Abstract G32.00004

Time resolved, near wall PIV measurements in a high Reynolds number turbulent pipe flow

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Outline

- Project aims
- Background on pipe flow facility CICLoPE
- Implementation of high-speed PIV on facility
- Sample results
  - mean profiles
  - variances, co-variance
  - ~~spectra, space-time-correlations, etc.~~

Note: This is work in progress!!

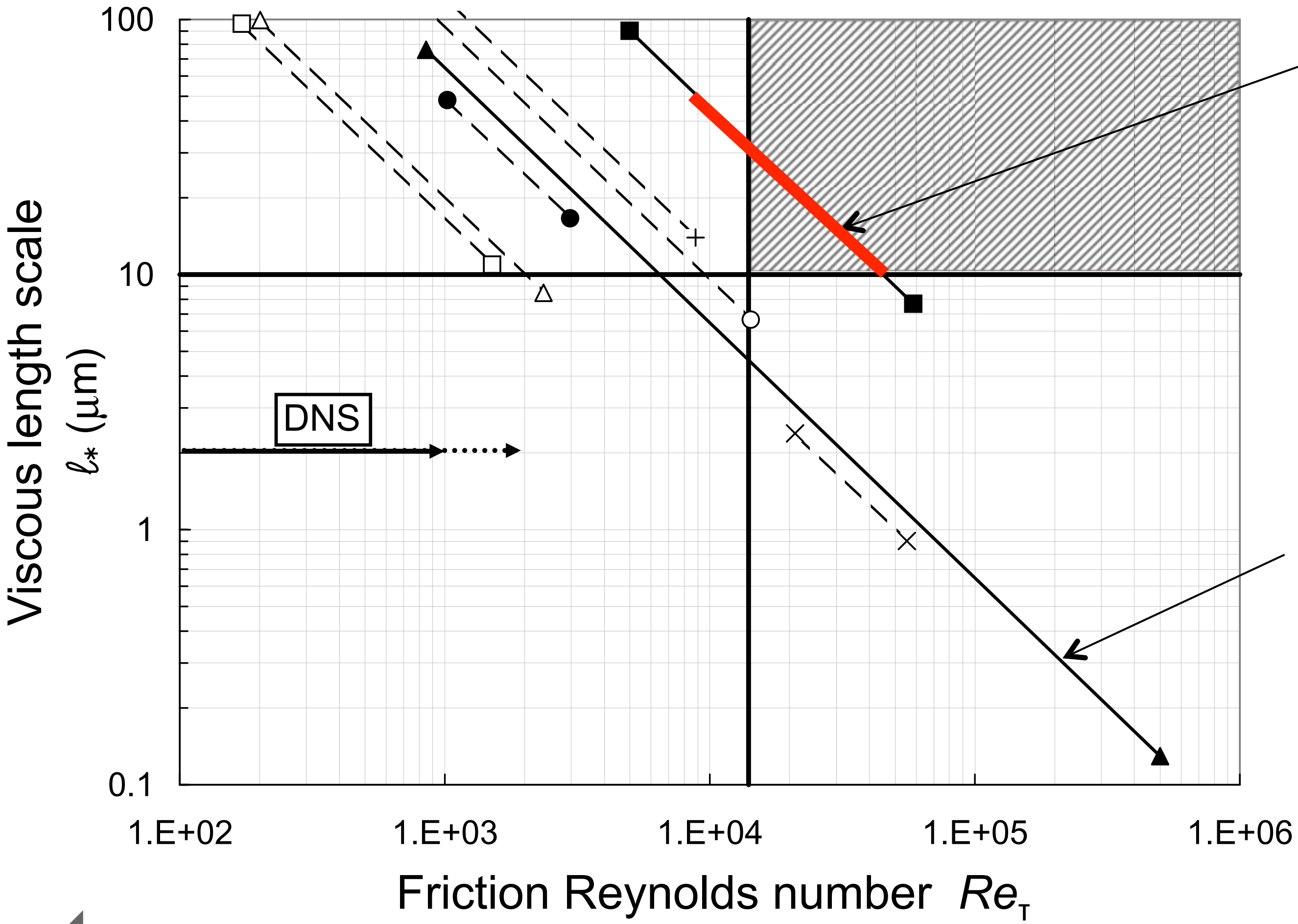
Motivation

- near wall flow structure of pipe flow so far has not been characterized well quantitatively through measurements, mainly due to finite size of probes
- for high-Re hotwire data is only available for wall distances y > 20$^+$ (e.g. *SuperPipe* Princeton)
- DNS only available at low Reynolds numbers
  for pipe flows $Re_{\tau,max} \leq 1050$ (Satake *et al,* HPC, 2000),
  for channel flow $Re_{\tau,max} = 5200$ (Lee & Moser, JFM, 2015)
- DNS difficult to perform using spectral methods due to singularity at center of pipe.
- CICLoPE pipe facility offers combination of
  high Reynolds number <u>and</u> viscous scales that can be experimentally captured
  → application of PIV becomes possible using standard imaging

CICLoPE = **C**enter for **I**nternational **C**ooperation in **Lo**ng **P**ipe **E**xperiments
www.ciclope.unibo.it

Reynolds number range for various pipe facilities

Talamelli et al. "CICLoPE—a response to the need for high Reynolds number experiments", Fluid Dyn. Res. **41** (2009) 021407

