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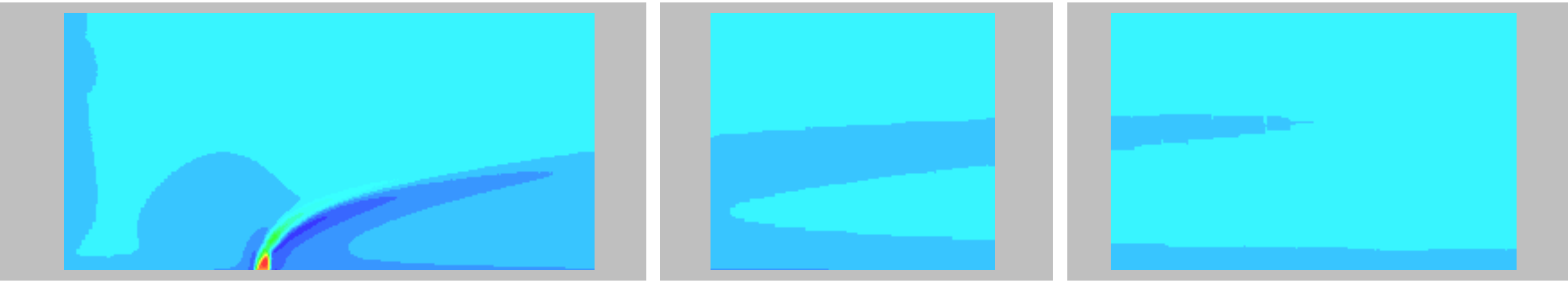


Evaluating RANS Assumptions

Comparison to PIV Data in a Transonic Jet-in-Crossflow

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Overview

- k-ϵ turbulence model

$$\nabla \cdot (\rho U) = 0$$

$$U \cdot \nabla U = \nabla \cdot \left(C_\mu \frac{k^2}{\epsilon} \nabla U \right)$$

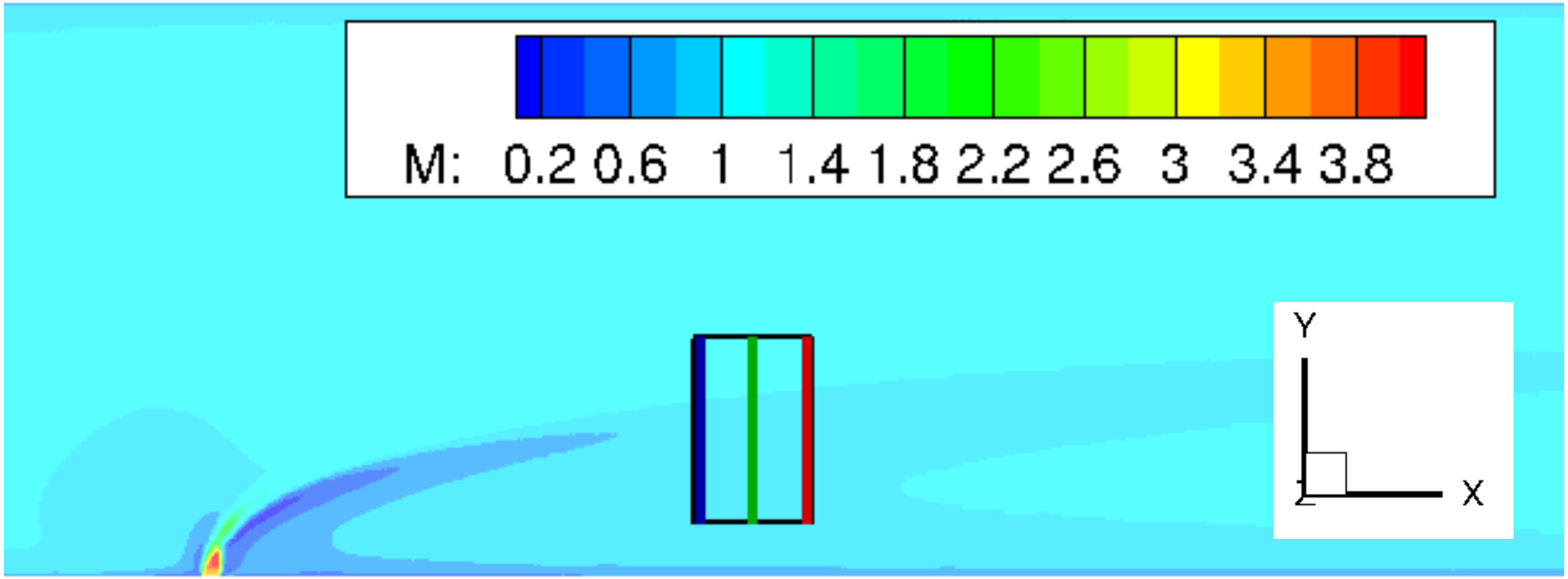
$$U \cdot \nabla k = \nabla \cdot \left(C_\mu \sigma_k \frac{k^2}{\epsilon} \nabla k \right) + C_\mu \frac{k^2}{\epsilon} |\nabla U|^2 - f(M)\epsilon$$

$$U \cdot \nabla \epsilon = \nabla \cdot \left(C_\mu \sigma_\epsilon \frac{k^2}{\epsilon} \nabla \epsilon \right) + C_{\epsilon 1} C_\mu k |\nabla U|^2 - C_{\epsilon 2} \frac{\epsilon^2}{k}$$

$$\nu_t \equiv l_t^2 / \tau_t \sim \frac{k^2}{\epsilon}$$

Jet-in-crossflow

- $M = 0.8$
- $J \in \{8.1, 10.2\}$
- Profiles at $x/d \in \{27, 30, 33\}$



Quantities of interest

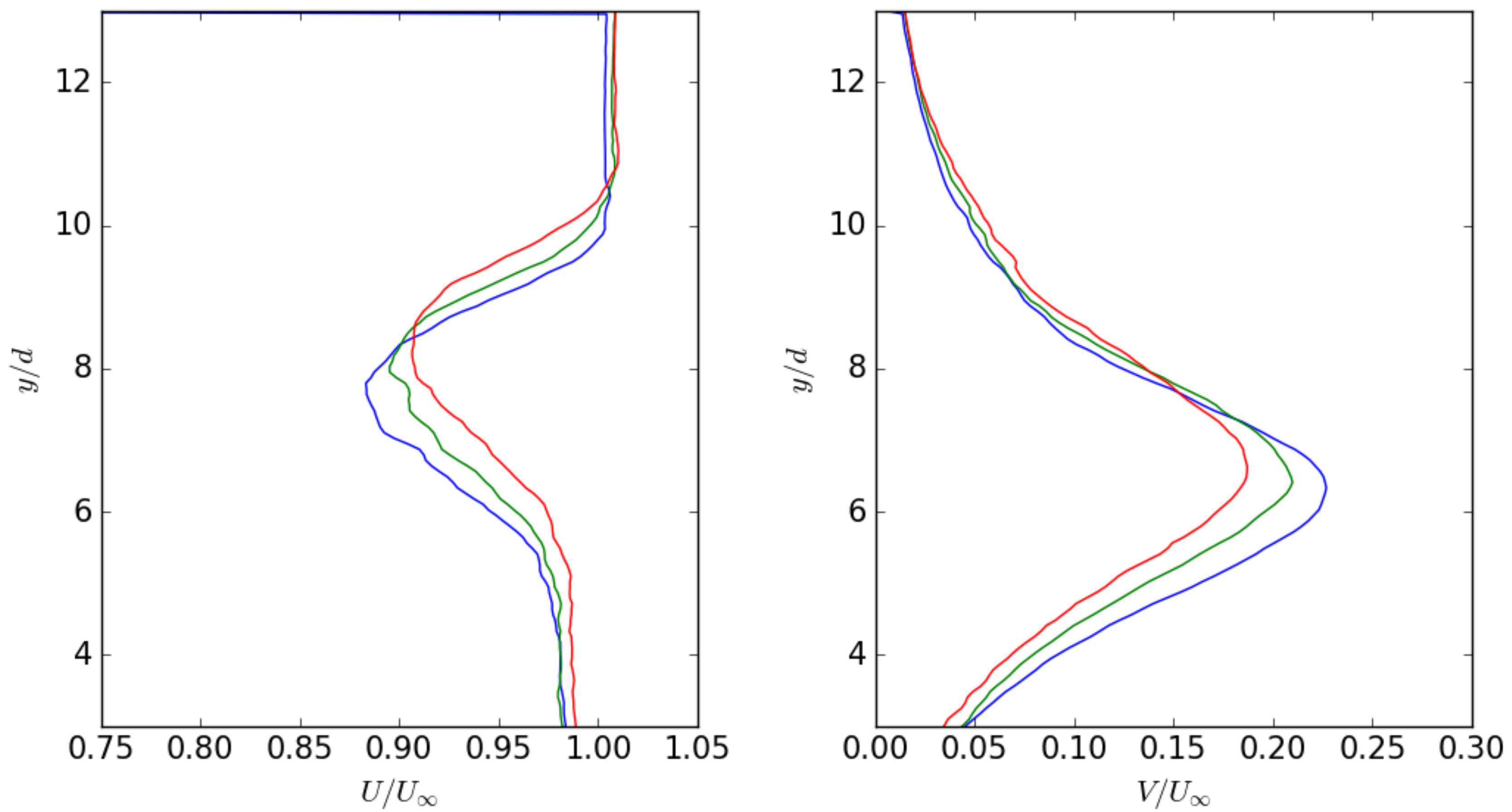
#	QOI	Description	Formula
1	ν_t	Turbulent Viscosity	$\nu_t = \frac{-\overline{u_i' u_j'} S_{ij} + \frac{2}{3} k \delta_{ij} S_{ij}}{2 S_{kl} S_{kl}}$
2	l_t	Characteristic turbulence length scale	$l = \frac{\nu_t}{\sqrt{k}}$
3	l_{int}	Integral length scale	$\frac{\overline{u_\xi'(\mathbf{x},t) u_\xi'(\mathbf{x}+r\mathbf{e}_\xi,t)}}{\overline{u_\xi'(\mathbf{x},t)^2}} \approx e^{-\frac{r}{l_{int,\xi\xi}(\mathbf{x})}}$
4	τ_t	Characteristic turbulence time scale	$\tau_t = \frac{k}{\epsilon} = \frac{\nu_t}{C_\mu k} \approx \frac{k}{\overline{u_i' u_j'} S_{ij}}$
5	τ_{int}	Integral time scale	$\frac{\overline{u_\xi'(\mathbf{x},t) u_\xi'(\mathbf{x},t+\sigma)}}{\overline{u_\xi'(\mathbf{x},t)^2}} \approx e^{-\frac{\sigma}{\tau_{int,\xi\xi}(\mathbf{x})}}$
6	τ_{mean}	Mean strain rate time scale	$\tau_{mean} = \frac{1}{\lvert S_{ij} \rvert}$
7	a_{ij}	Anisotropy tensor	$a_{ij} = \frac{\overline{u_i' u_j'}}{2k} - \frac{1}{3}\delta_{ij}$
8	Δu_s	Jet centerline velocity defect	$\Delta u_s(\xi) = \overline{u_\xi}(\xi, \zeta = 0) - \overline{u_\xi}(\xi, \zeta \to \infty)$
9	δ	Jet half-width	$\Delta u_\xi(\xi, \zeta = \delta) = \frac{\Delta u_s(\xi)}{\mathrm{e}}$

