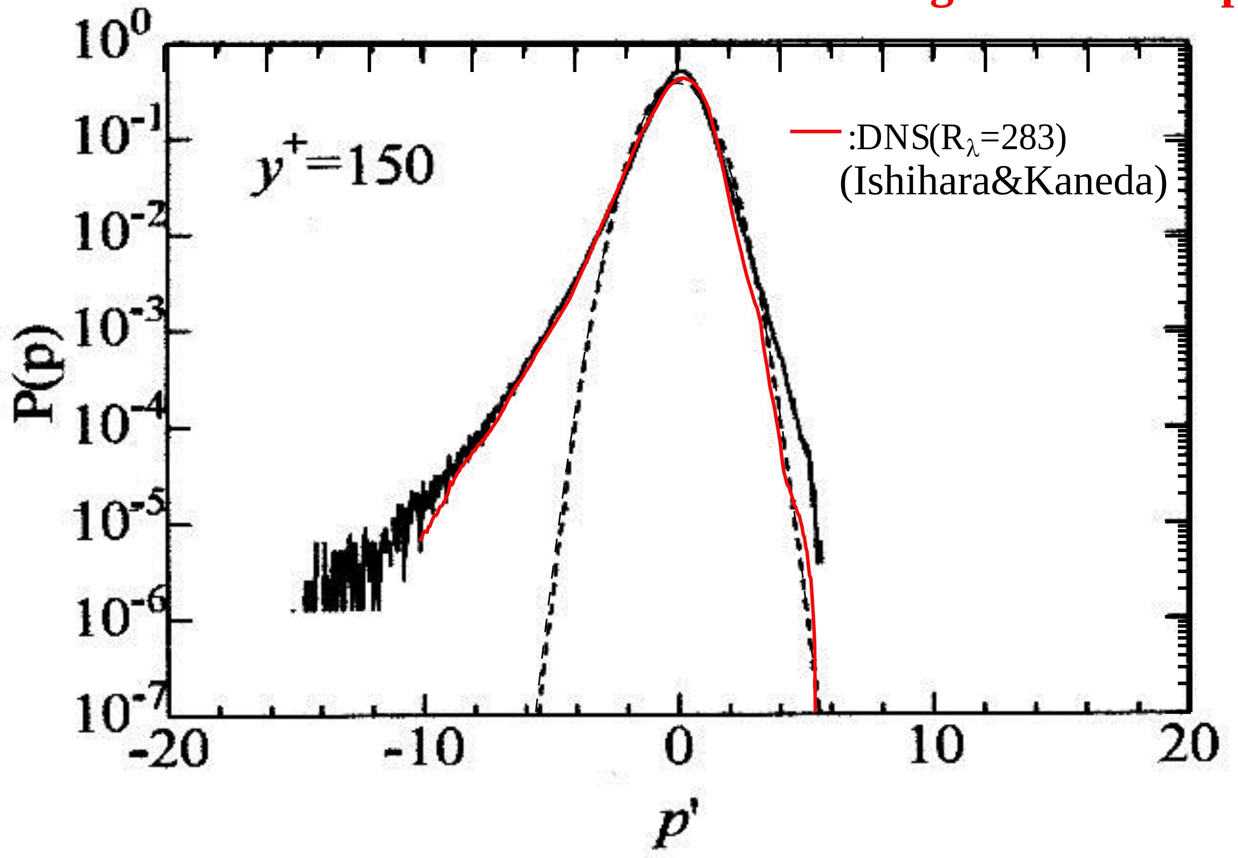


Negative tail is corrected by the stretched exponential form.

$$p(x) \cong \exp\left\{-\alpha|x|^{\beta} + \gamma\right\} \quad \beta = 0.7 \quad \gamma = \gamma(\alpha, \beta) \ \ (p'/\sigma \leq -1.5)$$

Pressure PDF in Shear flow and in HIT

Homogeneous isotropic flow field.



