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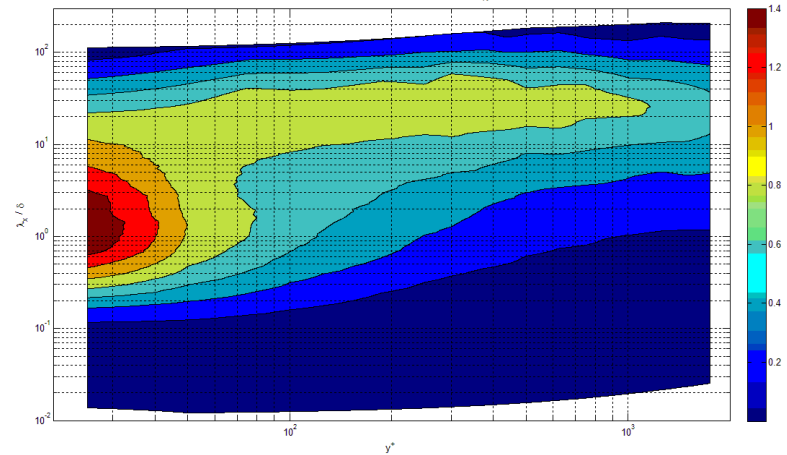
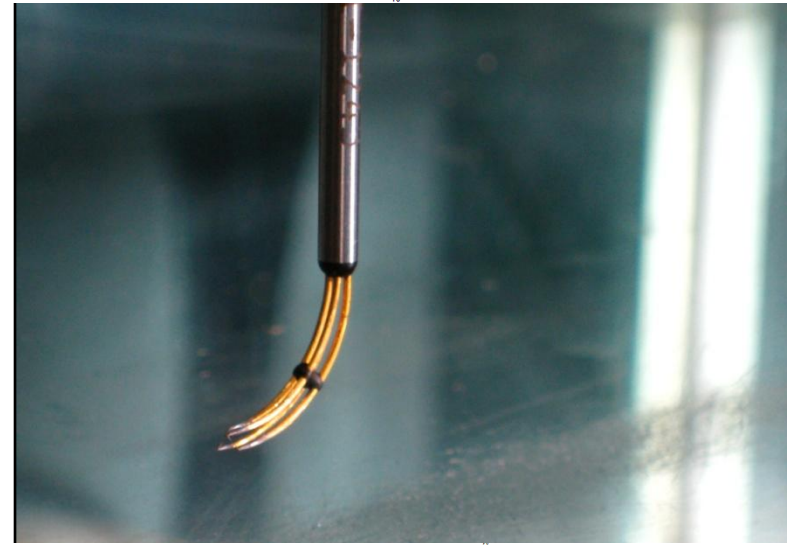
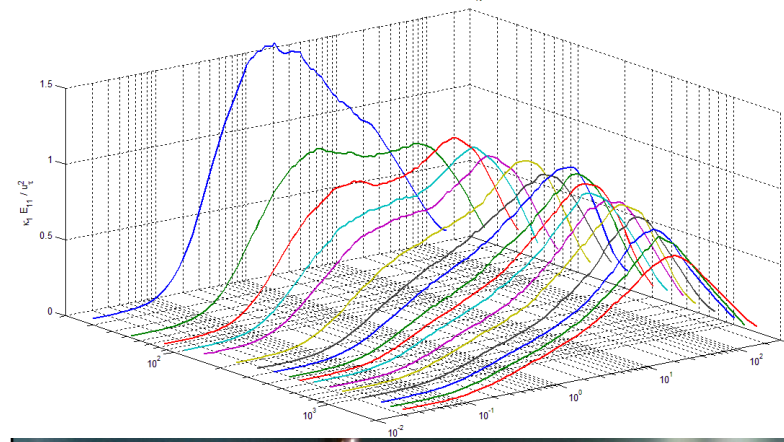
Complex dynamics of a boundary layer with free stream turbulence

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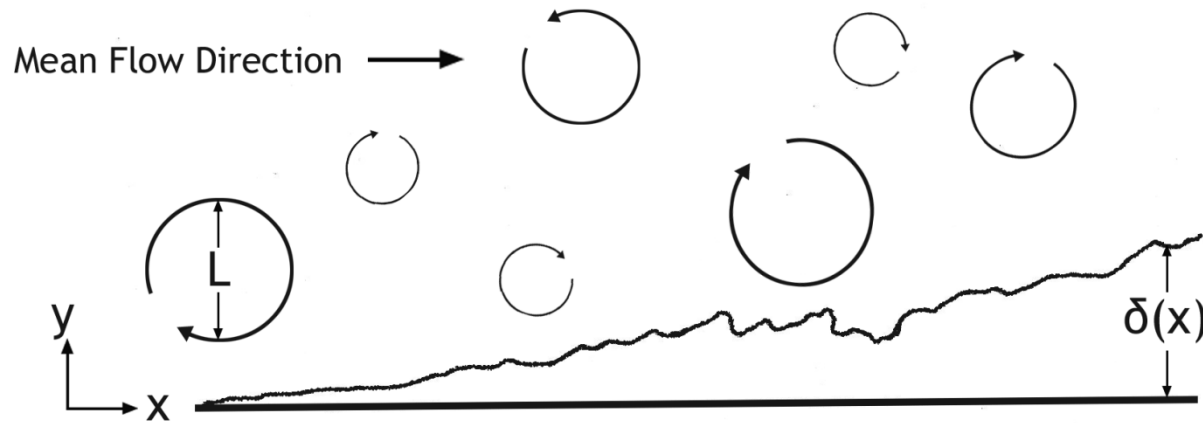
APS DFD Meeting San Antonio, TX