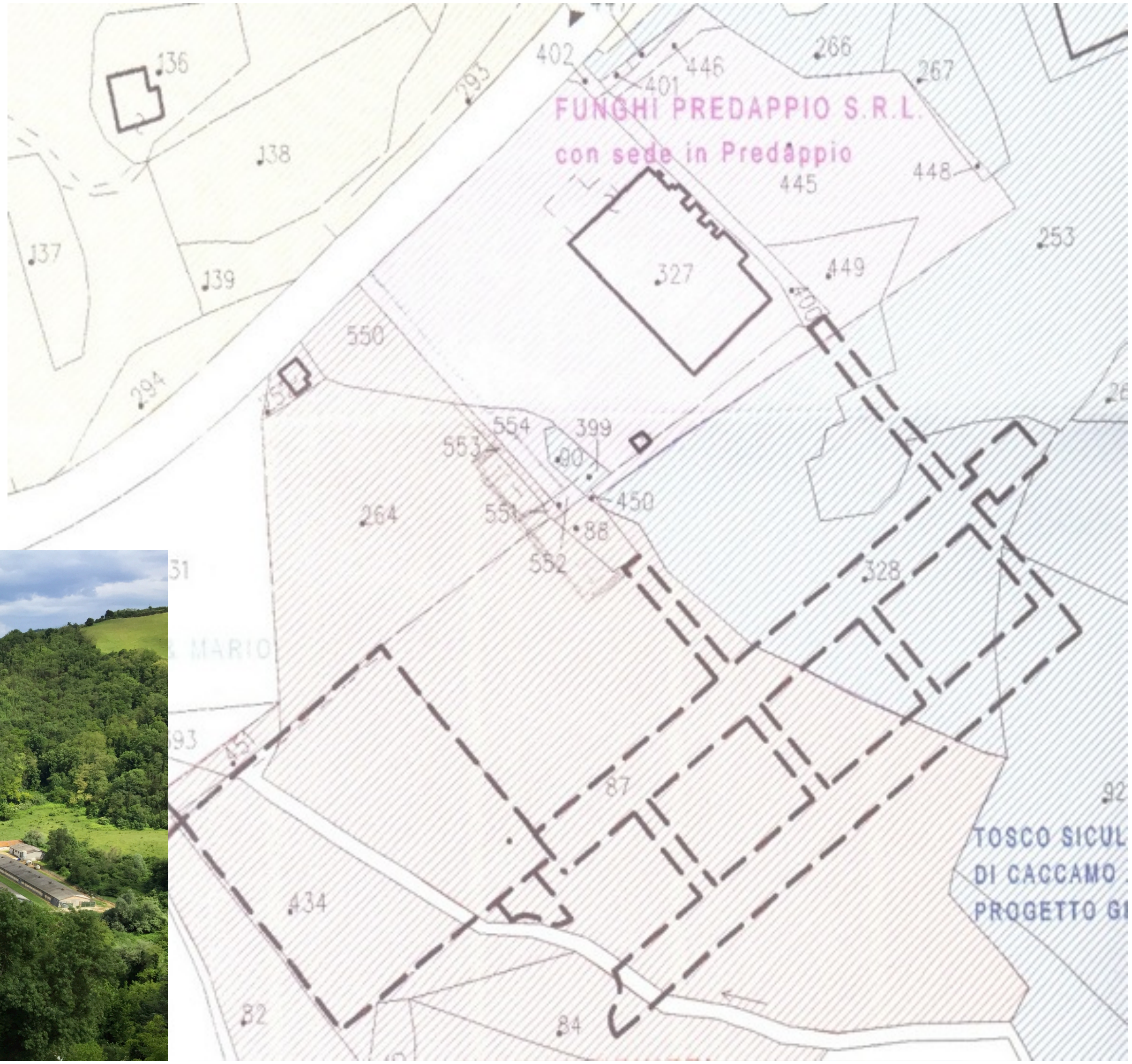


CICLoPE
Working: fluid air
Pressure: ambient
Diameter: 900 mm
Length: 110m (122D)

Princeton *Super-Pipe*
Working: fluid air