$\alpha \cong 2.6$

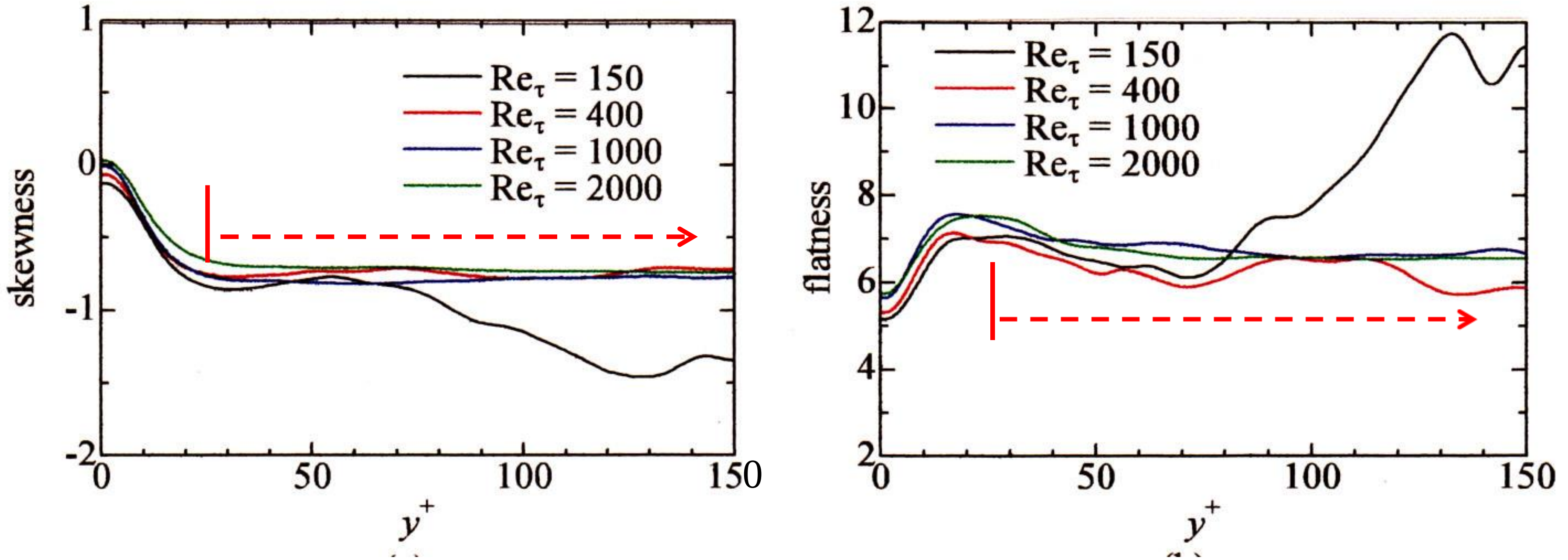
$\beta = 0.7$

Negative tail shows the similar stretched exponential tail.

HIT show the closer positive tail to Gaussian profile.