24 November 2008





Introduction



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

- Simplification of flow over turbine / compressor blades

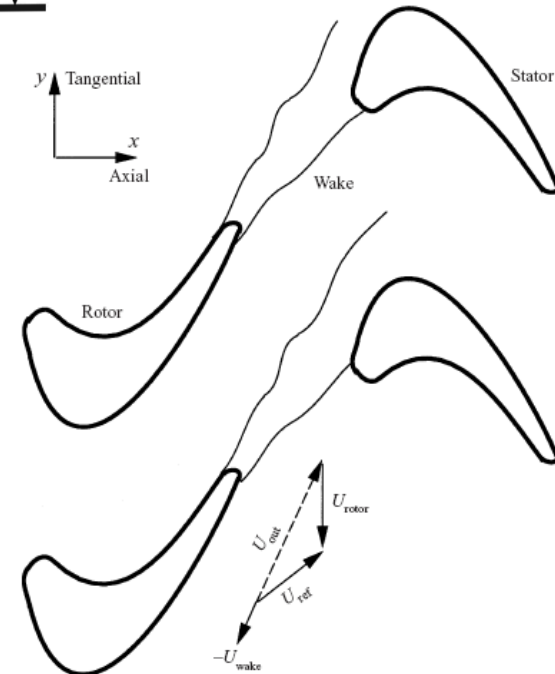
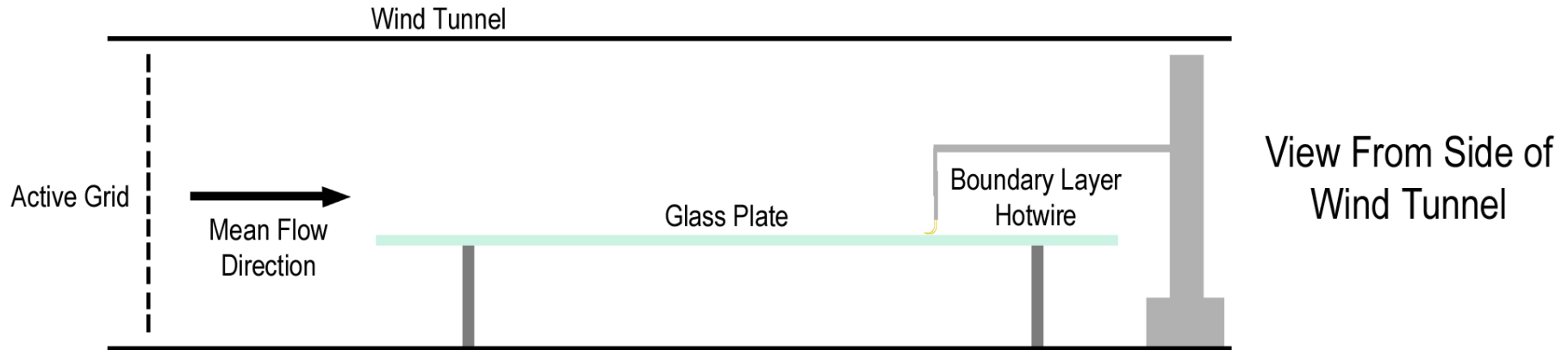


Figure from Wu, Jacobs, Hunt, and Durbin. *JFM*, v. 398, 1999.



Experimental Set-Up



Active grid
introduces large-
scale turbulent
eddies
→ higher Re_λ



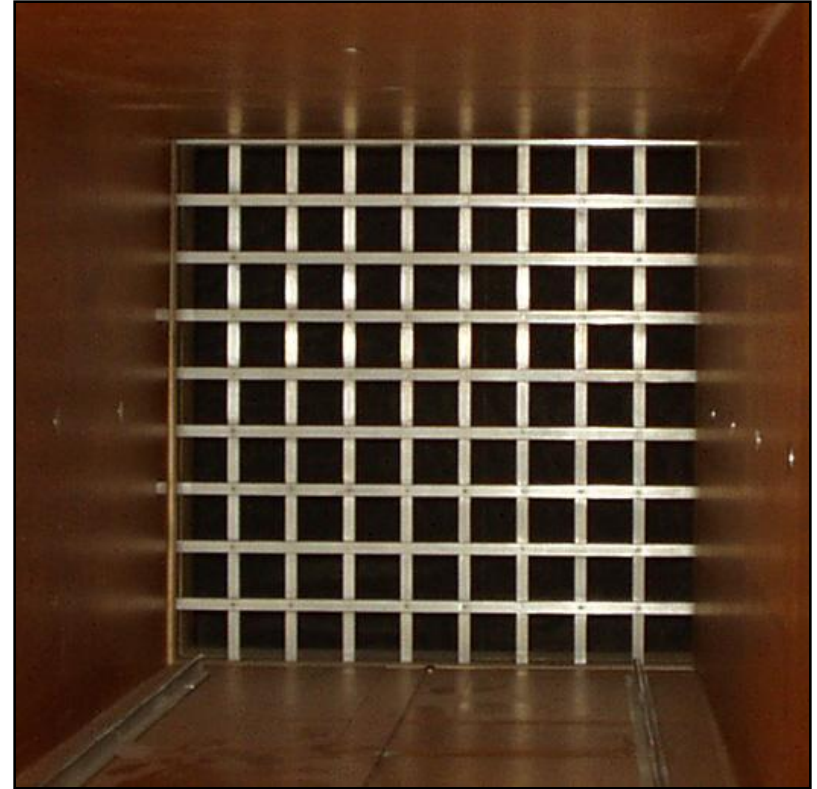
Previous Work

Hancock and Bradshaw (1989)

- Intensities $< 6\%$
- $Re_\theta > 2,000$
- Studied variances

Thole and Bogard (1996)

- Intensities $< 20\%$
- $Re_\theta \sim 600$
- Found integral length scales at free stream values until $y/\delta \sim 0.3$



