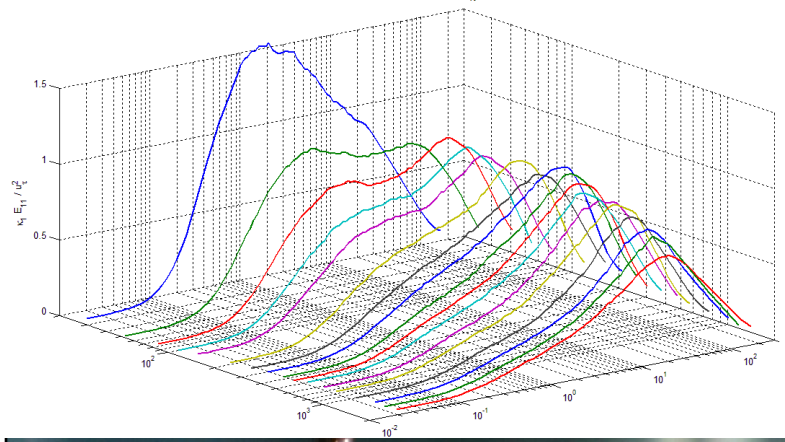
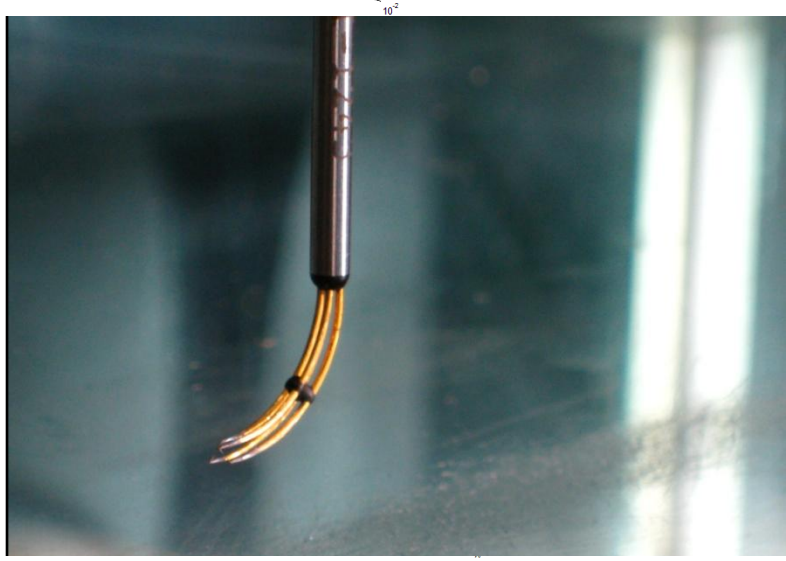
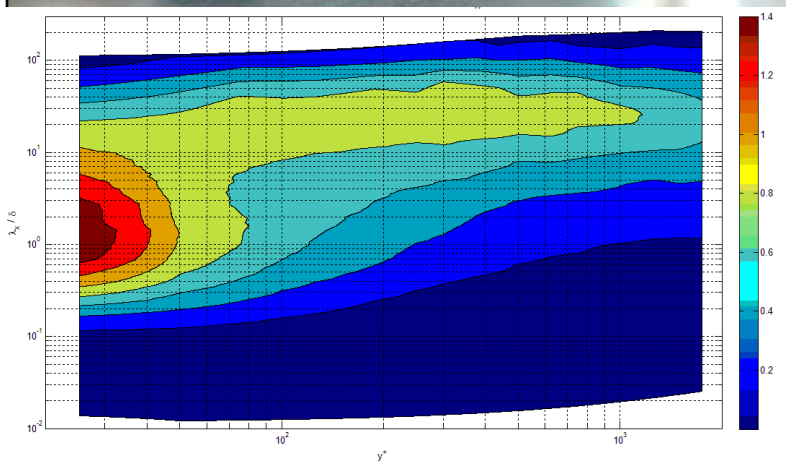
Cornell University

Complex dynamics of a boundary layer with free stream turbulence







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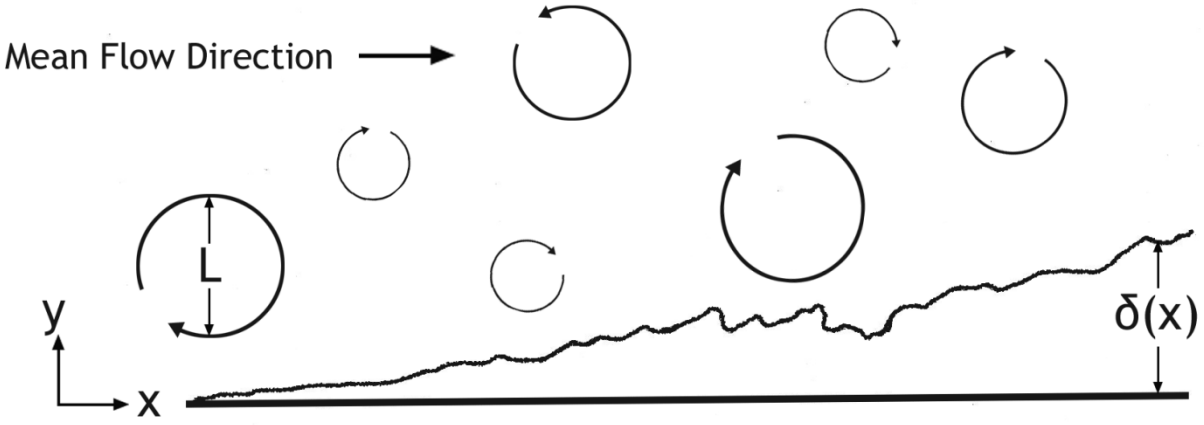
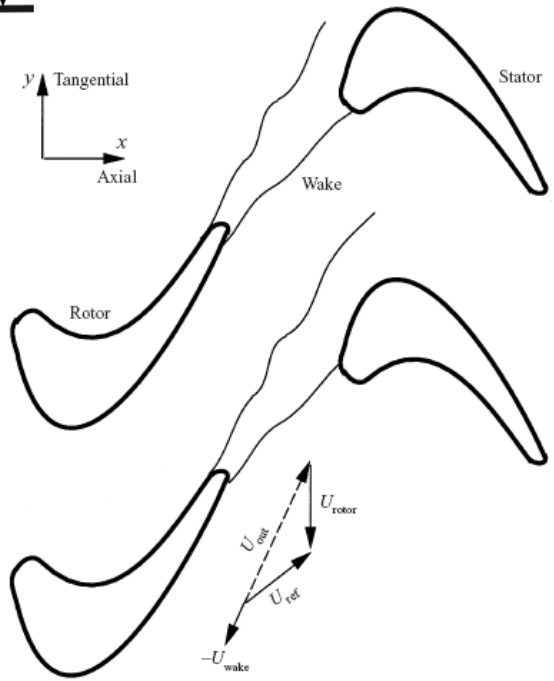
APS DFD Meeting San Antonio, TX