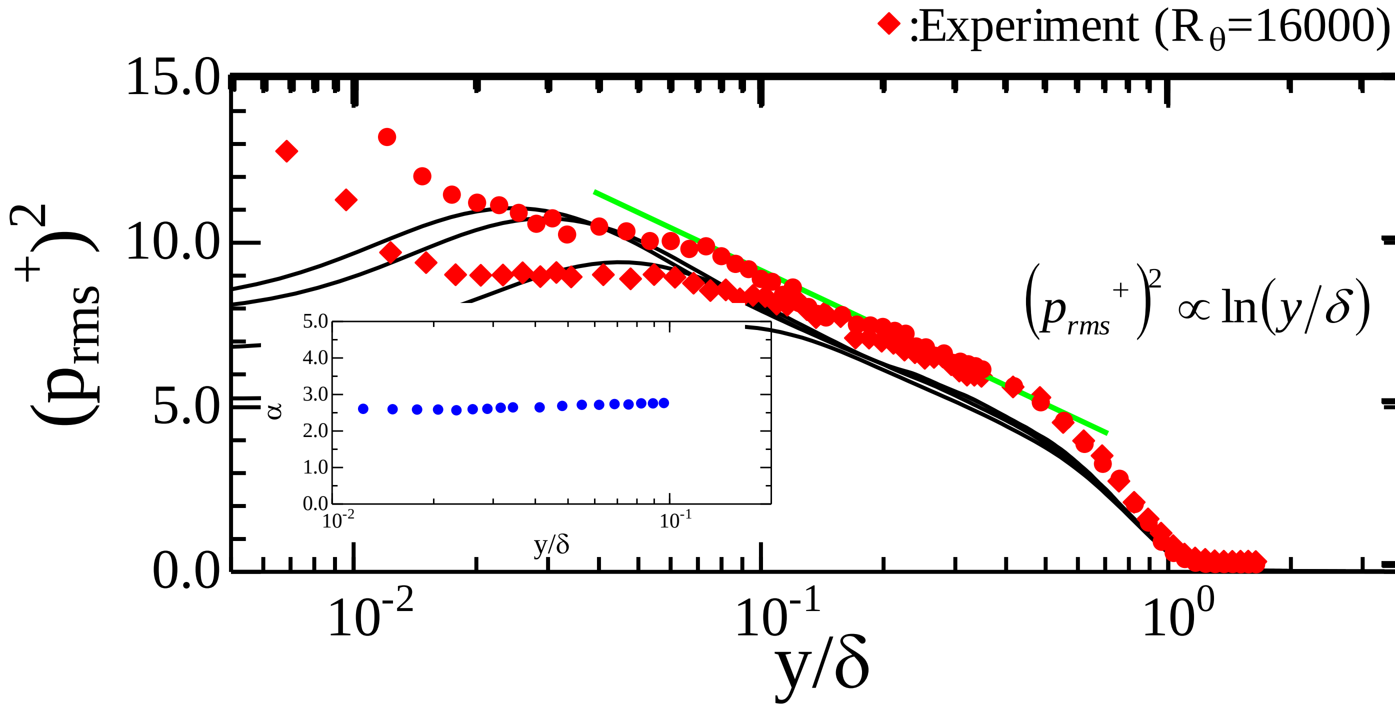
PDF shape close to the wall

Chanel Flow DNS



PDF shapes seem to be invariant from outside buffer layer to the overlap region.