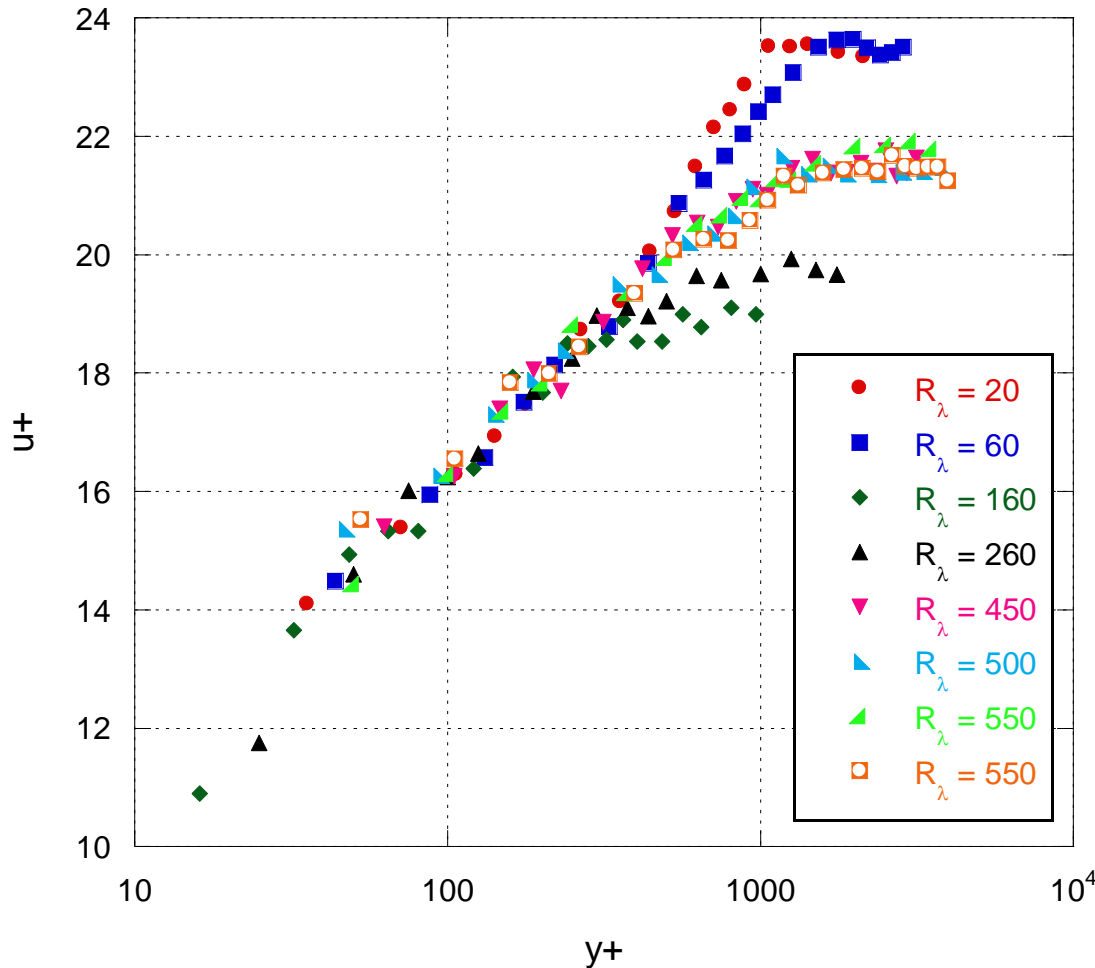
Hancock, P.E. and Bradshaw, P. "Turbulence structure of a boundary layer beneath a turbulent free stream." *JFM*, vol. 205, 1989.