24 November 2008

Introduction



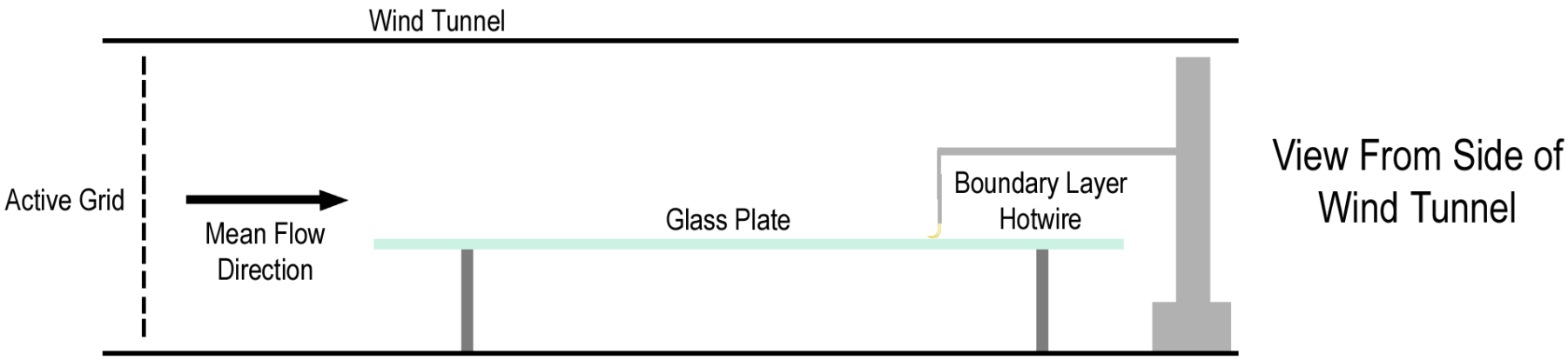
FSTI = free stream turbulence intensity = $(u_{rms} / U)_{freestream}$



- Simplification of flow over turbine / compressor blades

Figure from Wu, Jacobs, Hunt, and Durbin. *JFM*, v. 398, 1999.

Experimental Set-Up



Active grid introduces large-scale turbulent eddies
→ higher Re_λ

Previous Work

Hancock and Bradshaw (1989)

- Intensities < 6%
- Re_θ > 2,000
- Studied variances

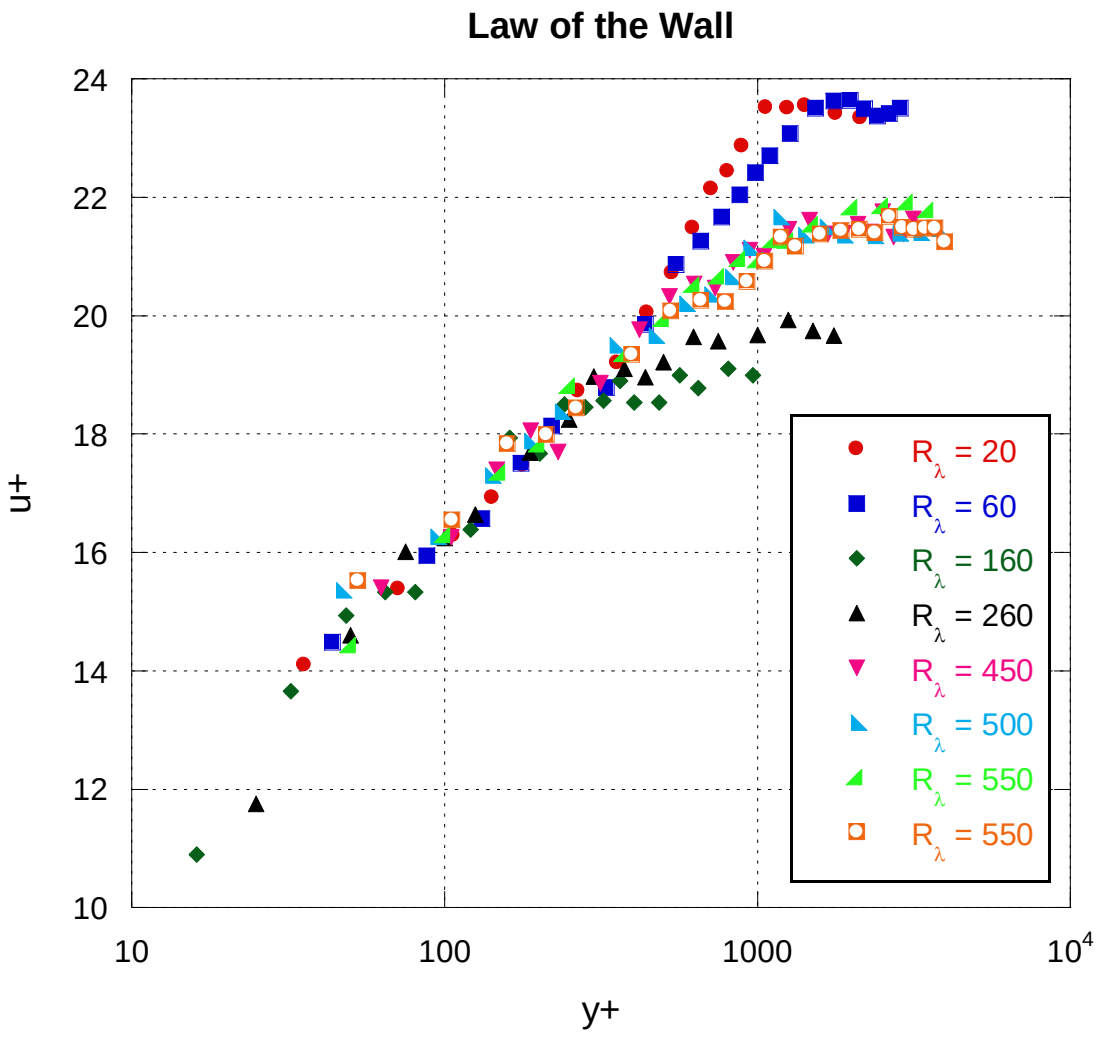
Thole and Bogard (1996)

- Intensities < 20%
- Re_θ ~ 600
- Found integral length scales at free stream values until y/δ ~ 0.3

Hancock, P.E. and Bradshaw, P. "Turbulence structure of a boundary layer beneath a turbulent free stream." *JFM*, vol. 205, 1989.