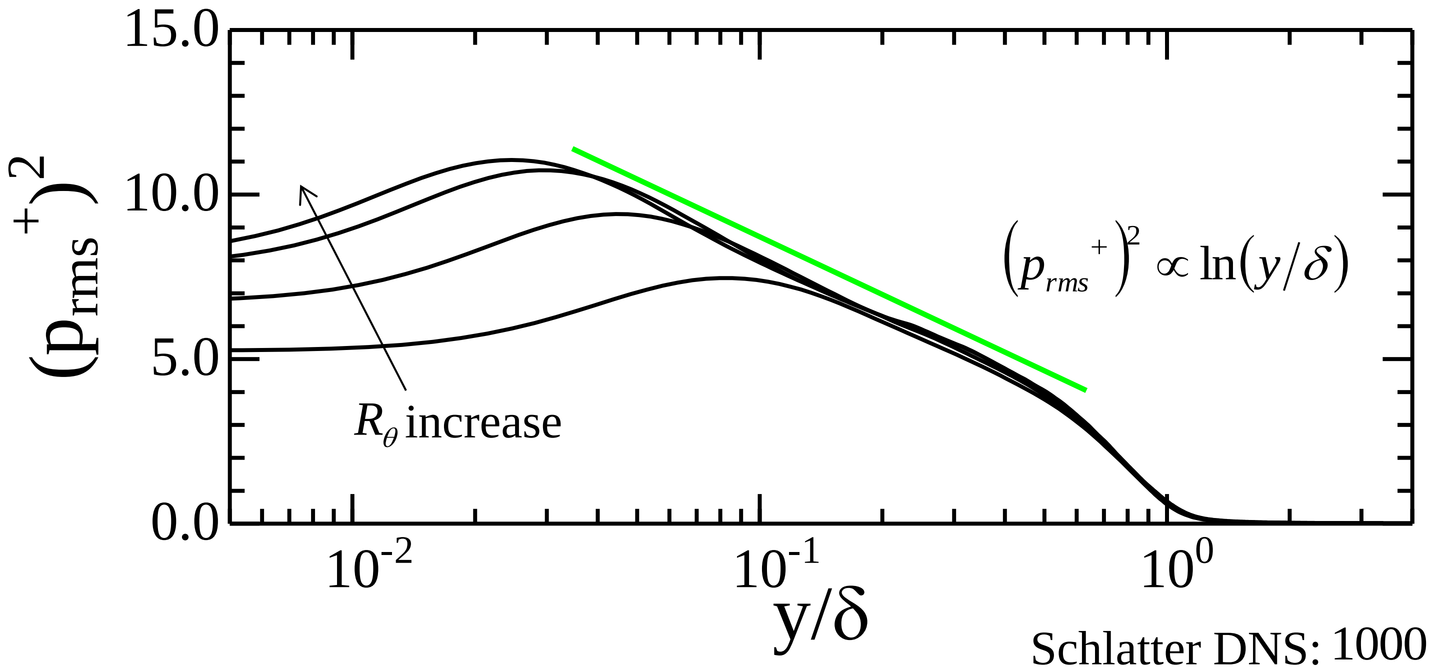
Corrected pressure r.m.s. in TBL



Pressure negative tail is corrected by the empirical form.
PDF shapes are almost invariant close to the wall.

$$p(x) \cong \exp\left\{-\alpha|x|^{\beta} + \gamma\right\} \qquad \alpha \cong 2.6 \quad \beta = 0.7$$

Objective 2



Schlatter DNS: $1000 \le R_\theta \le 4060$

The logarithmic relation is observed in relatively low Re numbers.

$$\left(p_{rms}^{+}\right)^2 \propto \ln(y/\delta)$$

Attached eddy model?

Does this relation relate to the large scale motions?