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



Results

Law of the Wall



8 Cases

$$20 < R_\lambda < 550$$

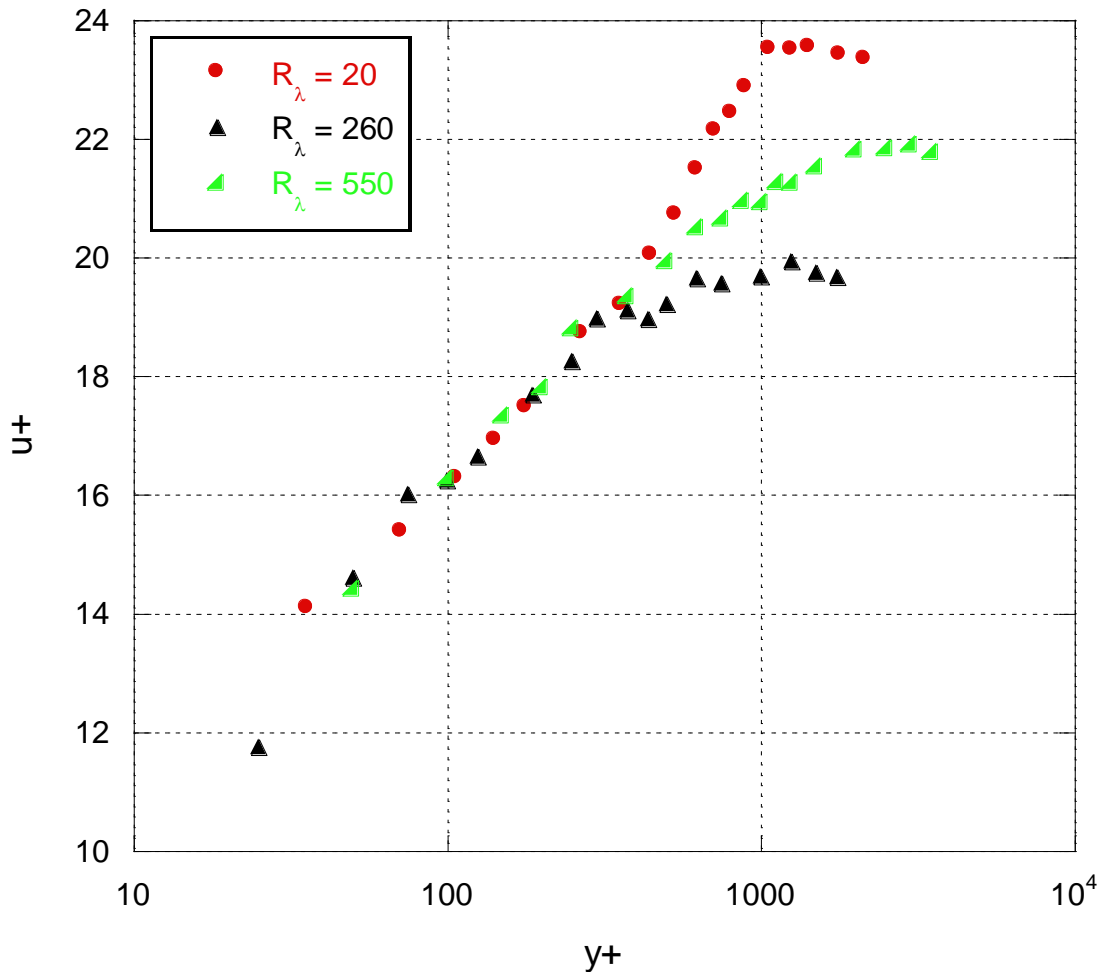
$$0.25\% < \text{FSTI} < 10.5\%$$

$$550 < Re_\theta < 2840$$



Results

Law of the Wall



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

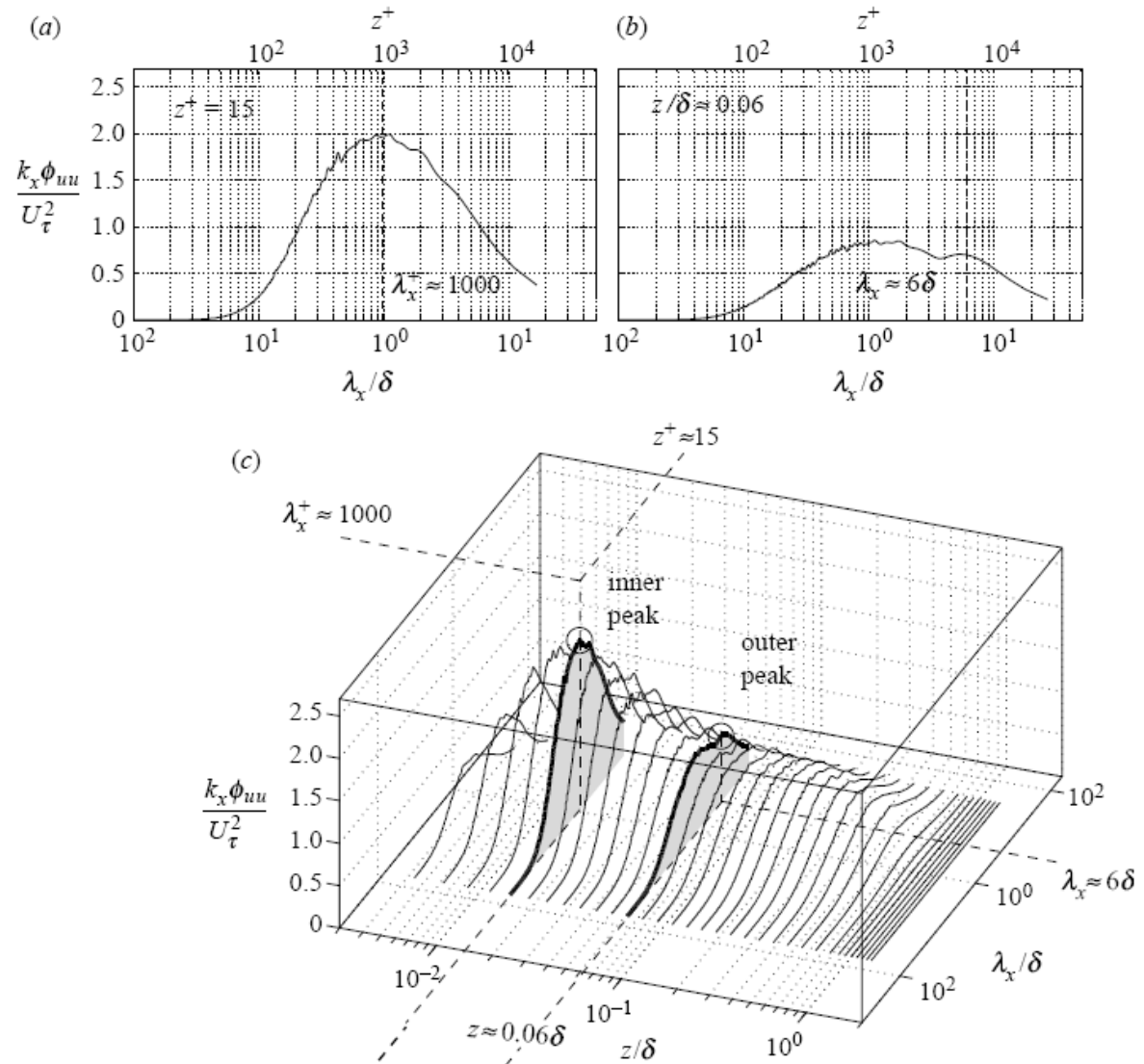
- Canonical boundary layer shows two peaks in the energy spectra

$$\lambda_x^+ = \frac{2\pi u_\tau}{K_x V}$$

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

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

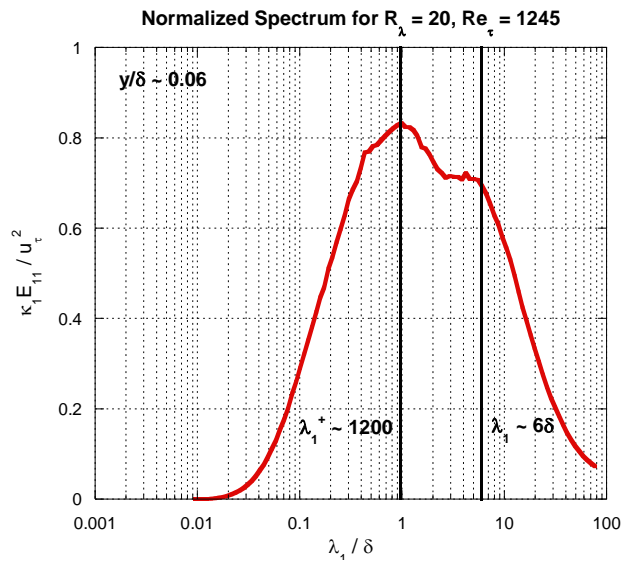
Hutchins N, and Marusic I. "Large-scale influences in near-wall turbulence." *Phil. Trans. R. Soc. A.* v. 365, 2007.