Pressure: up to 200 bar
Diameter: 129 mm
Length: 26m (202D)

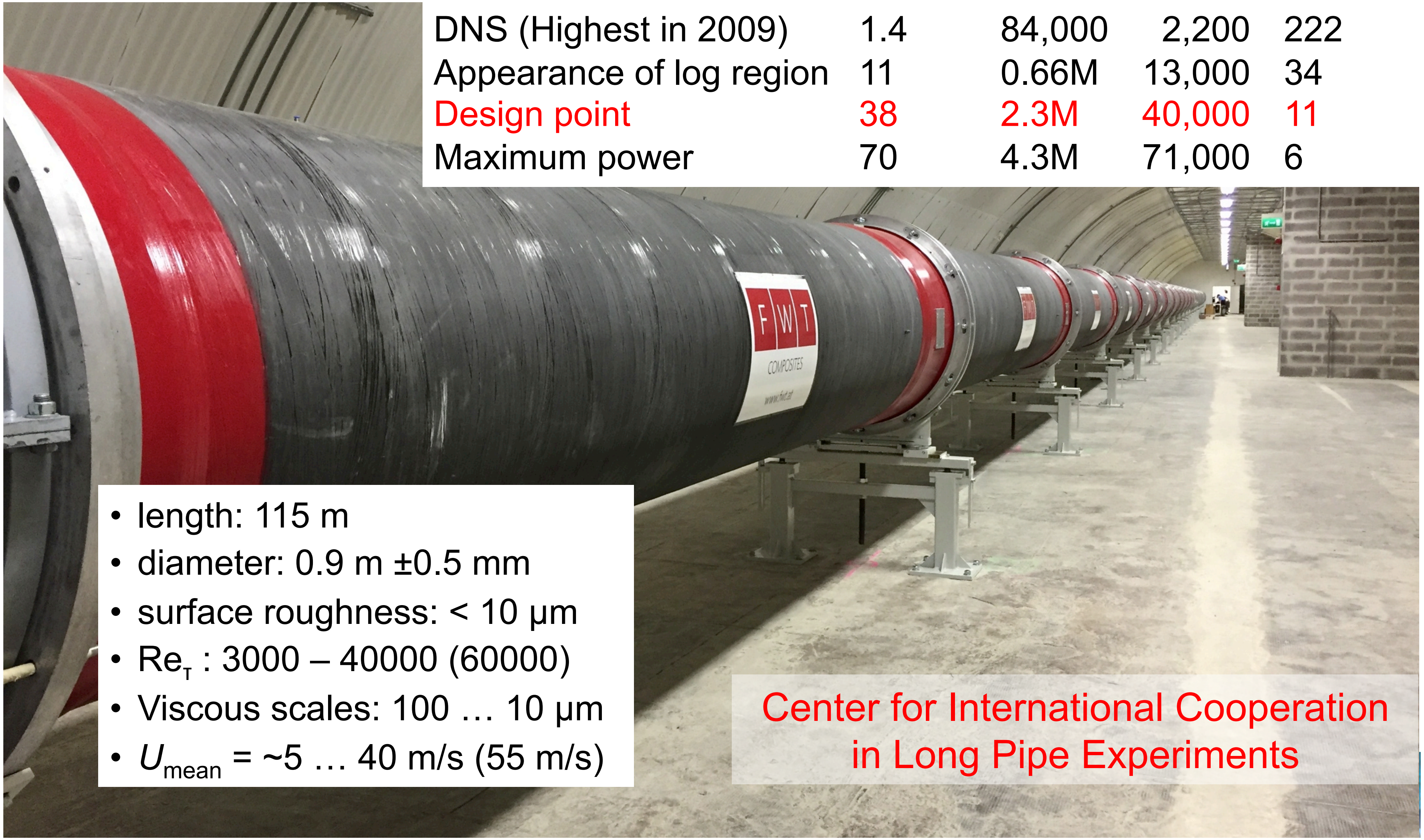
Location: Former WW2 Caproni Aircraft tunnel complex