Thole, K.A. and Bogard, D.G. "High free stream turbulence effects on turbulent boundary layers." *J. Fluids Engi.*, vol. 118, 1996.

Results



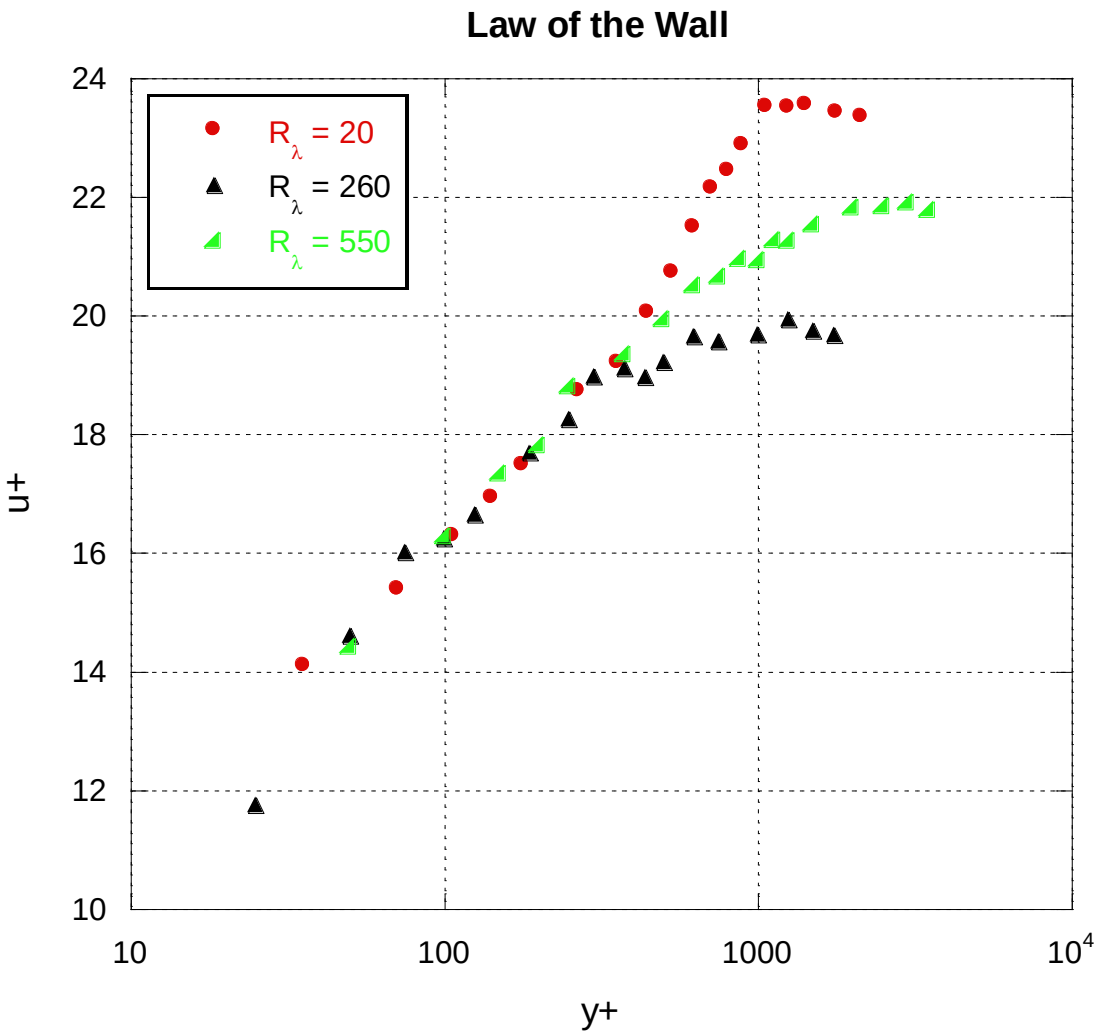
8 Cases

$20 < R_\lambda < 550$

$0.25\% < FSTI < 10.5\%$

$550 < Re_\theta < 2840$

Results



R_λ	20	260	550
U_0 (m/s)	6.25	3.70	8.15
FSTI	0.25%	8.0%	10.2%
Re_θ	2460	775	1980
Re_τ	1245	915	2020
Grid	none	active, off	active, on