Energy Spectra: Non-Canonical

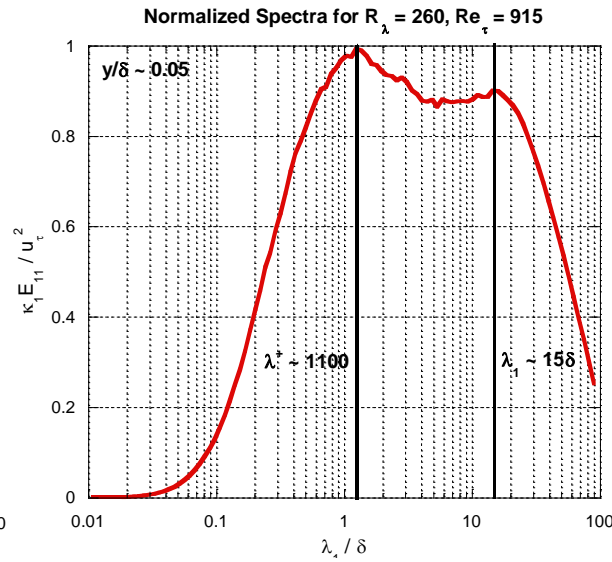
$R_\lambda = 20$



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

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

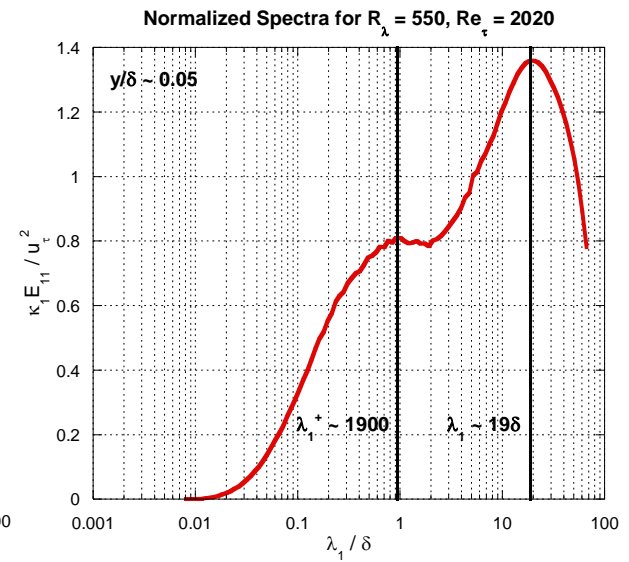
$R_\lambda = 260$



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