used for Mushroom farming until recently



CICLoPE Facility

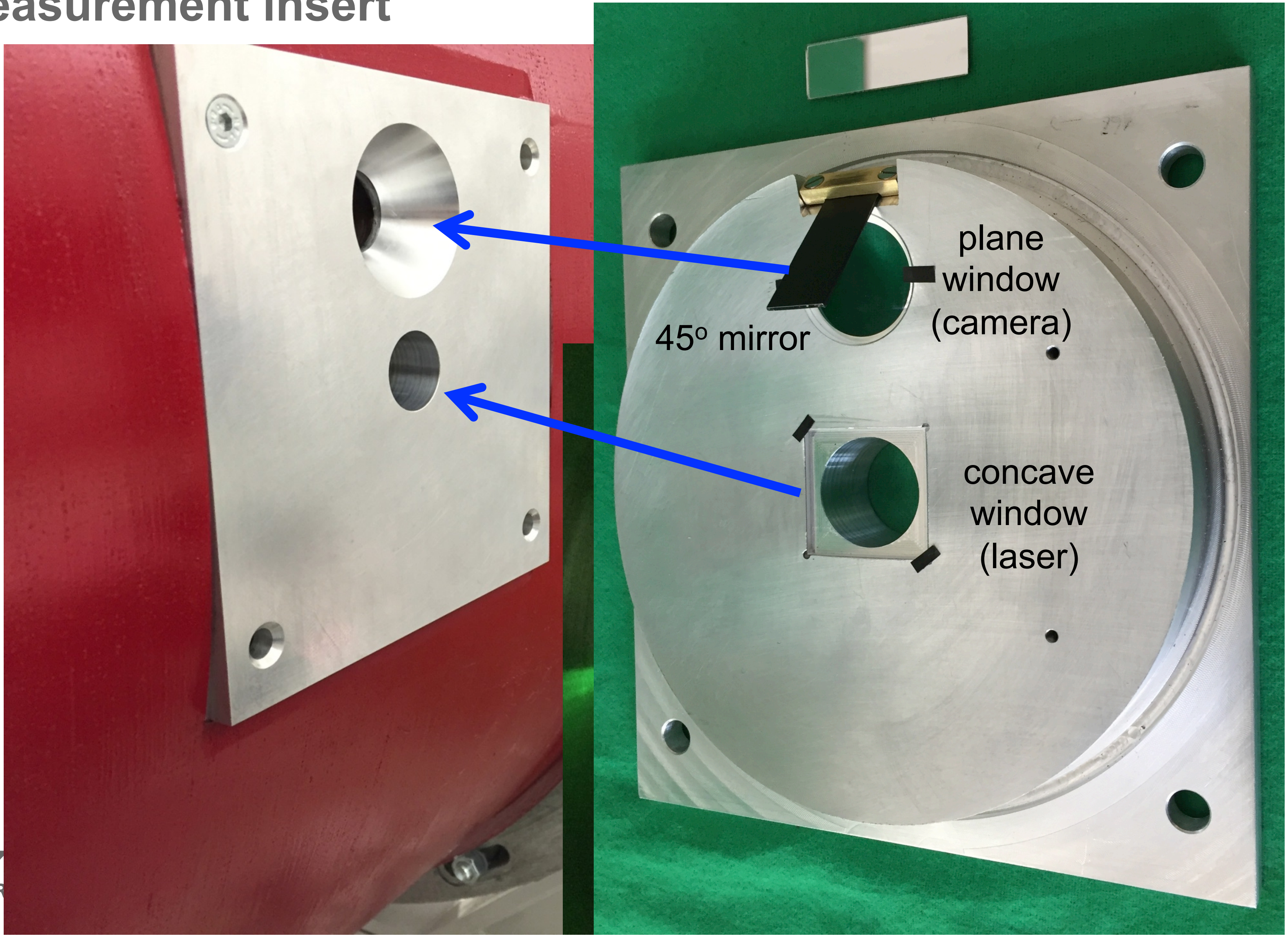
Conditions	U_m [m/s]	Re_D [-]	R^+ [-]	L^* [µm]
DNS (Highest in 2009)	1.4	84,000	2,200	222
Appearance of log region	11	0.66M	13,000	34
Design point	38	2.3M	40,000	11
Maximum power	70	4.3M	71,000	6