Attached Eddy Hypothesis Predictions

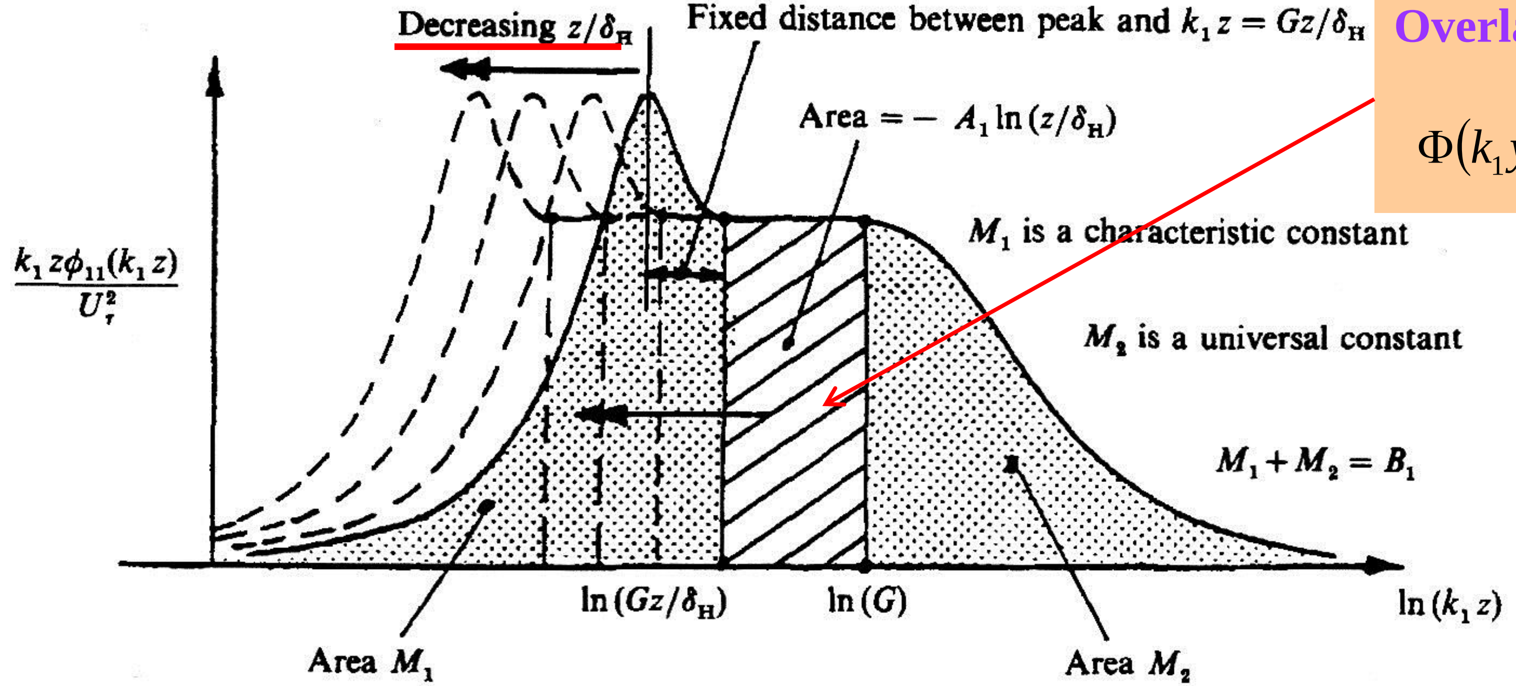


FIGURE 3. Graphic representation of terms in equation (3) for $K_\tau \to \infty$. G is a universal constant appropriately chosen so that $k_1 z = G$ and $k_1 z = G(z/\delta_H)$ fall in the -1 region.

Overlap region I

$$\Phi(k_1 y) \propto (k_1 y)^{-1}$$

$$\left(\frac{u_{rms}}{u_\tau}\right)^2 \cong -A_1 \log\left(\frac{y}{\delta}\right) + B_1$$