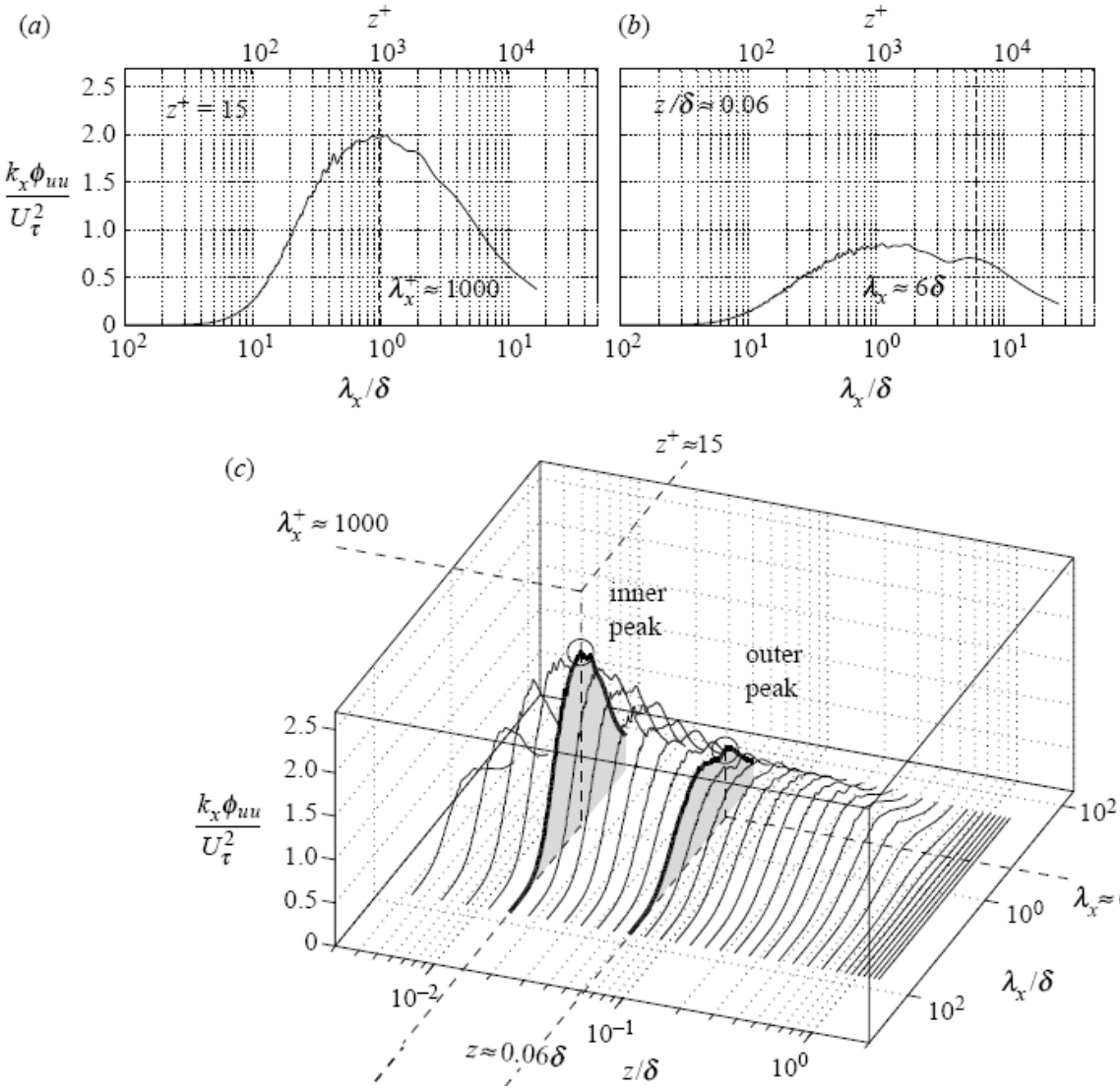
Energy Spectra: Canonical

- Canonical boundary layer shows two peaks in the energy spectra

$$\lambda_x^+ = \frac{2\pi}{\kappa_x}\frac{u_\tau}{\nu}$$

Inner peak: $\lambda_x^+ \sim 1000$

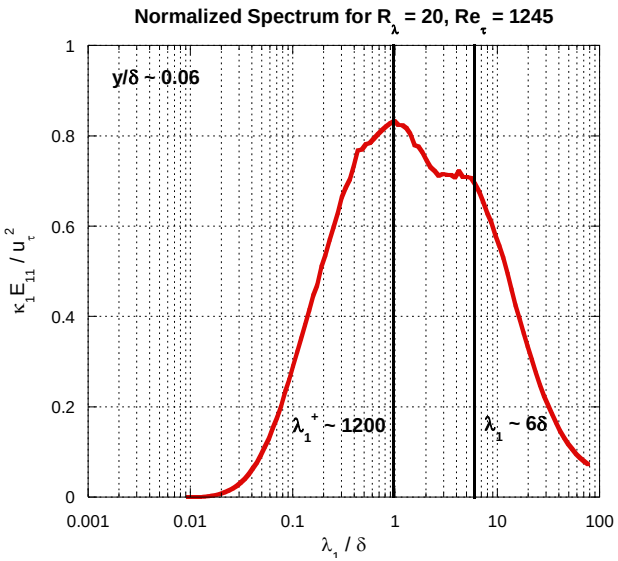
Outer peak: $\lambda_x \sim 6\delta$



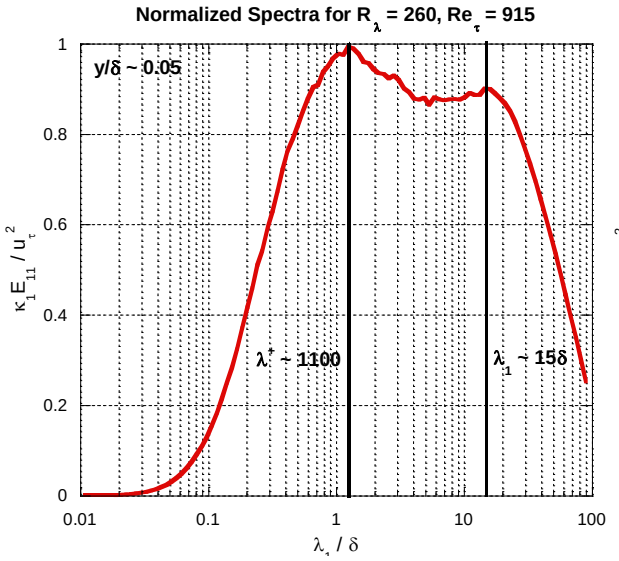
Hutchins N, and Marusic I. "Large-scale influences in near-wall turbulence." *Phil. Trans. R. Soc. A.* v. 365, 2007.