Experimental Results

- Compare effect of varying jet momentum on QOIs
  - Mean velocity
  - TKE
  - Reynolds stresses
  - Turbulent viscosity
  - Length scales
    - Turbulent, integral
  - Time Scales
    - Turbulent, mean, integral
- Data from multiples camera configurations, 2C and stereo PIV, conventional and pulse-burst
- This presentation: West stereo camera data, RMS and gradient content filtered using 8x3 moving average filter

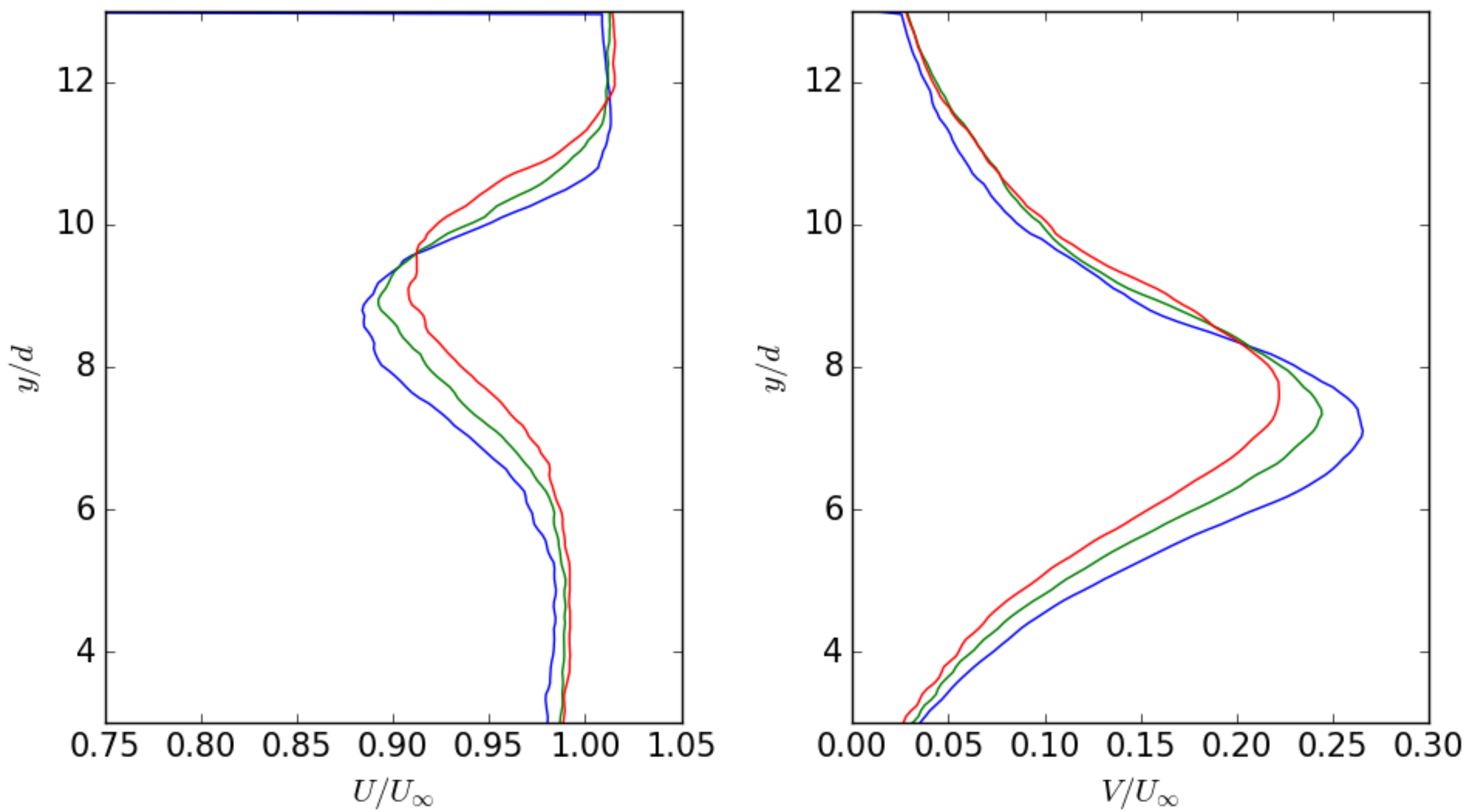
Mean velocity

- J = 8



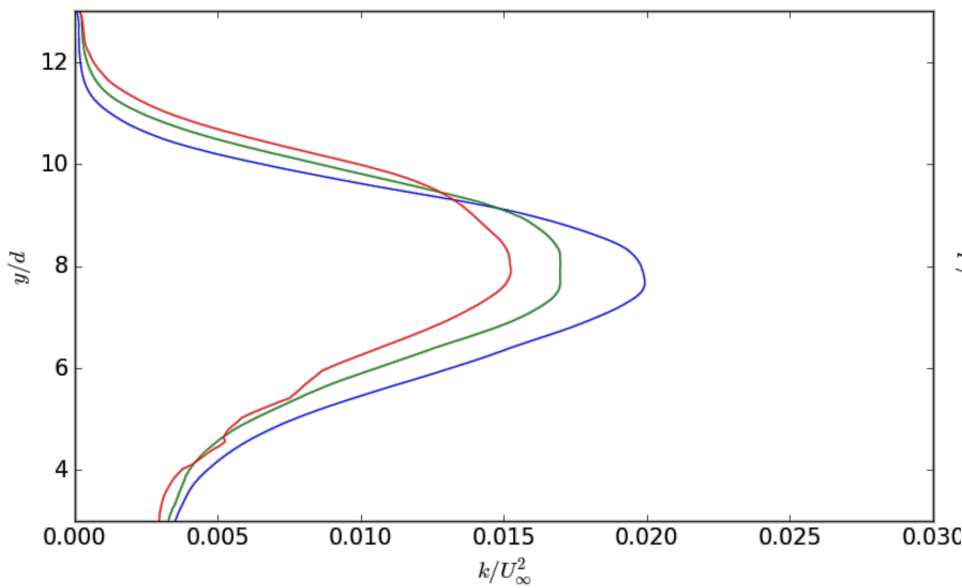
Mean velocity

- J = 10



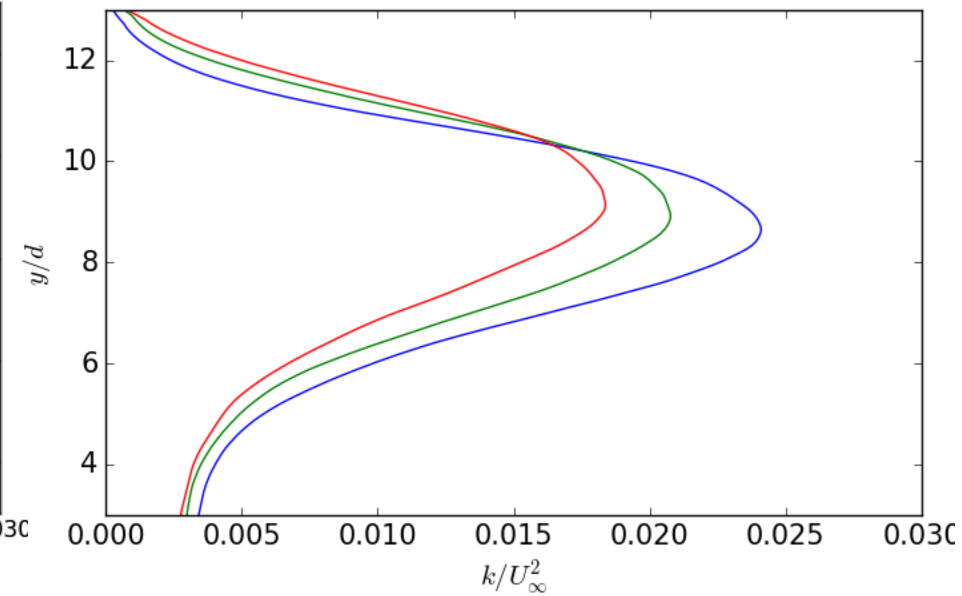
TKE

- J = 8



12
10
8