Perry, Henbest & Chong, 1986

Stream-wise velocity r.m.s. in TBL

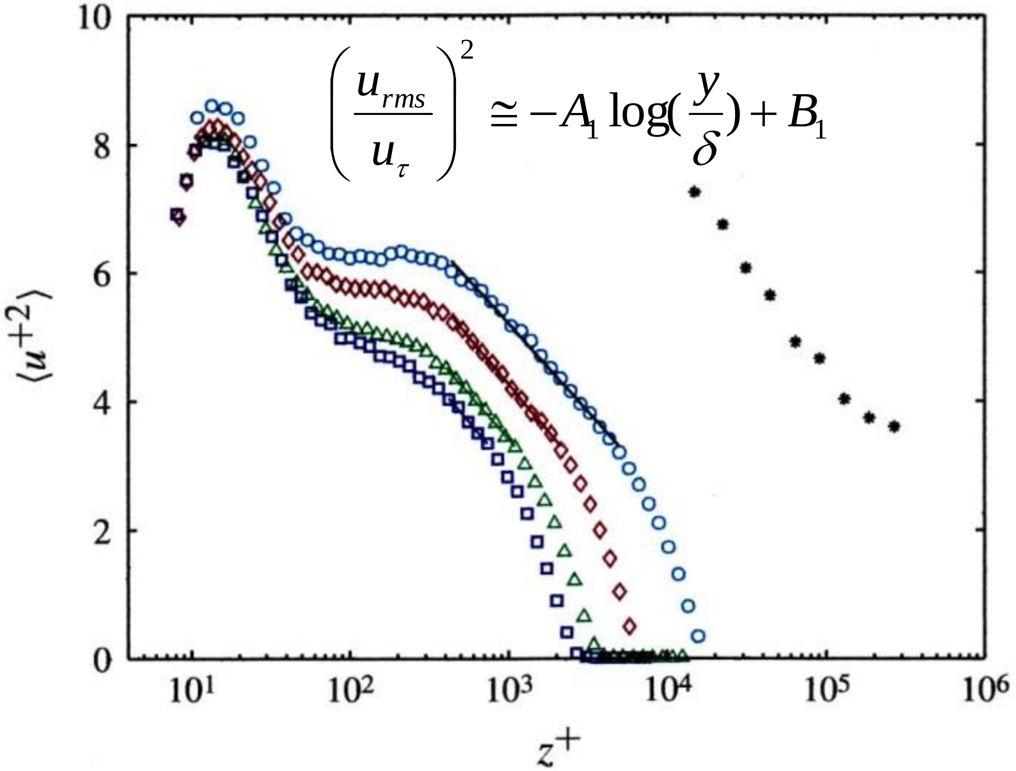
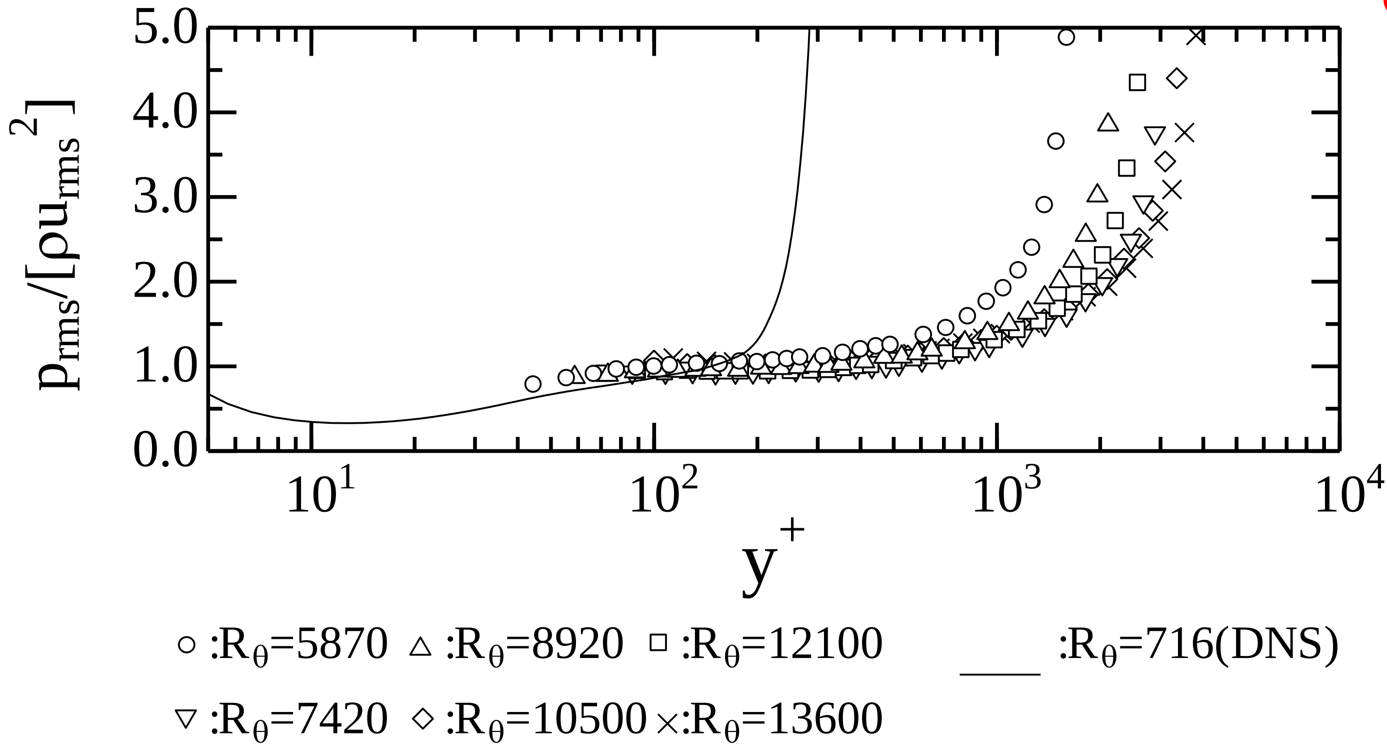


FIGURE 1. Variance of streamwise velocity in turbulent boundary layers at several Reynolds numbers $Re_\tau = 2800$ (□), 3900 (△), 7300 (◇) and 19 030 (○), respectively, and SLTEST data (∗). The solid lines indicate fits to the logarithmic region, performed in the range $z^+ > 400$ and $z/\delta < 0.3$.