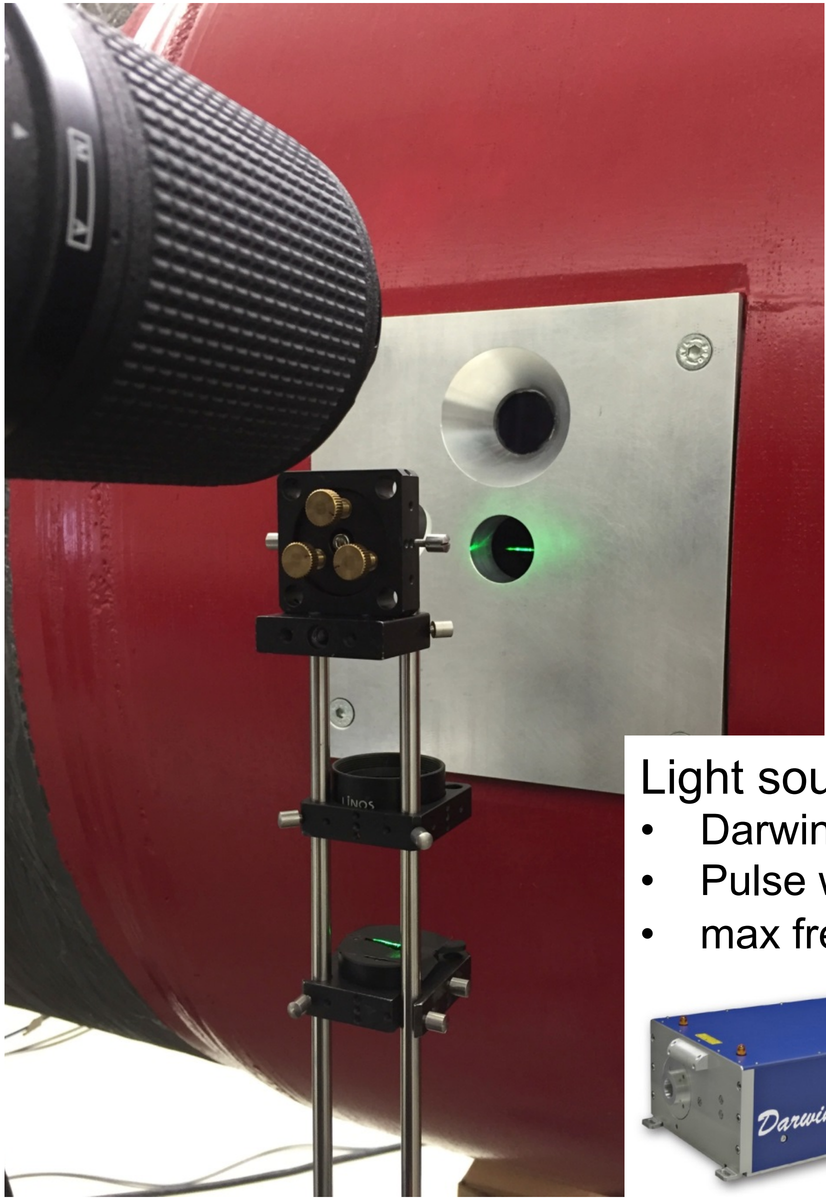
- length: 115 m
- diameter: 0.9 m ±0.5 mm
- surface roughness: < 10 µm
- Re_τ : 3000 – 40000 (60000)
- Viscous scales: 100 … 10 µm
- U_{mean} = ~5 … 40 m/s (55 m/s)