6
4
y/d
0.000
0.005
0.010
0.015
0.020
0.025
0.030
k/U_∞^2

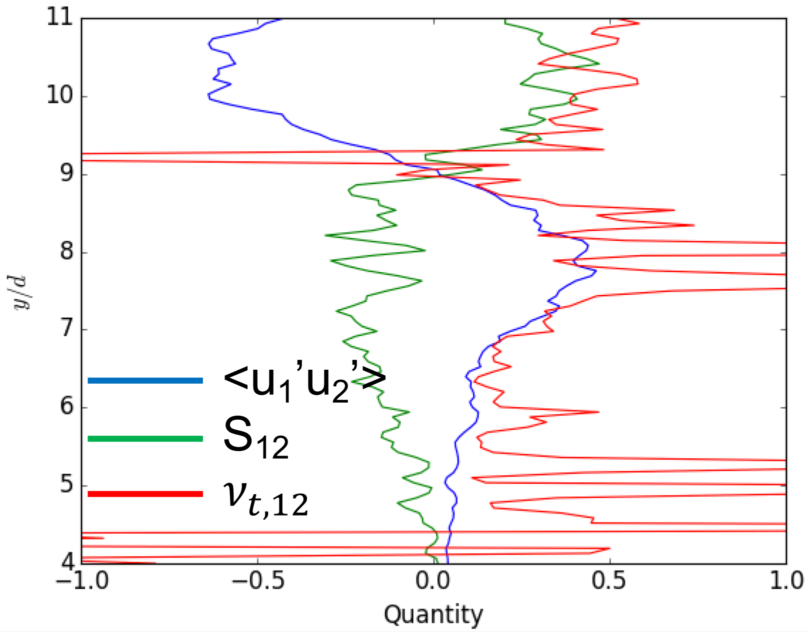
- J = 10



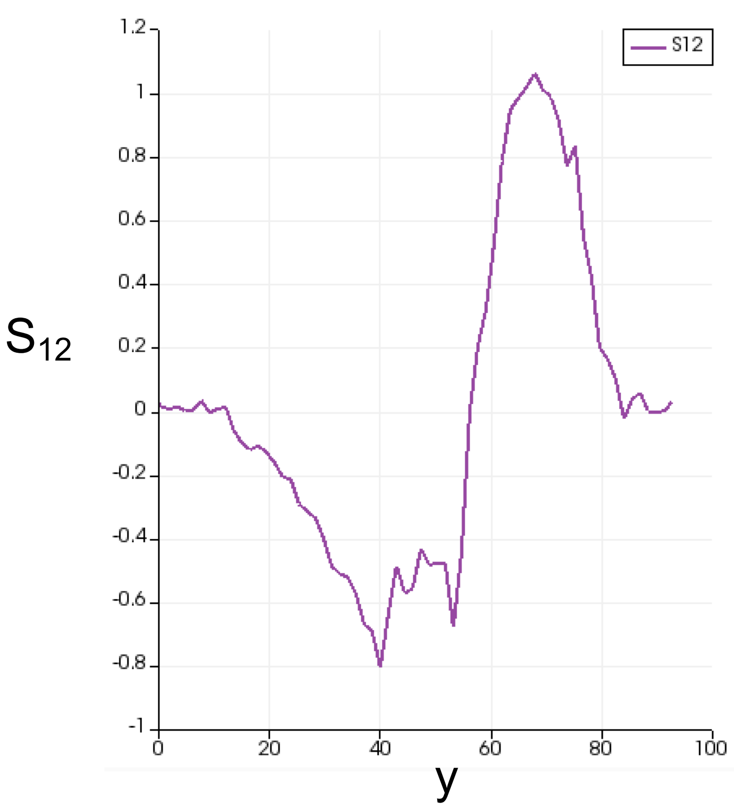
12
10
8
6
4
y/d
0.000
0.005
0.010
0.015
0.020
0.025
0.030
k/U_∞^2

Notes on filtering

- Unfiltered

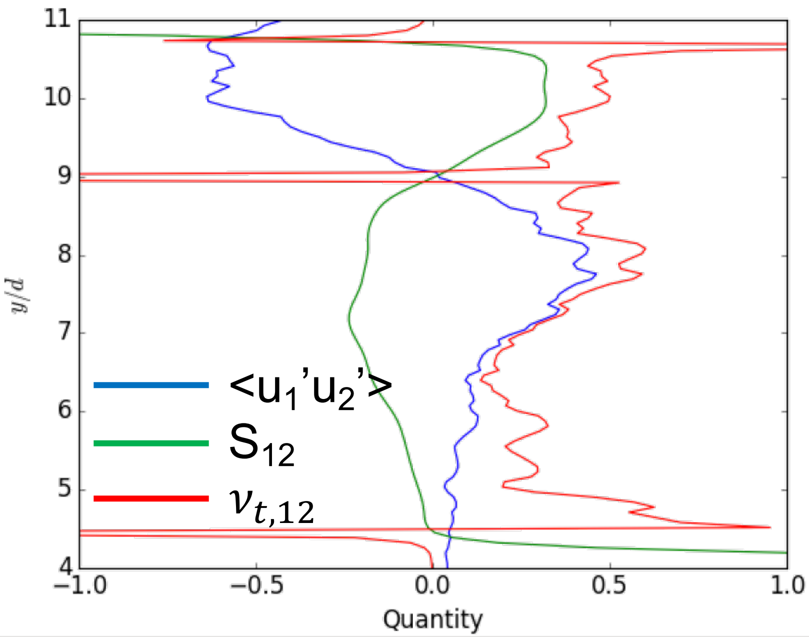


- S_{12} with larger interrogation regions

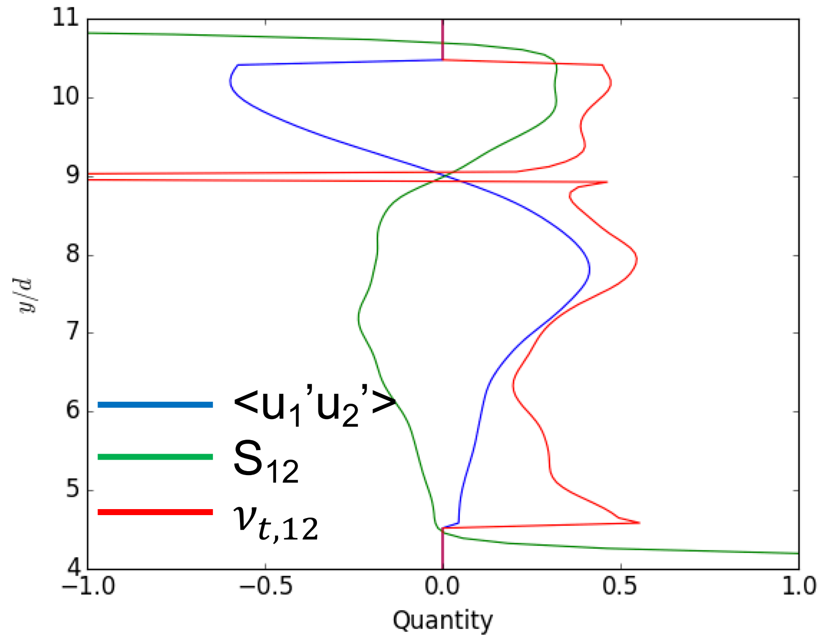


Notes on filtering

- S_{12} filtered



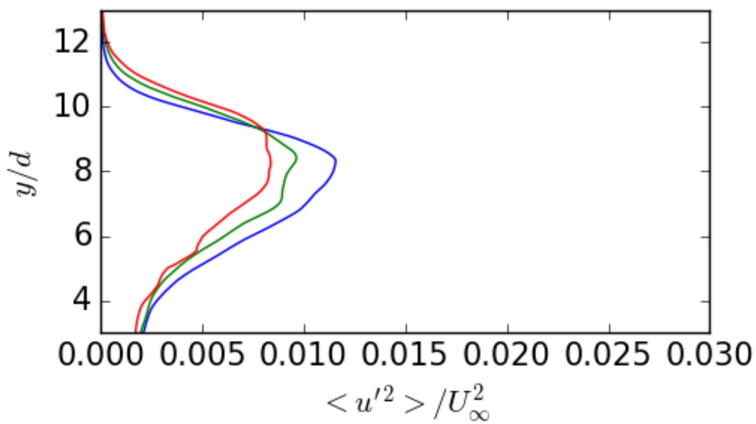
- S_{12} and $<u_1'u_2'>$ filtered

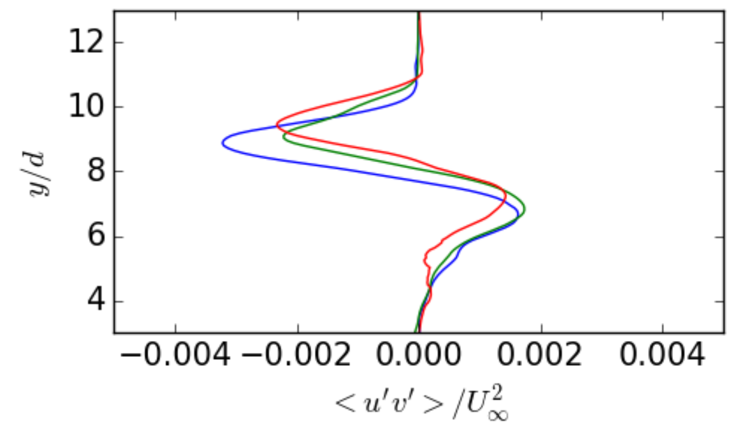


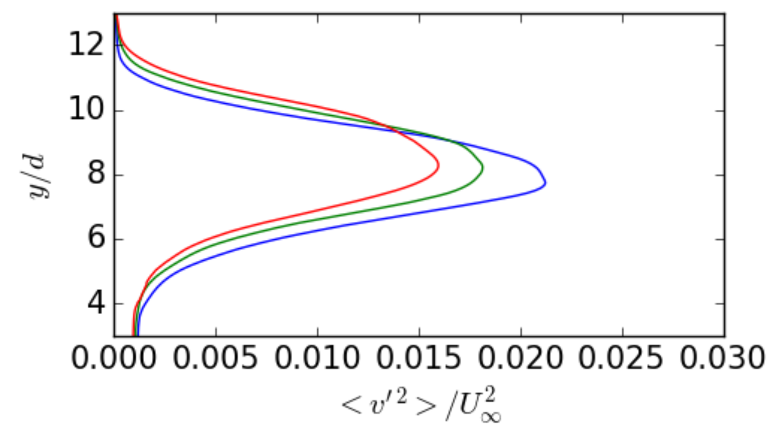
Filter used in the above plots: Gaussian, $\sigma = 3$