Energy Spectra: Non-Canonical

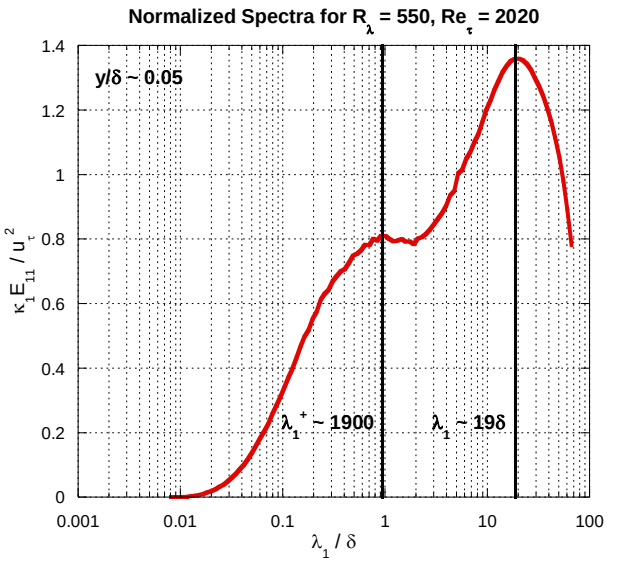
$R_\lambda = 20$



$R_\lambda = 260$



$R_\lambda = 550$



Inner peak: $\lambda_x^+ \sim 1200$

Outer peak: $\lambda_x \sim 6\delta$

Inner peak: $\lambda_x^+ \sim 1100$

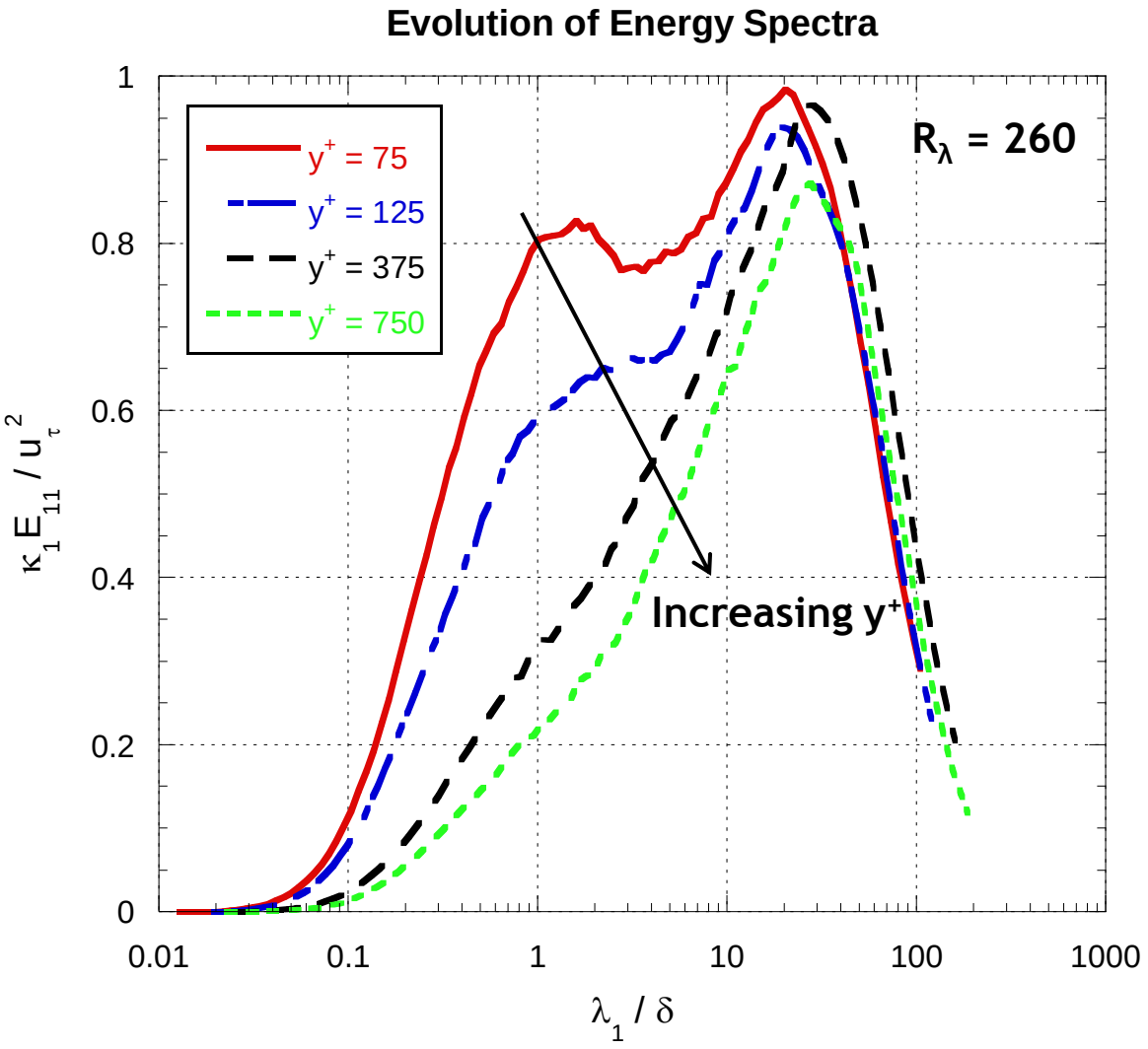
Outer peak: $\lambda_x \sim 15\delta$

Inner peak: $\lambda_x^+ \sim 1900$

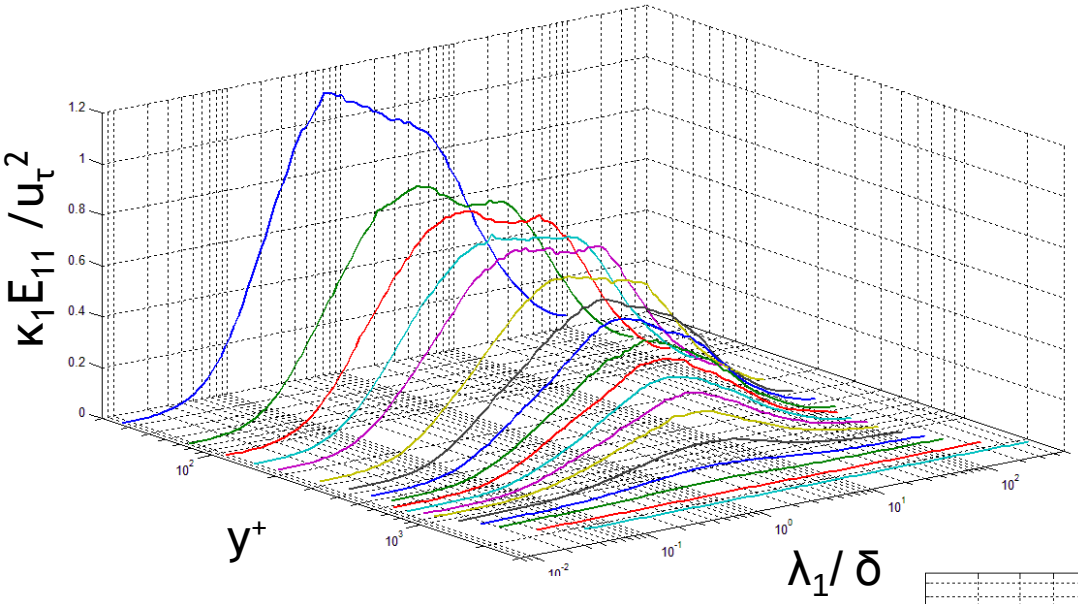
Outer peak: $\lambda_x \sim 19\delta$

Evolution of Spectra

- Inner peak fades further from the wall, indicating the presence of a scale native to the boundary layer.