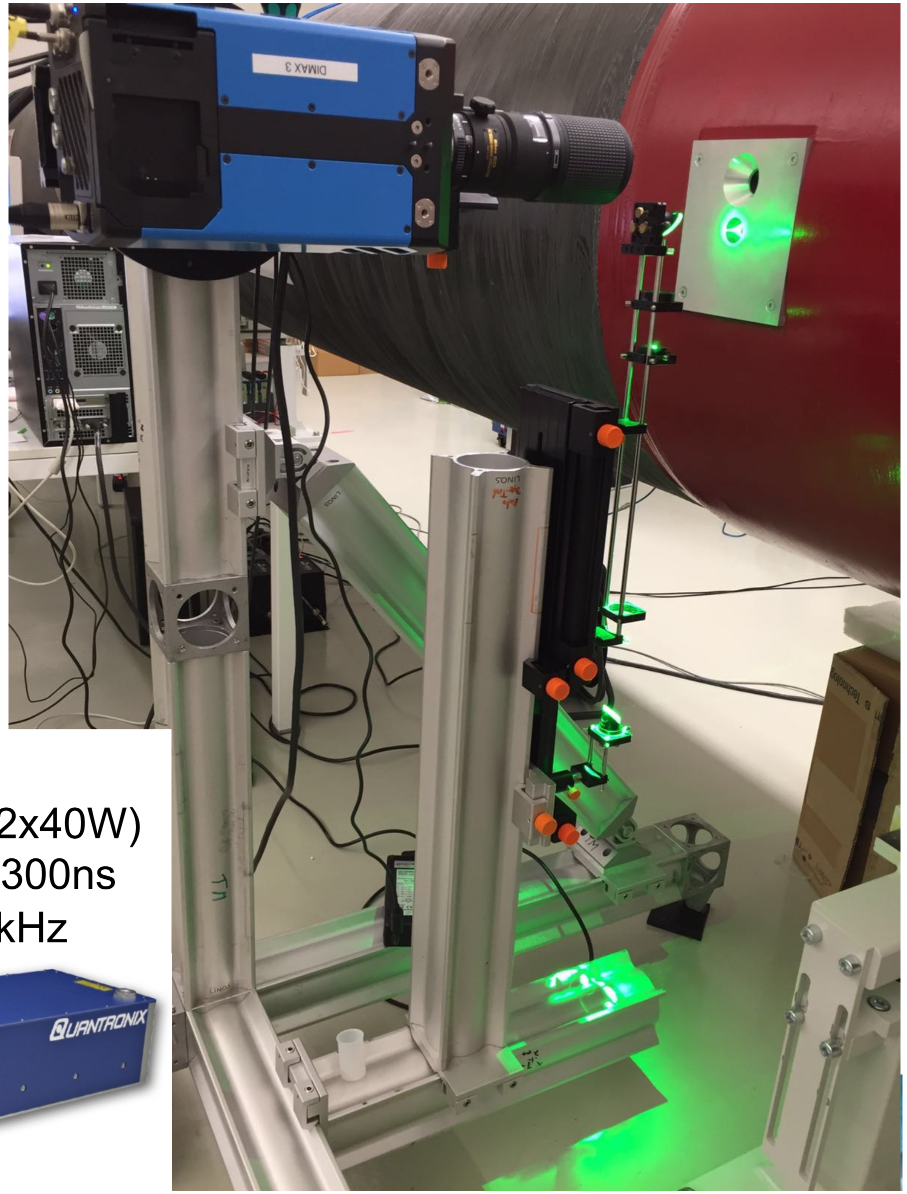
Center for International Cooperation in Long Pipe Experiments