Reynolds stresses

- J = 8

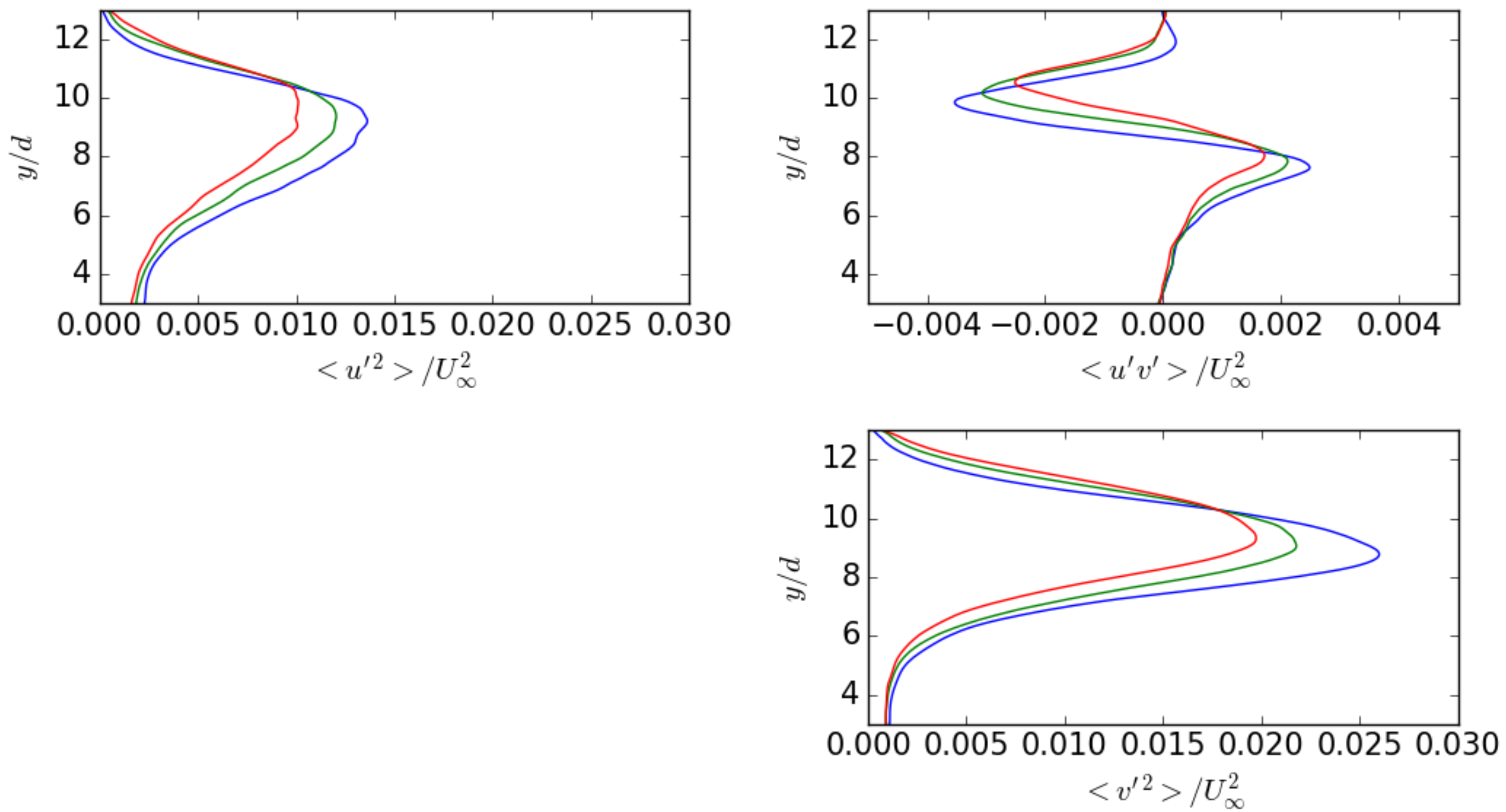






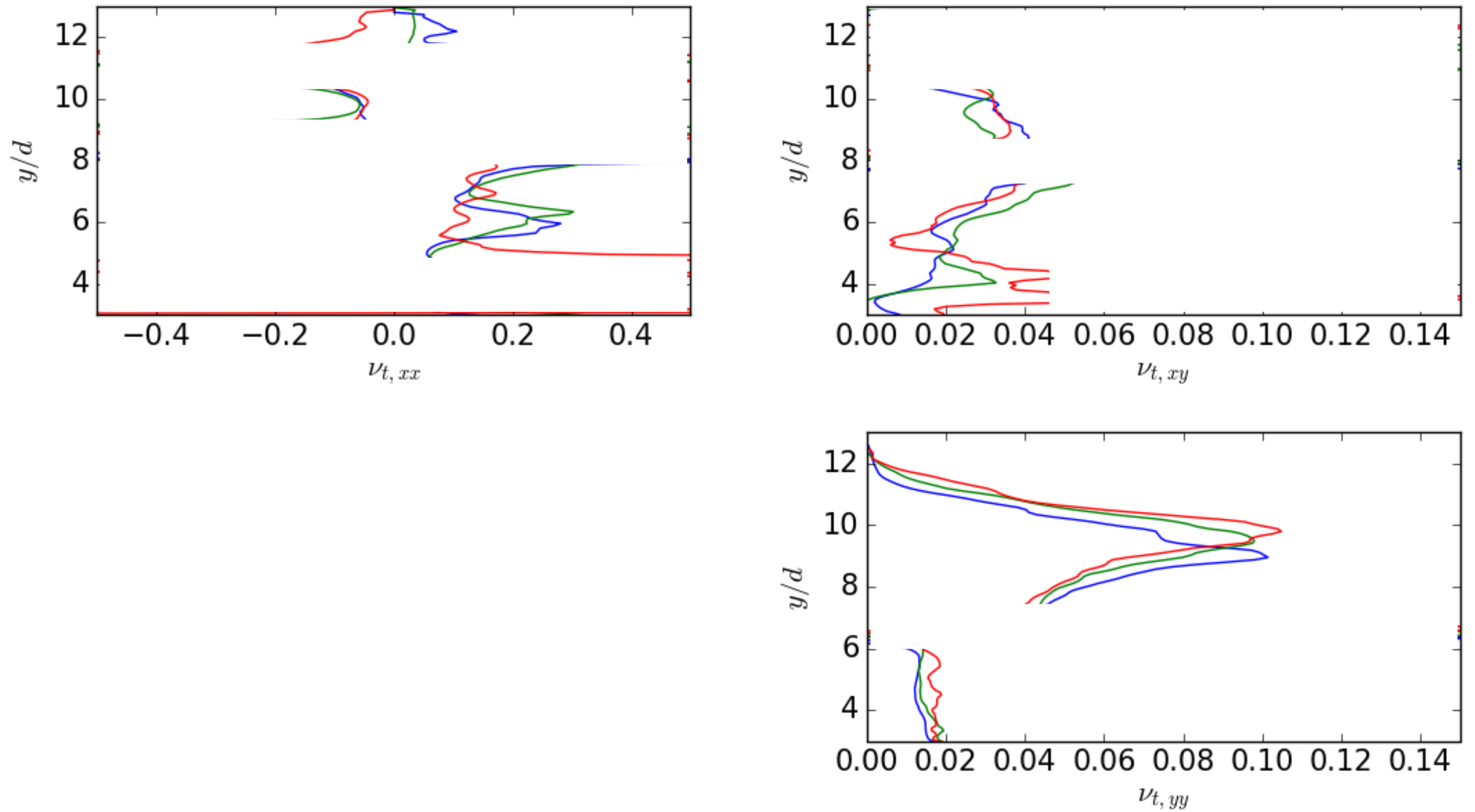
Reynolds stresses

- J = 10



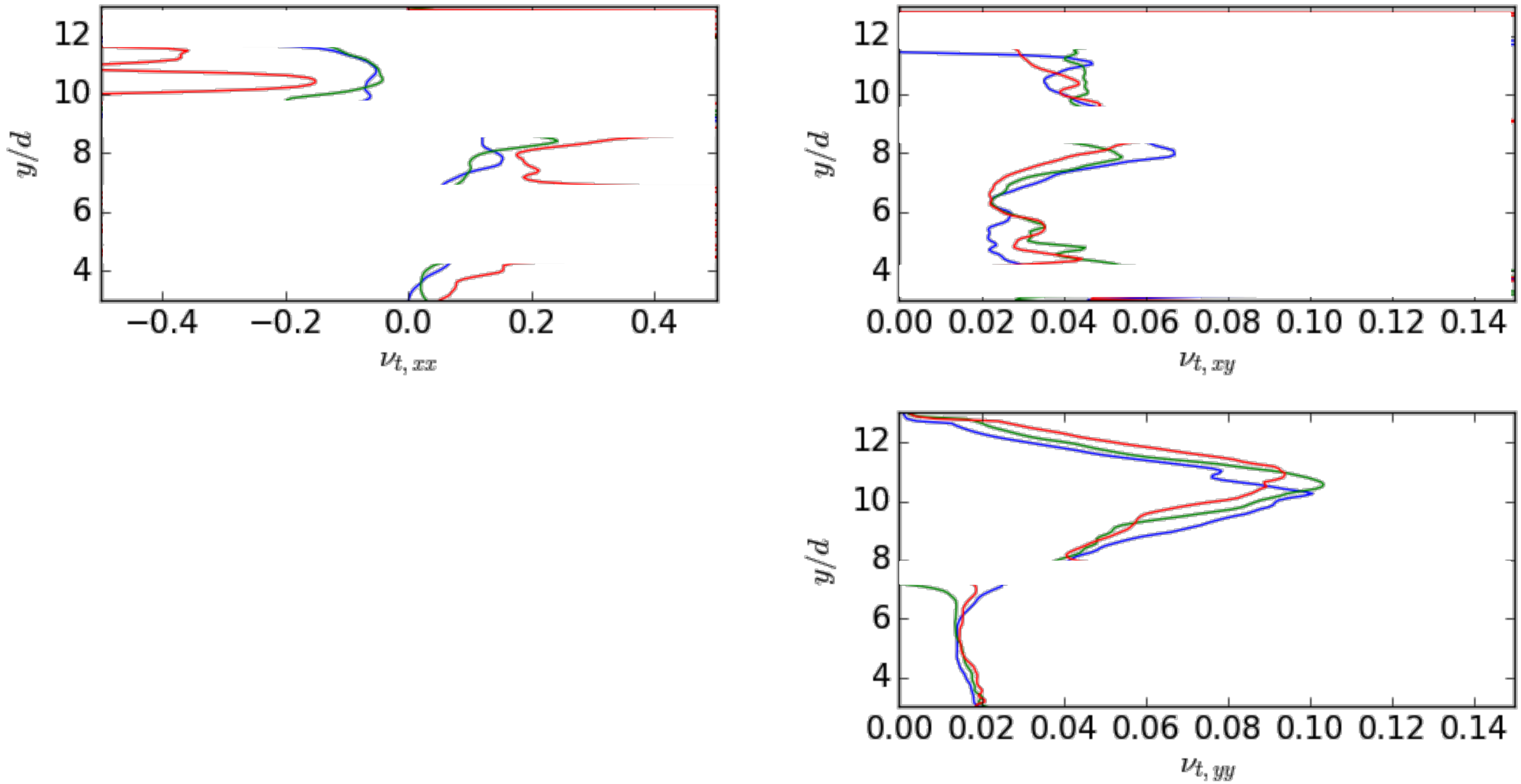
Turbulent viscosity

- J = 8



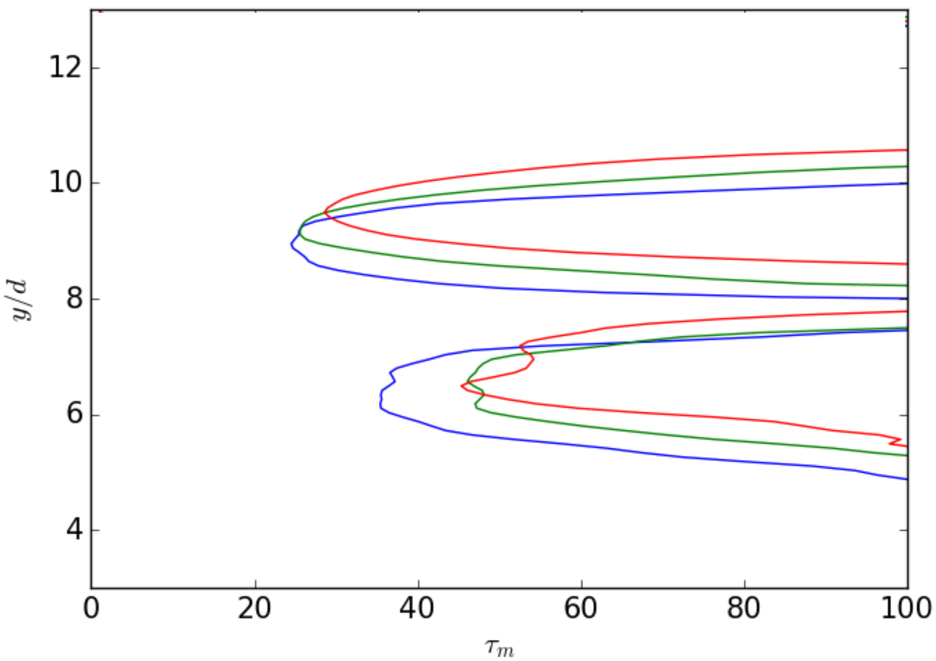