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

$R_\lambda = 550$



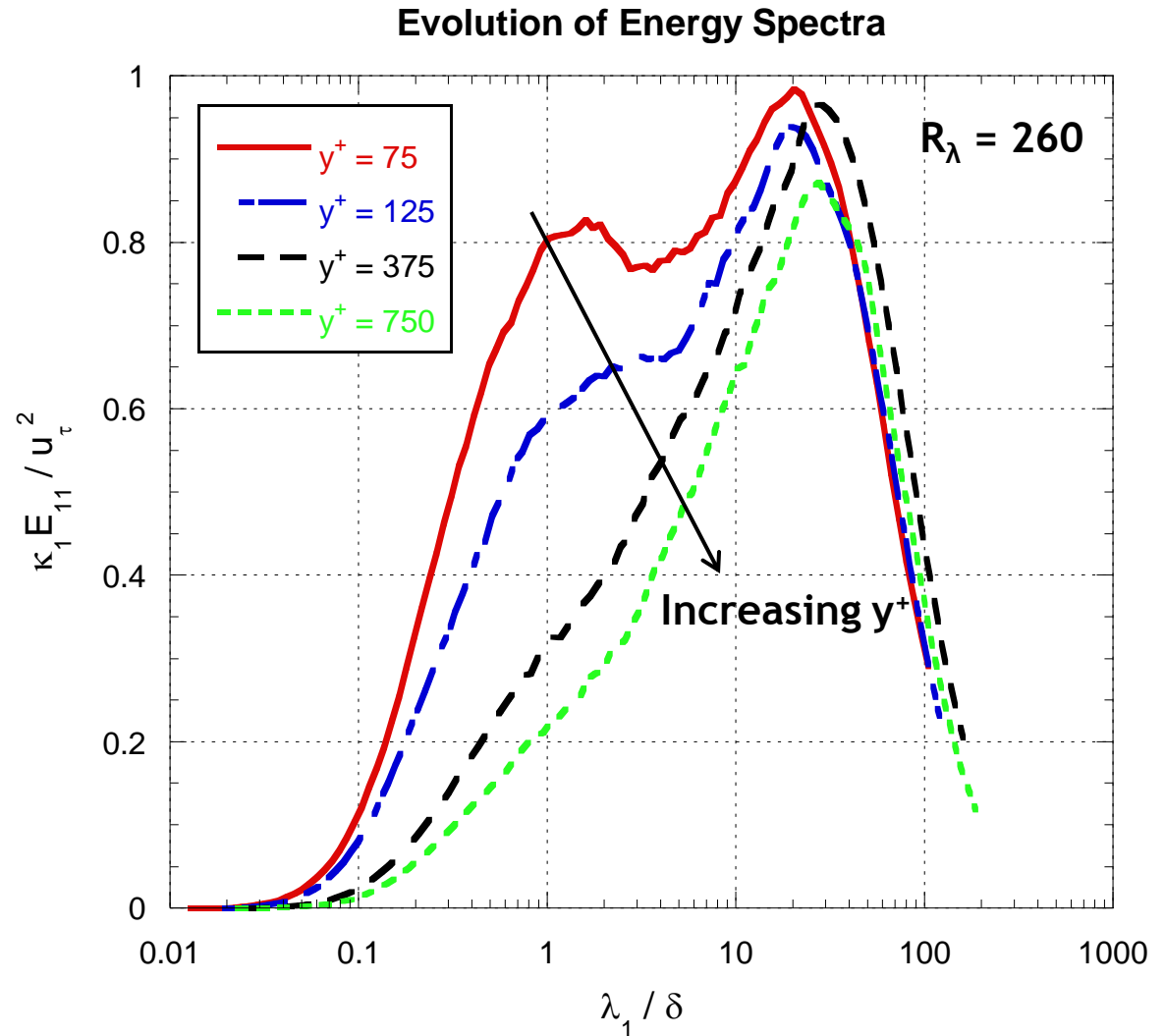
Inner peak: $\lambda_x^+ \sim 1900$

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



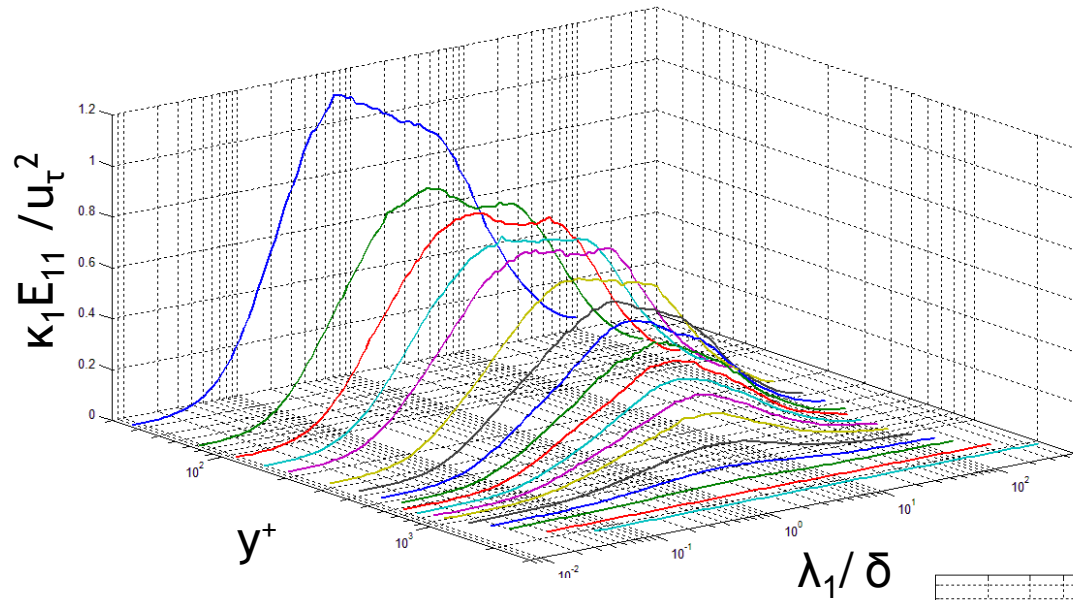
Evolution of Spectra

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