C. Meneveau and I. Marusic J. Fluid Mech. (2013), vol. 719, R1

Relation between velocity and pressure

experiment



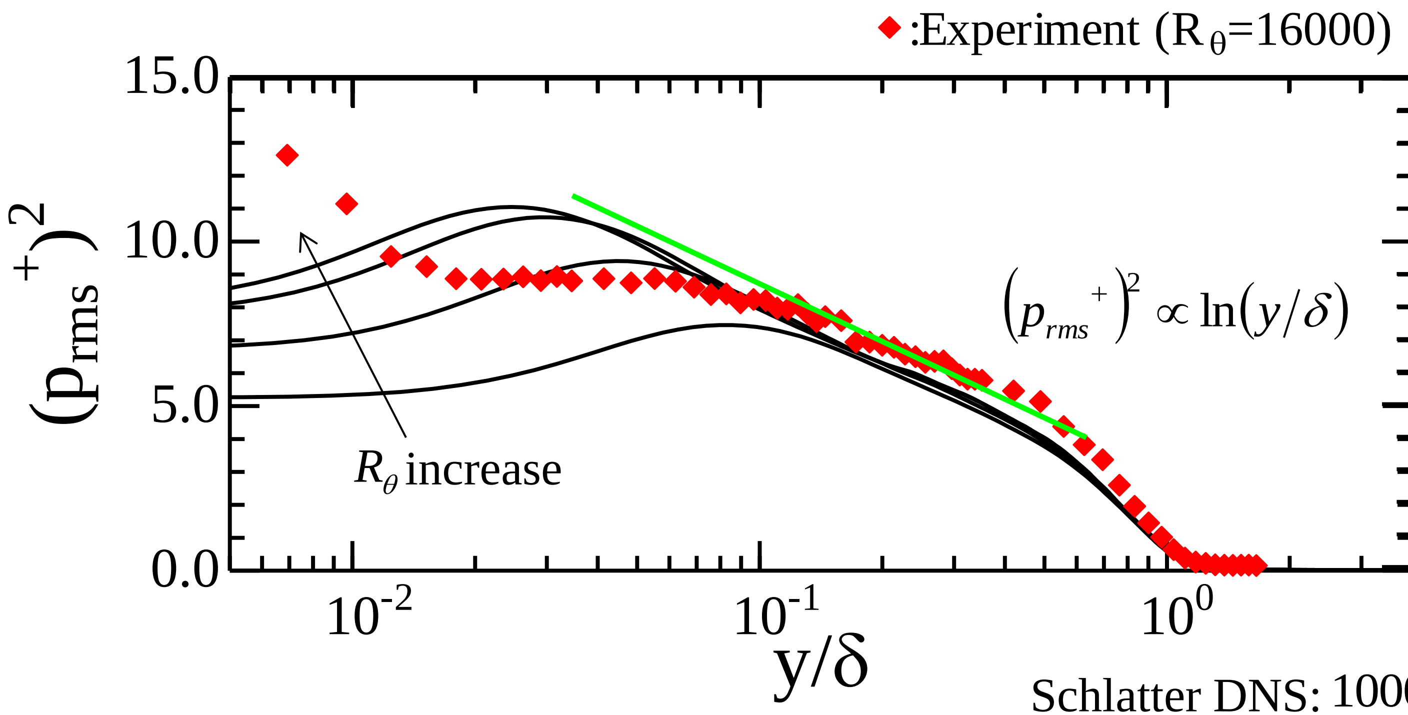
$$\left(u_{rms}^{\ +}\right)^2 = -A_u \log(y/\delta) + B_u$$

$$p_{rms}/\left(\rho u_{rms}^{\ 2}\right) \cong O(1)$$

⇒

$$\left(p_{rms}^{\ +}\right)^2 \neq -A_p \log(\frac{y}{\delta}) + B_p$$

Static pressure r.m.s. in TBL



Schlatter DNS: $1000 \le R_\theta \le 4060$

The logarithmic relation is reconstructed by the correction of small scales

$$\left(p_{rms}^{+}\right)^2 \propto \ln(y/\delta)$$

Then the small scale is probably import for this logarithmic relation.

Summary

From the pressure measurements in turbulent boundary layer, the results may be summarized as follows.

- The attenuation effect is significantly appear in the tail part in PDF.
- If the negative tail part is corrected by the empirical form, then the pressure intensity is improved. And it shows the Similar trend with DNS.

$$p(x) \cong \exp\left\{-\alpha|x|^{\beta} + \gamma\right\} \qquad \alpha \cong 2.6 \quad \beta = 0.7 \;\; (p'/\sigma \leq -1.5)$$

- The logarithmic relation for the pressure may be generated by the small scale, not only by the large scale.

$$\left(p_{rms}{}^{+}\right)^2 \propto \ln(y/\delta)$$