Turbulent viscosity

- J = 10

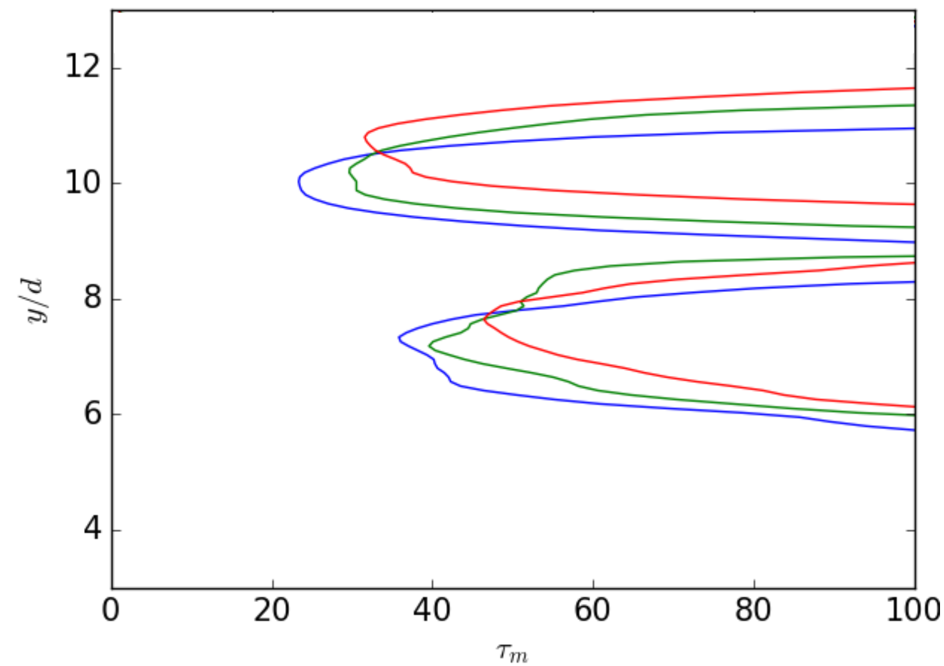


Mean time scale

- J = 8

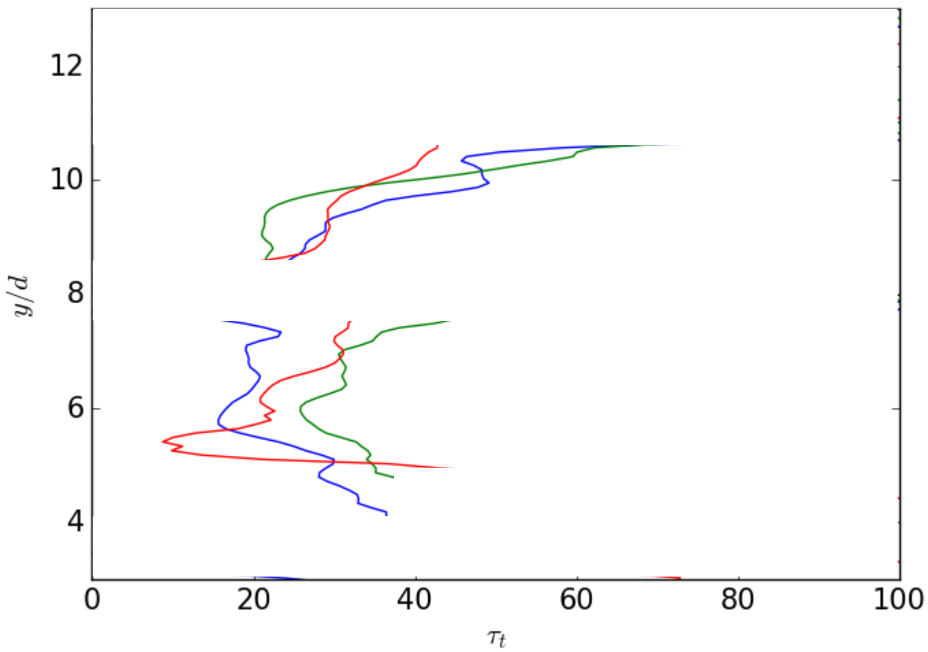


- J = 10

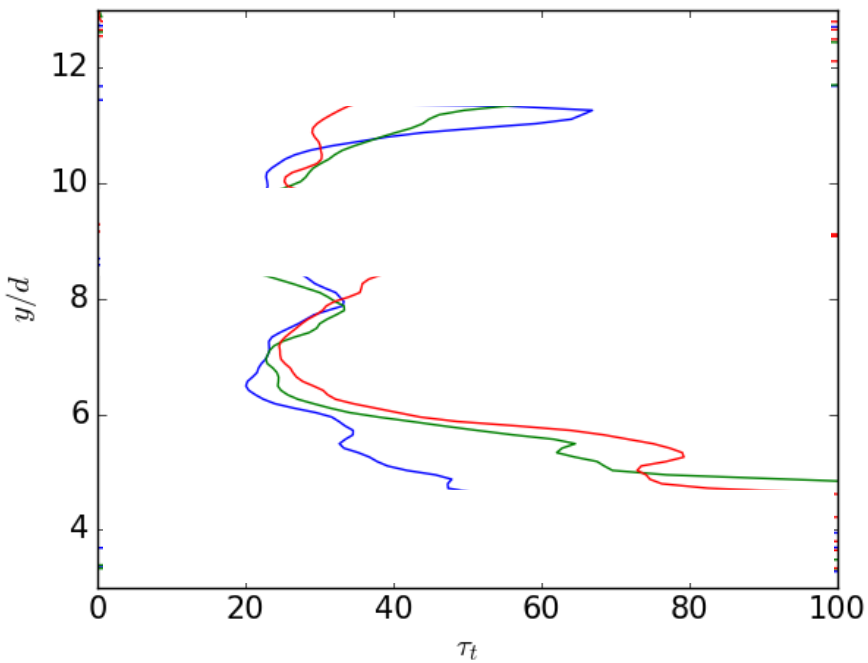


Turbulent time scale

- J = 8

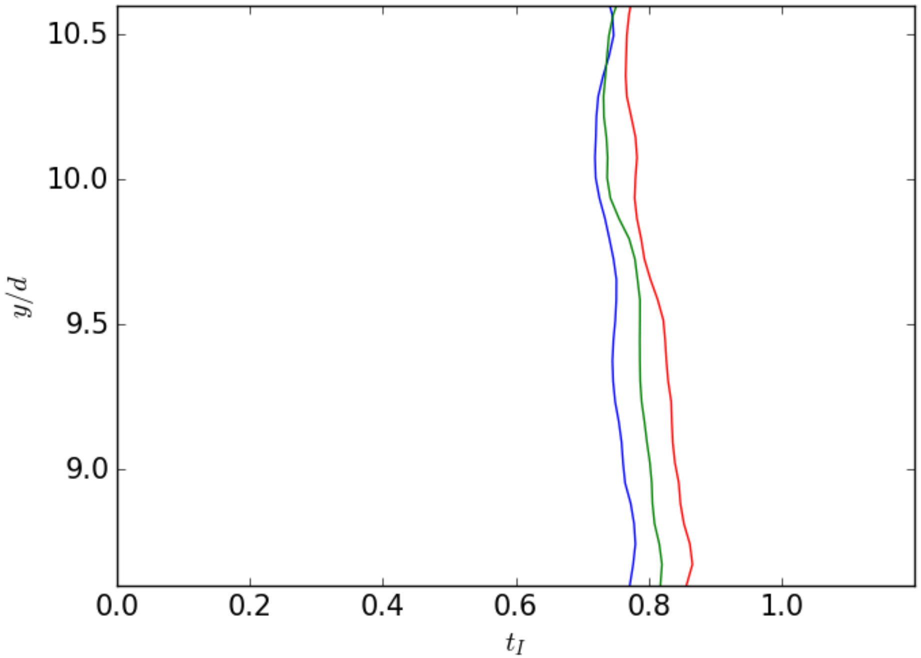