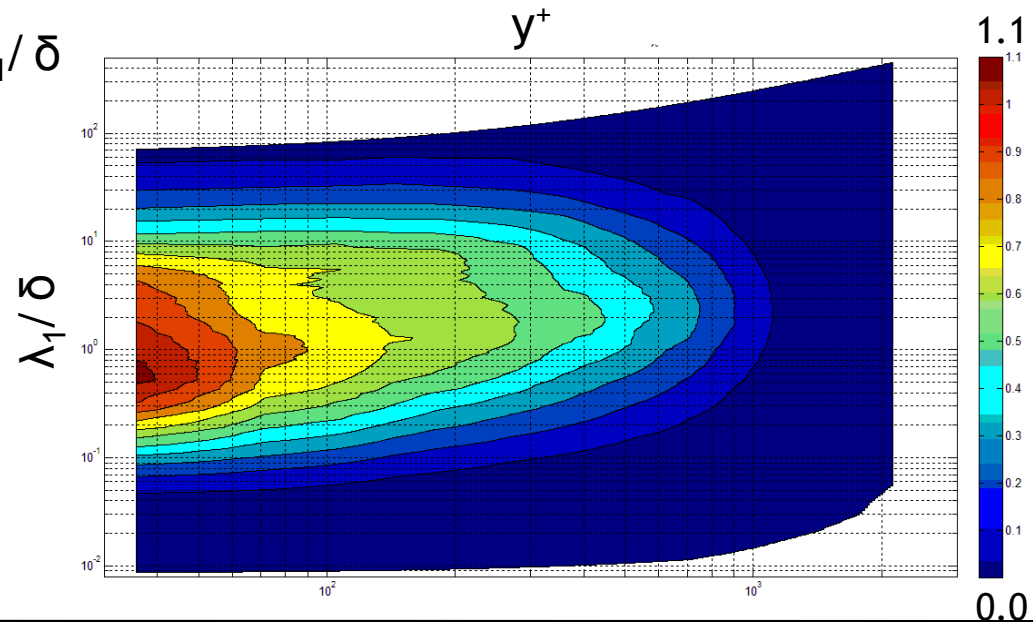


Evolution of Spectra, $R_\lambda = 20$



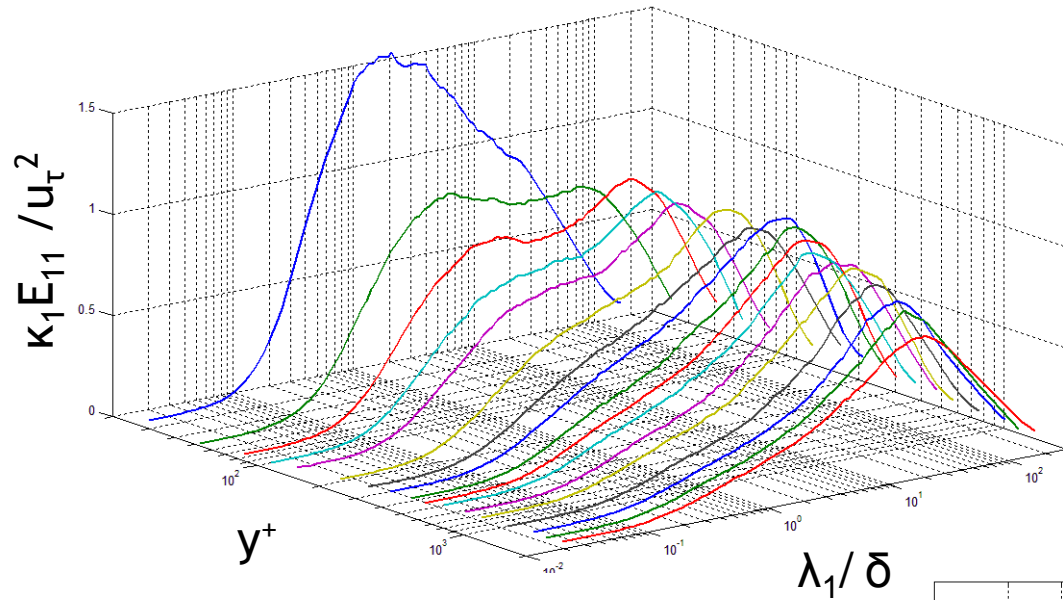
← 3D View from Side

Contour View from Top →



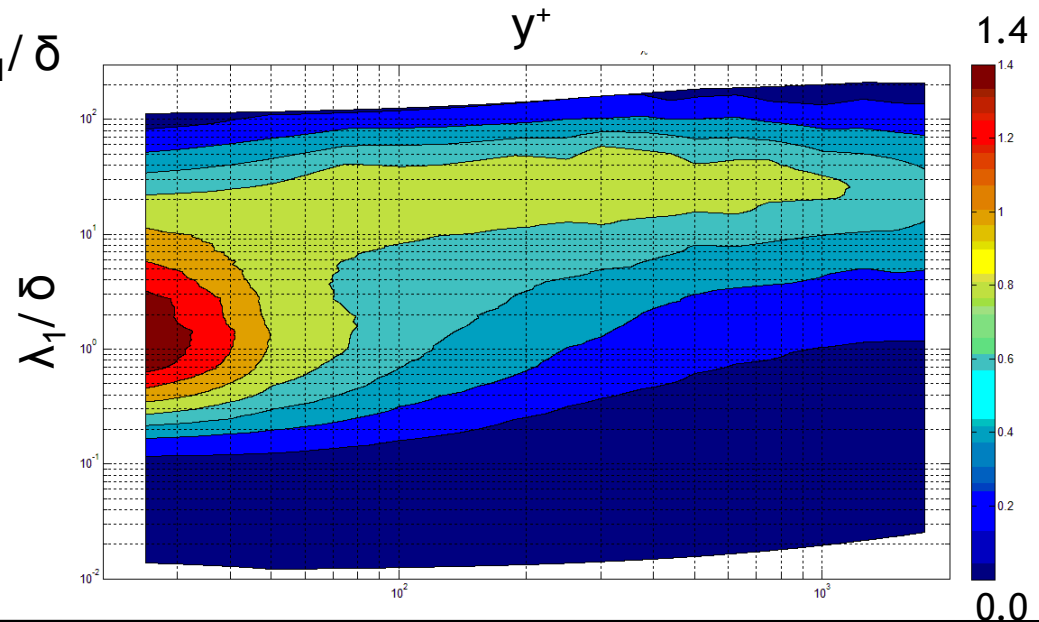


Evolution of Spectra, $R_\lambda = 260$



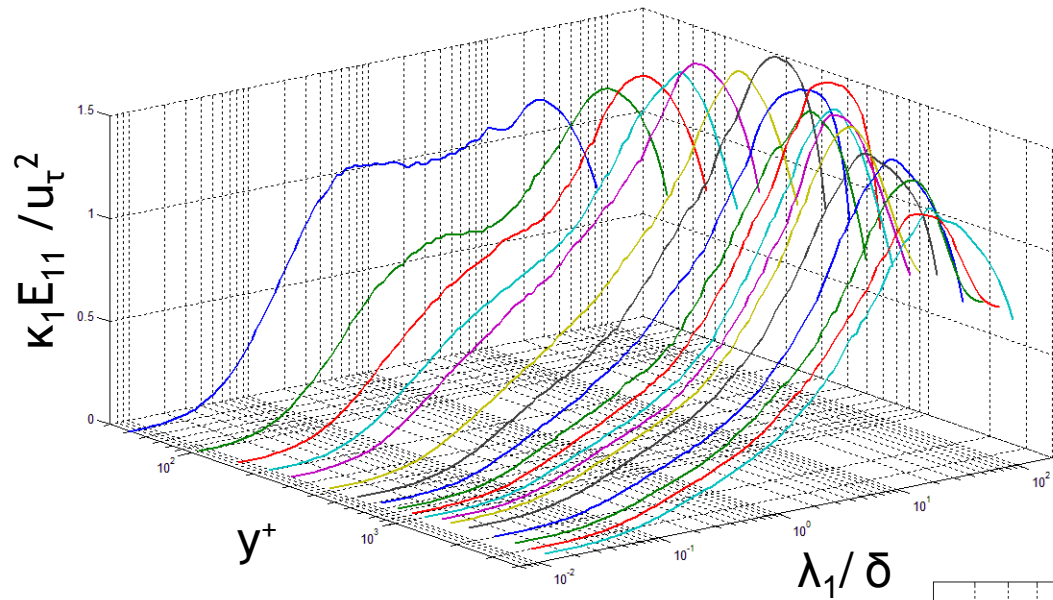
← 3D View from Side