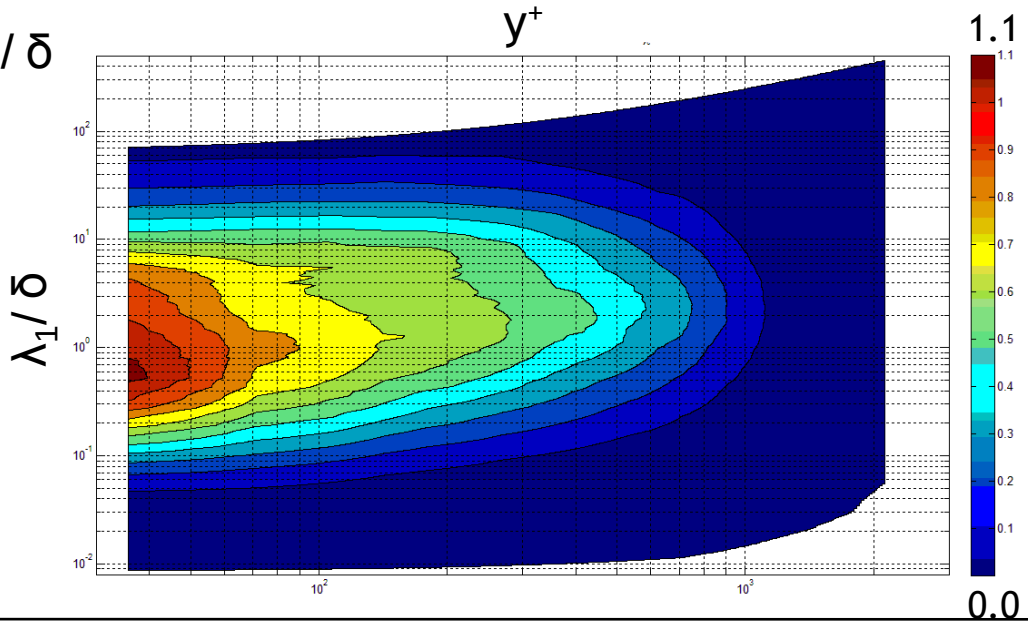


Evolution of Spectra, $R_\lambda = 20$

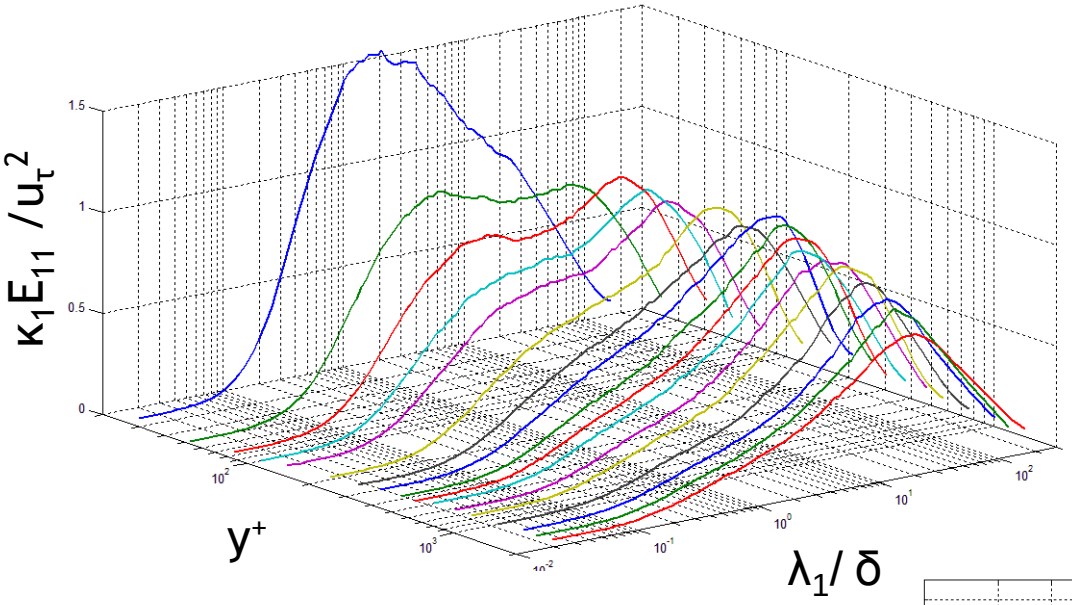


← 3D View from Side

Contour View from Top →

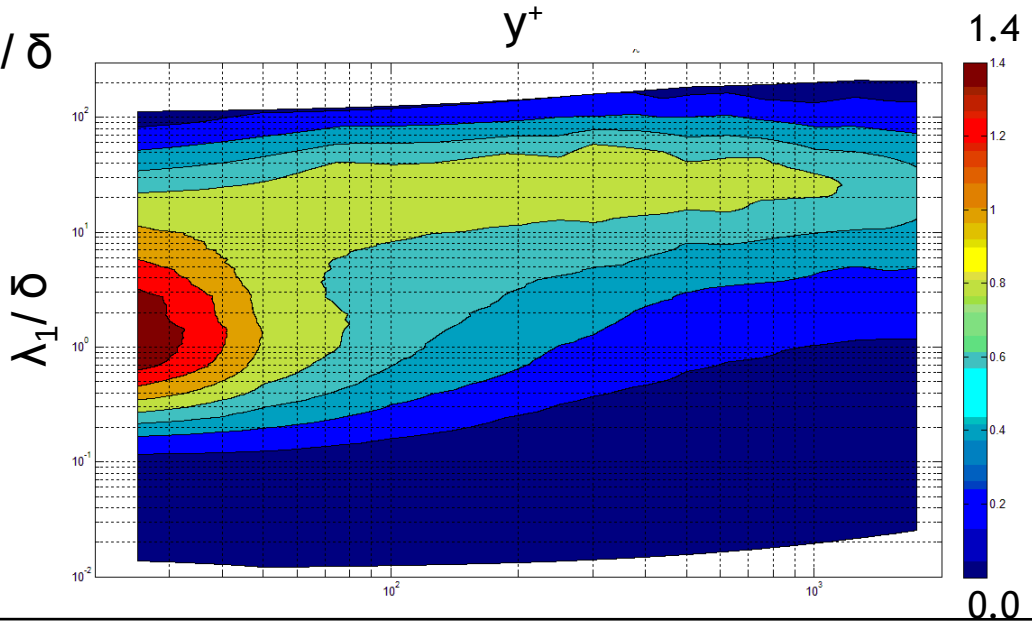


Evolution of Spectra, $R_\lambda = 260$

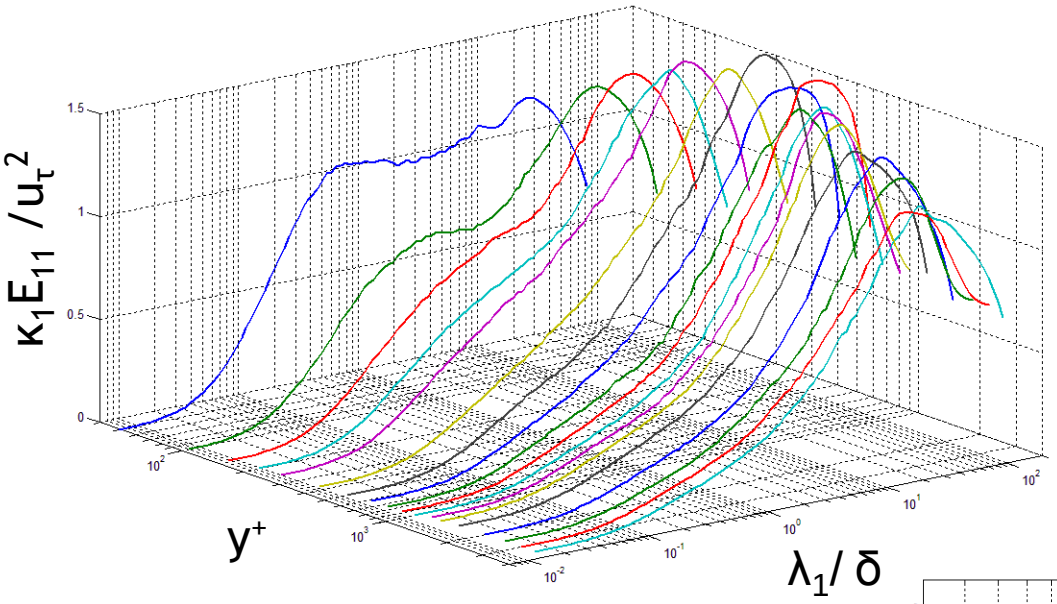


← 3D View from Side

Contour View from Top →