- J = 10

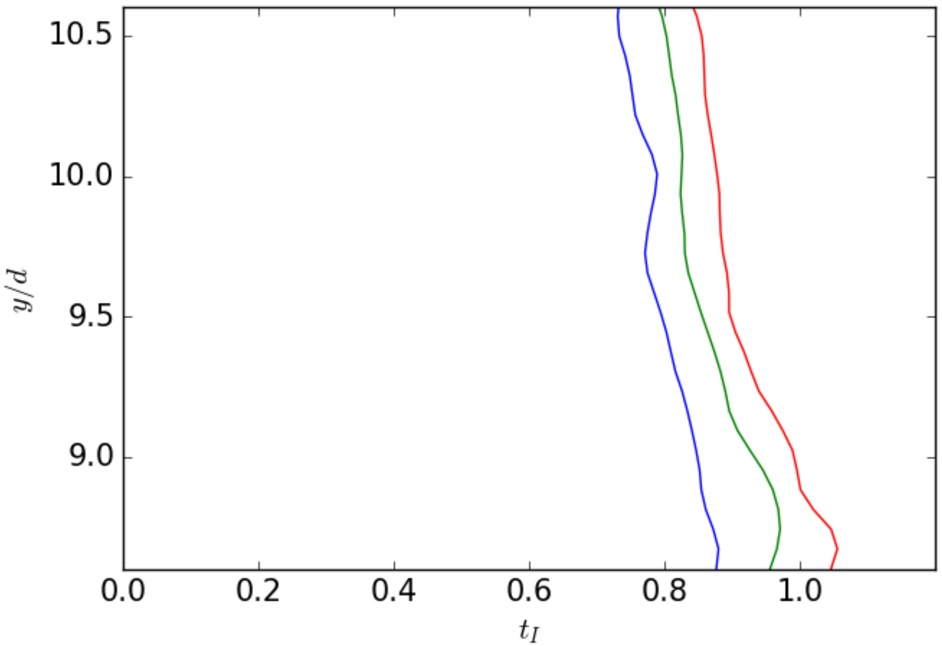


Integral time scale

- J = 8



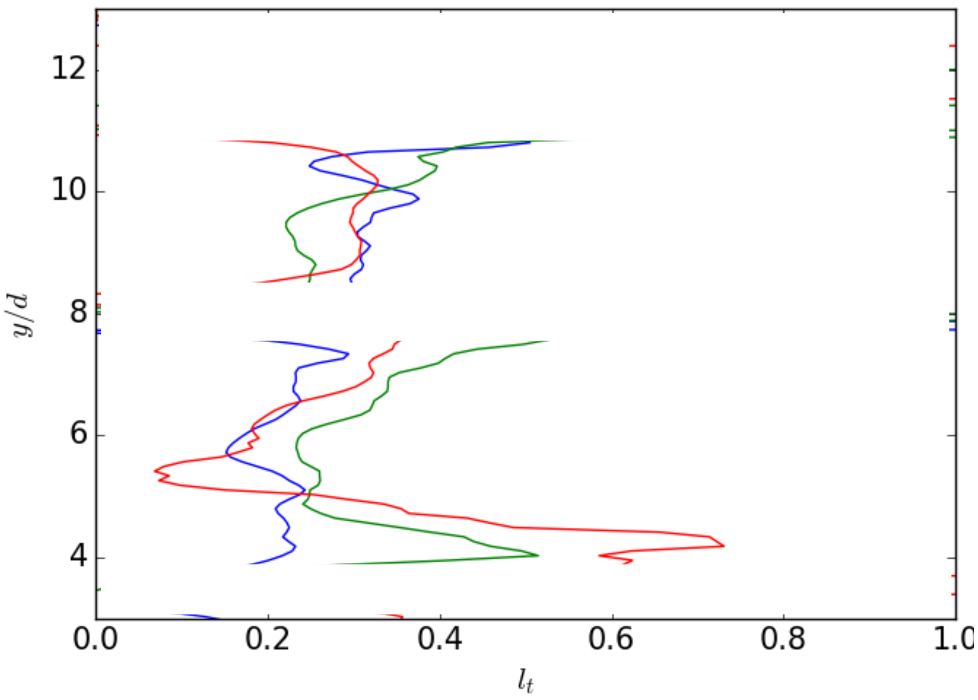
- J = 10



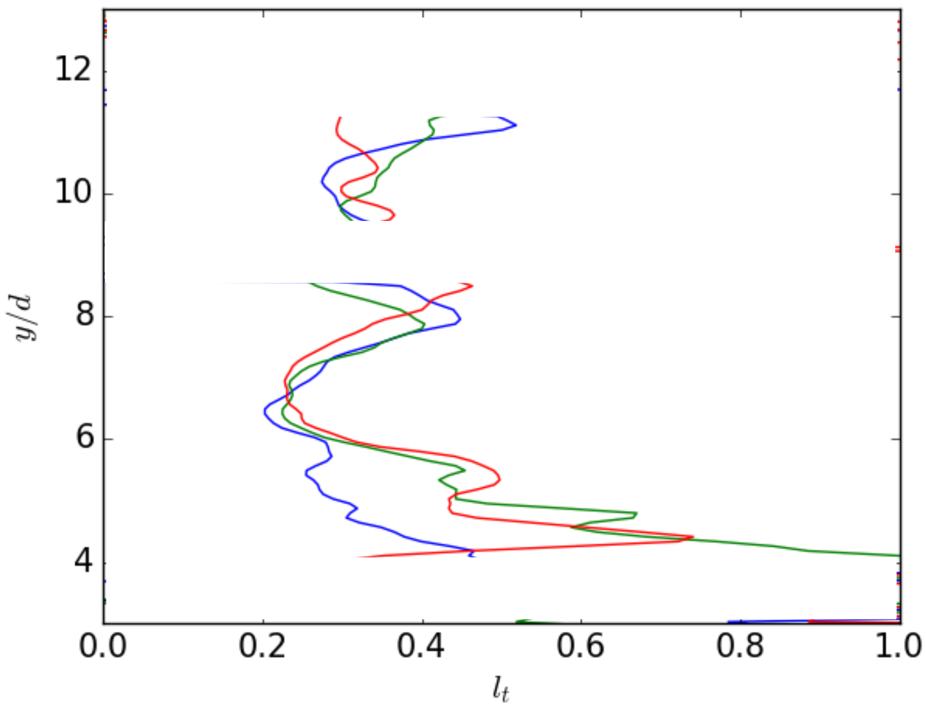
Computed by integrating to first zero crossing using trapezoidal method