Contour View from Top →



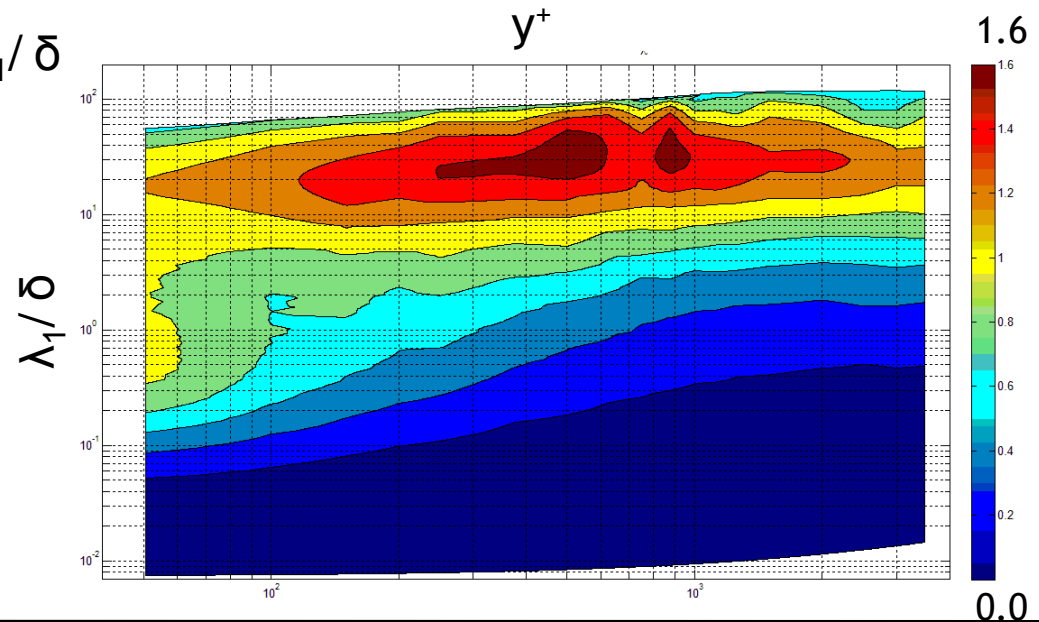


Evolution of Spectra, $R_\lambda = 550$



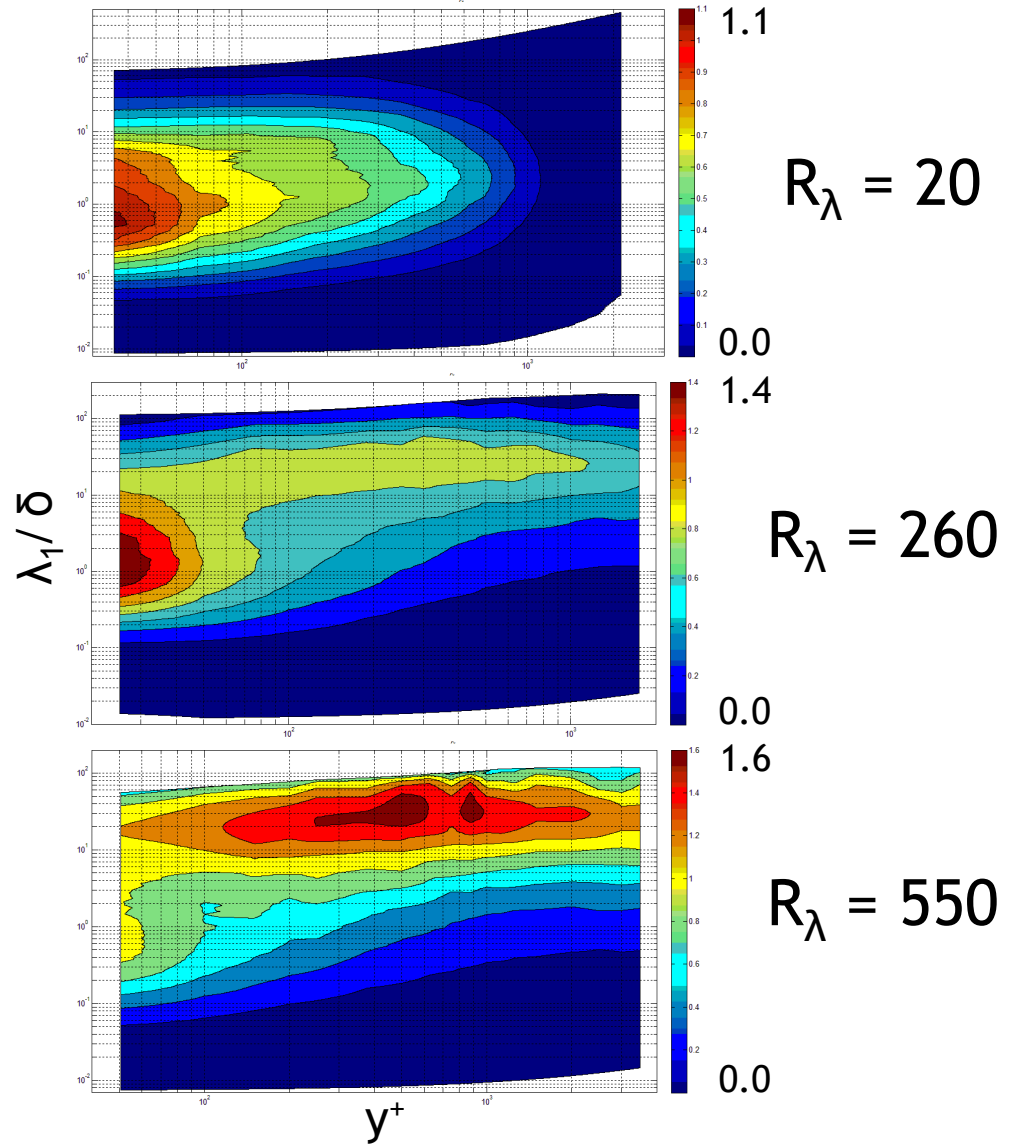
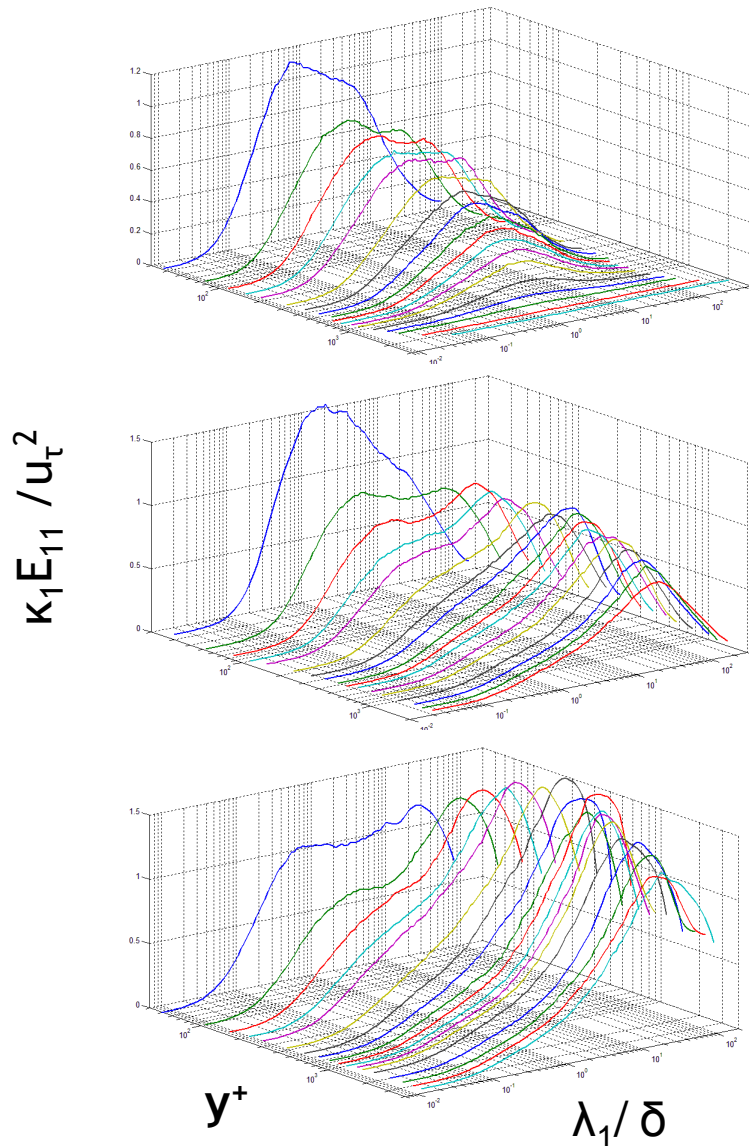
← 3D View from Side

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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