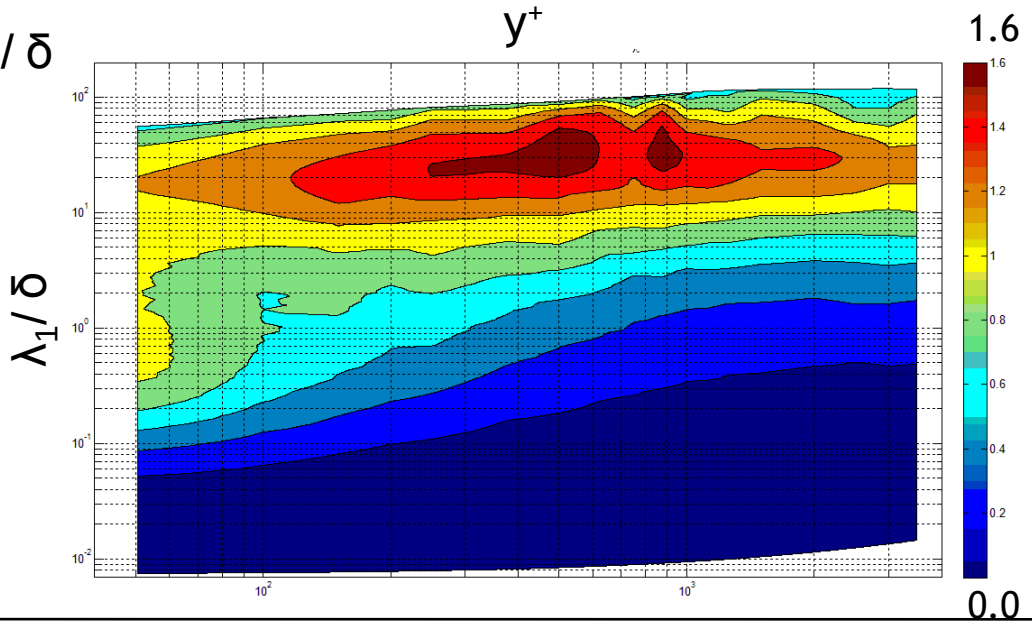


Evolution of Spectra, $R_\lambda = 550$

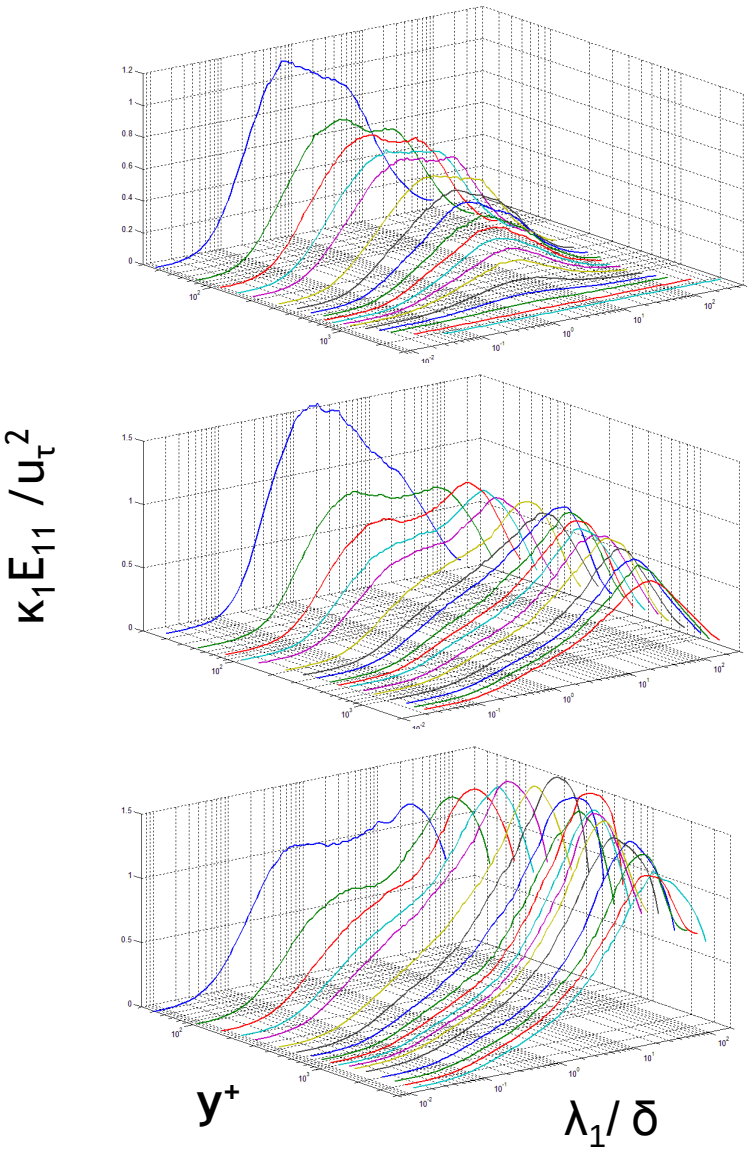


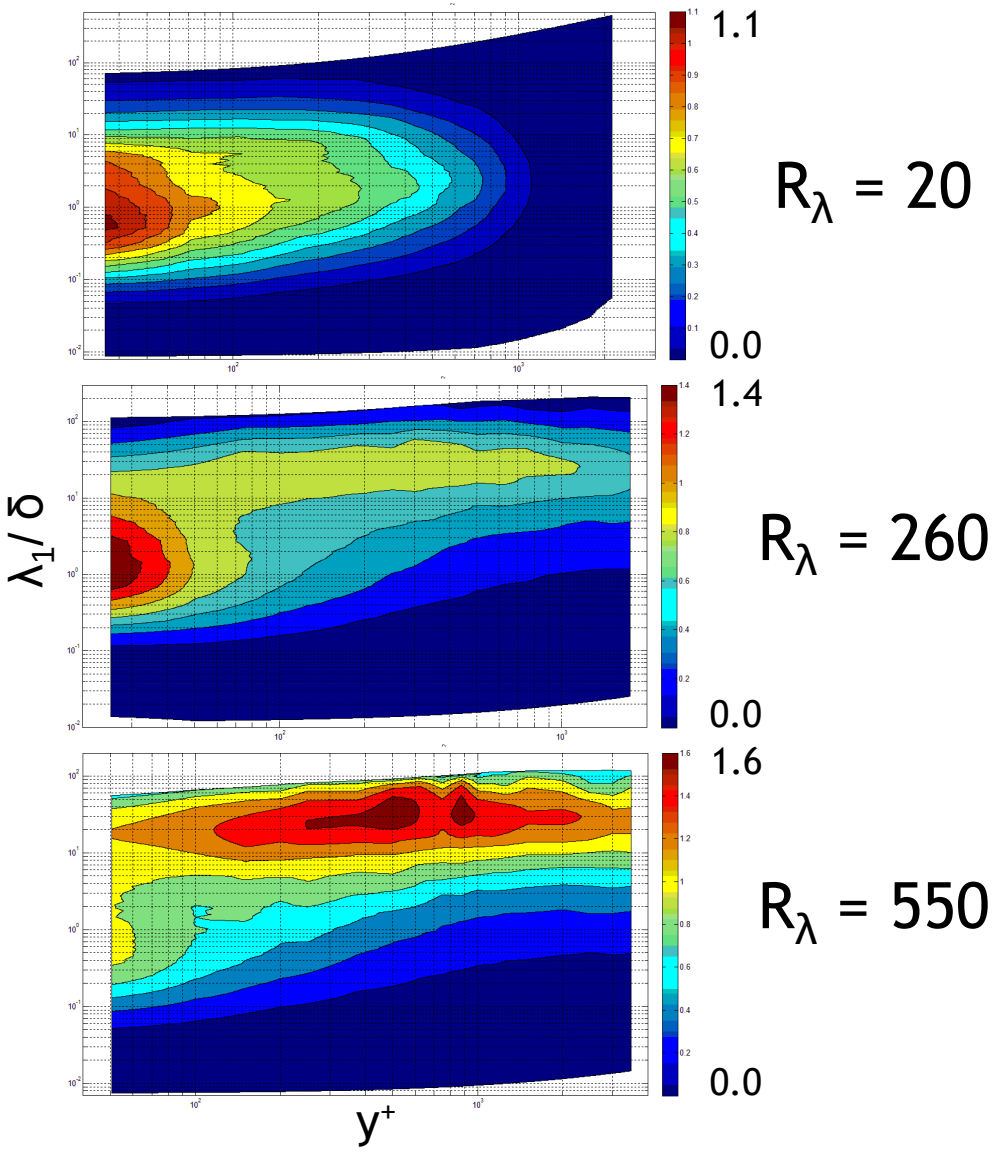
← 3D View from Side

Contour View from Top →



Evolution of Spectra





Conclusions

- Observed effects of free stream turbulence on structure throughout the boundary layer
- Matched findings of Hutchins and Marusic for near-canonical boundary layer case
- Observed two broadened peaks rather than three distinct peaks in boundary layers with free stream turbulence
- Noted complex interactions between free stream and boundary layer structure extending even below $y^+ = 100$

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