Turbulent length scale

- J = 8



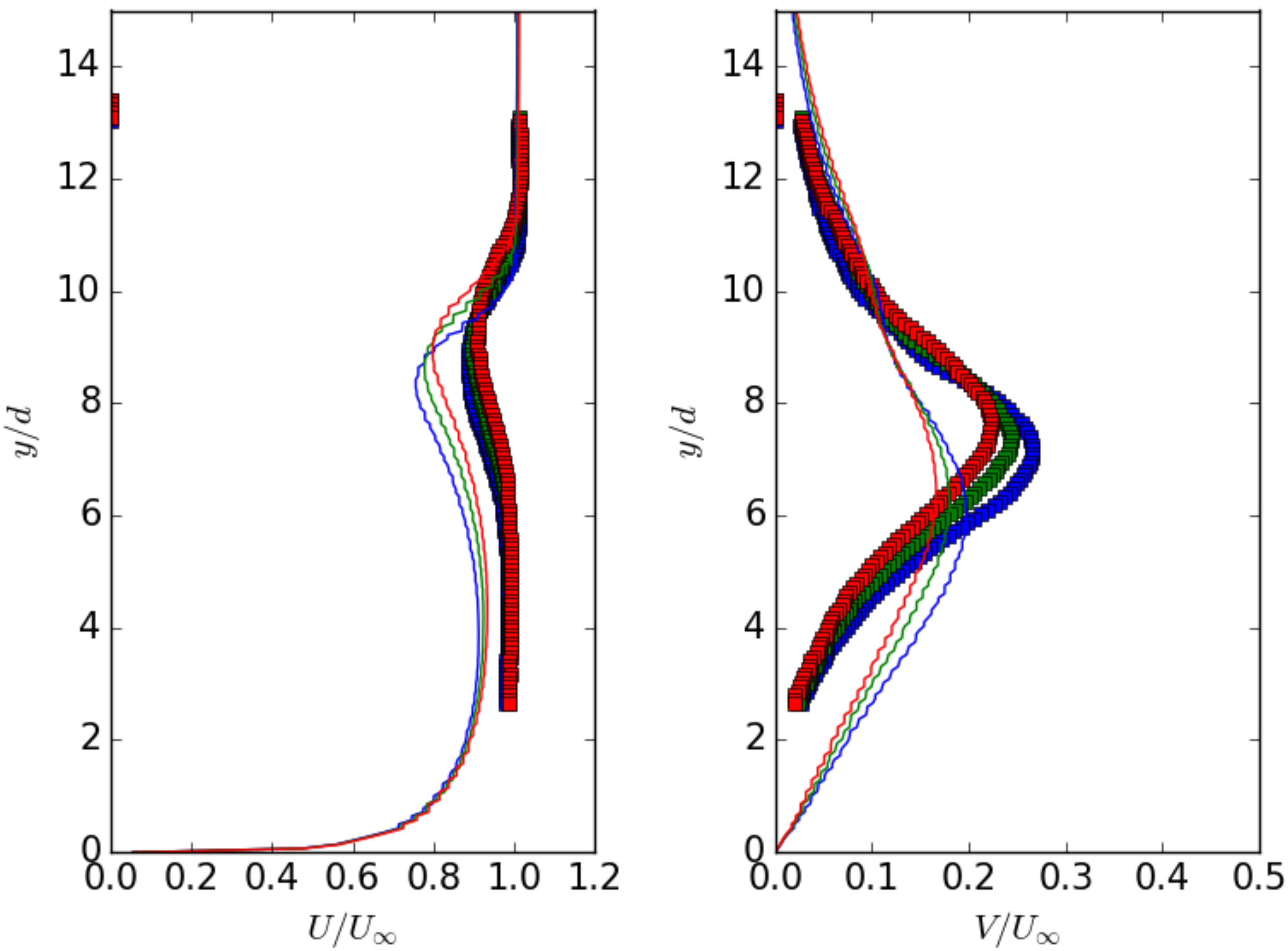
- J = 10



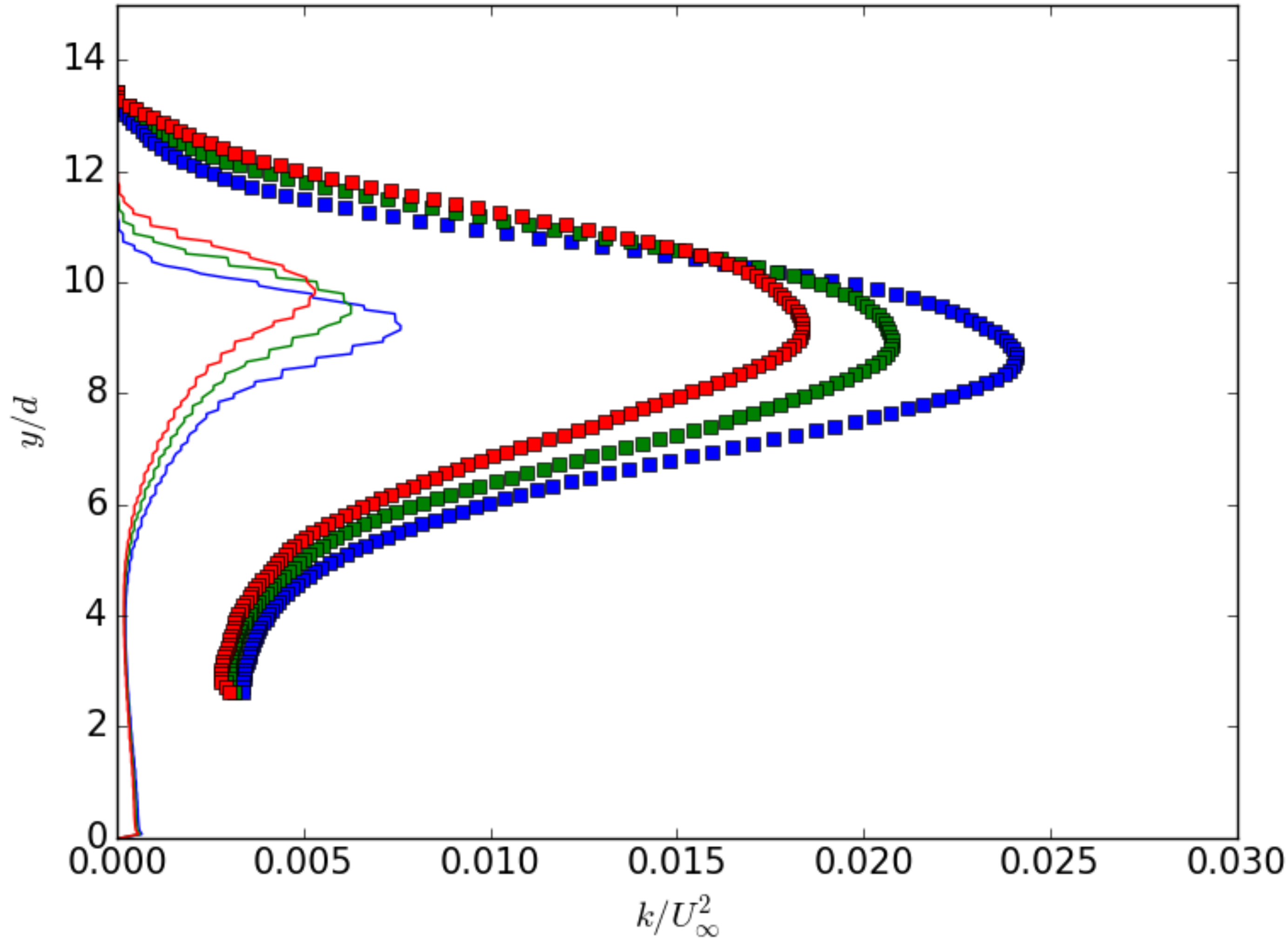
Comparison to RANS

- First comparison: J = 10.2
- Compare
  - Mean velocity
  - TKE
  - Turbulent viscosity
  - Time Scales
    - Turbulent, mean, integral
  - Length scales
    - Turbulent, integral

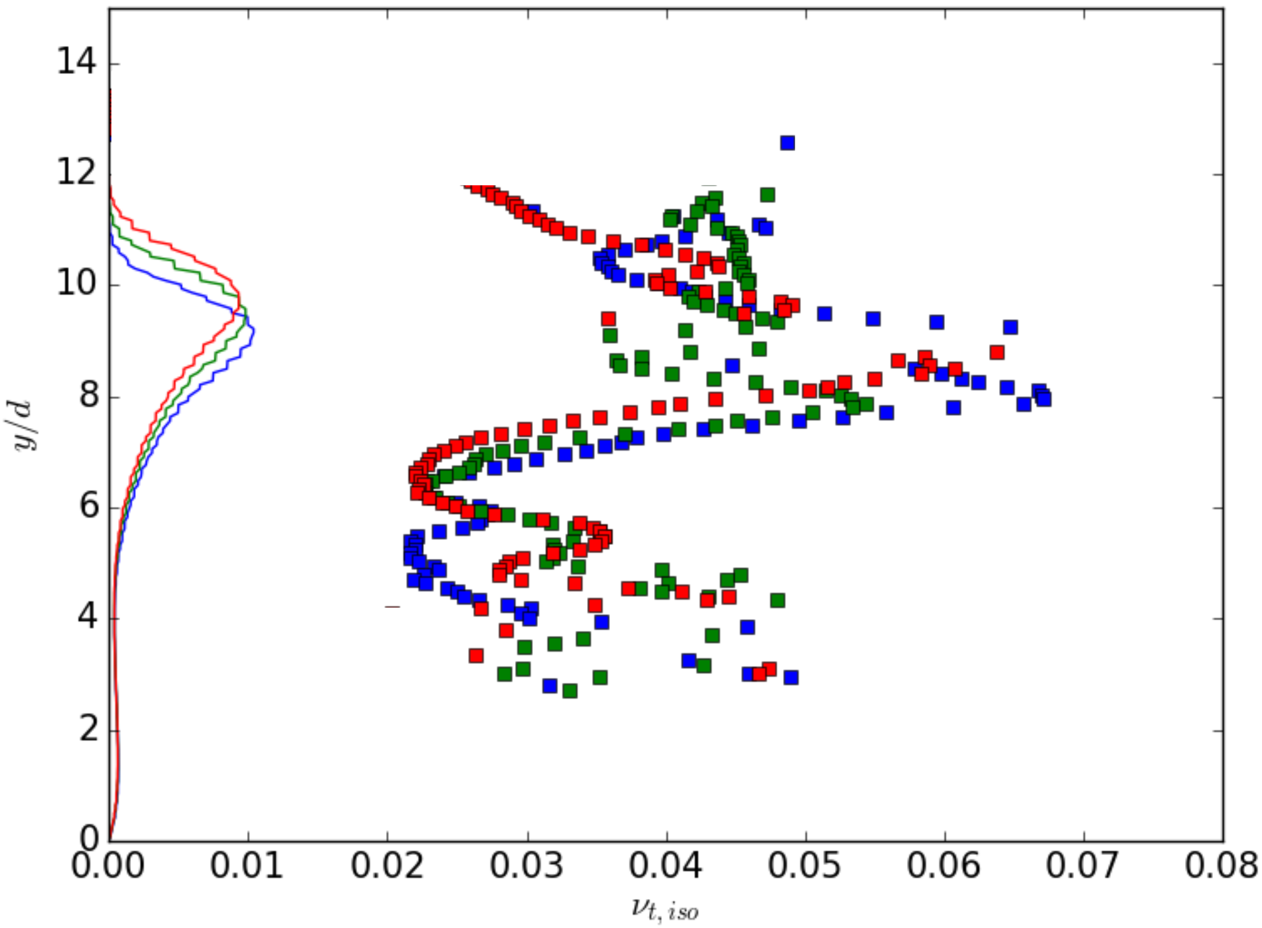
Mean velocity



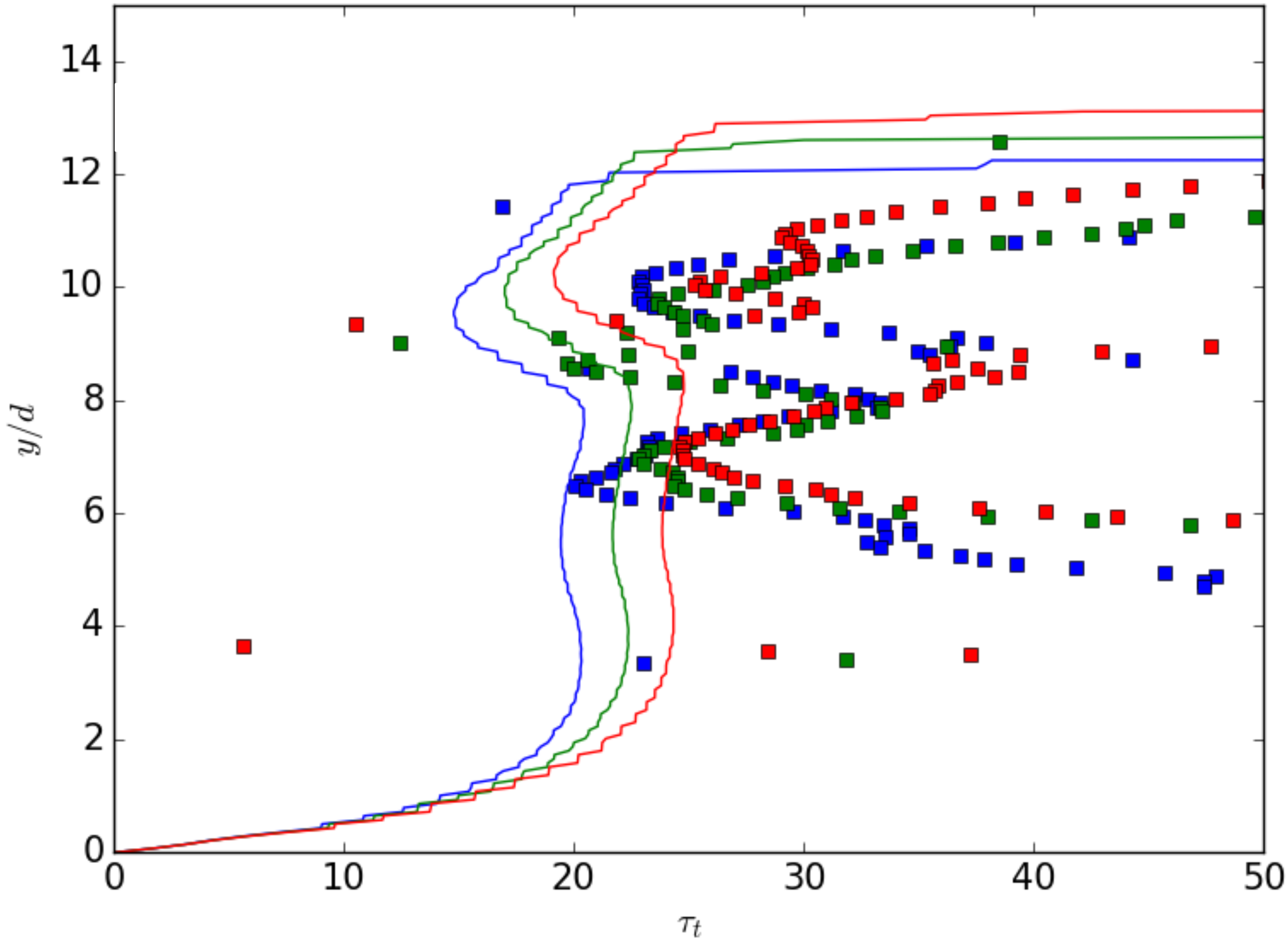
TKE



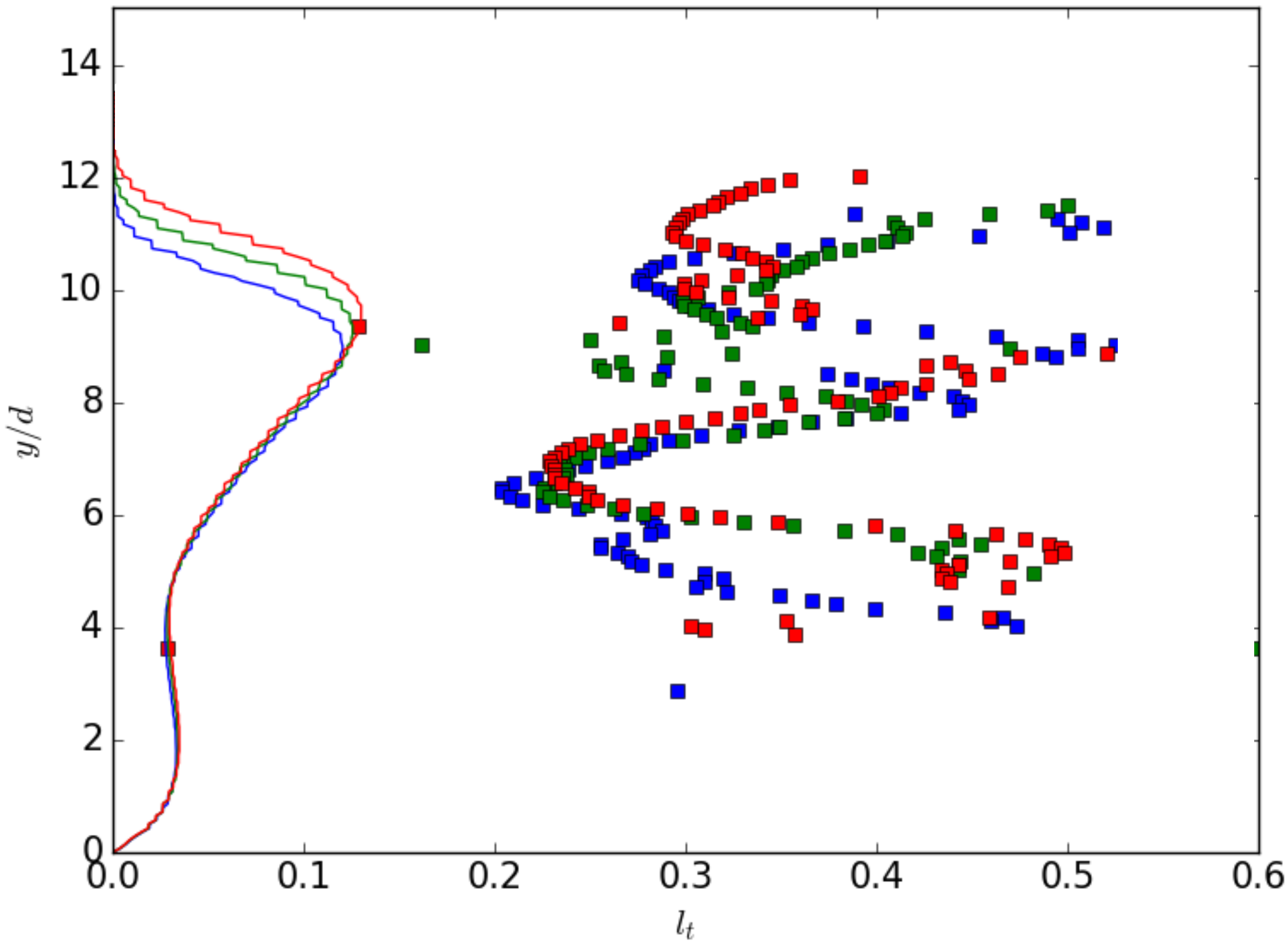
Turbulent viscosity



Turbulent time scale



Turbulent length scale



Future Work

- Refined processing methods
  - Obtain well-defined trends by optimizing processing techniques
    - Computing strain tensor
  - Higher frequency pulse burst data coming
    - Lagrangian integral time scales
    - Improved estimate of autocorrelation
- UQ
  - Statistical, measurement and propagation of uncertainty
  - Monte Carlo by generating perturbed data
  - Use redundant data sets as ensemble
- Additional QOIs
  - Scaling behavior of jet – might be out of reach with limited FOV of new data
    - Scaling of mean and turbulent quantities
    - Make a connection to L. Dechant's work
- Continued RANS comparison, including with optimized coefficients
- Repeat for cavity data