Measurement insert



Setup for near-wall PIV measurements



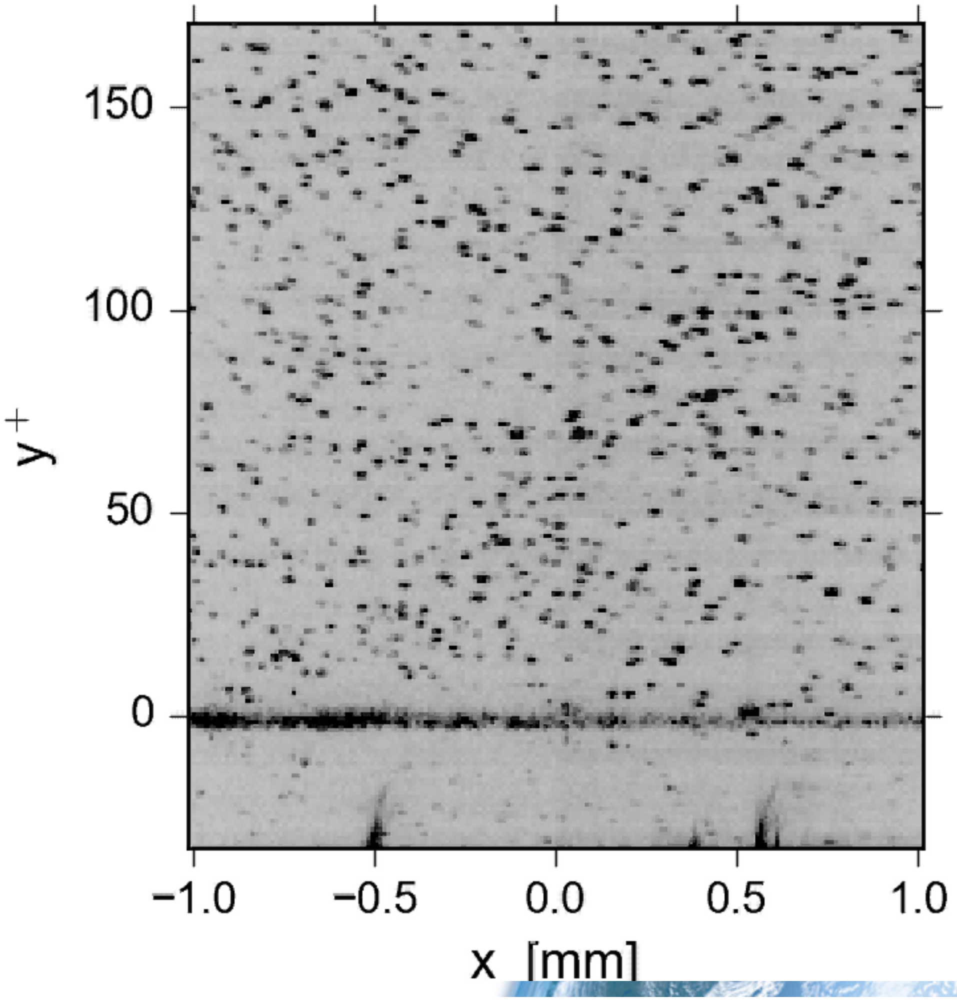


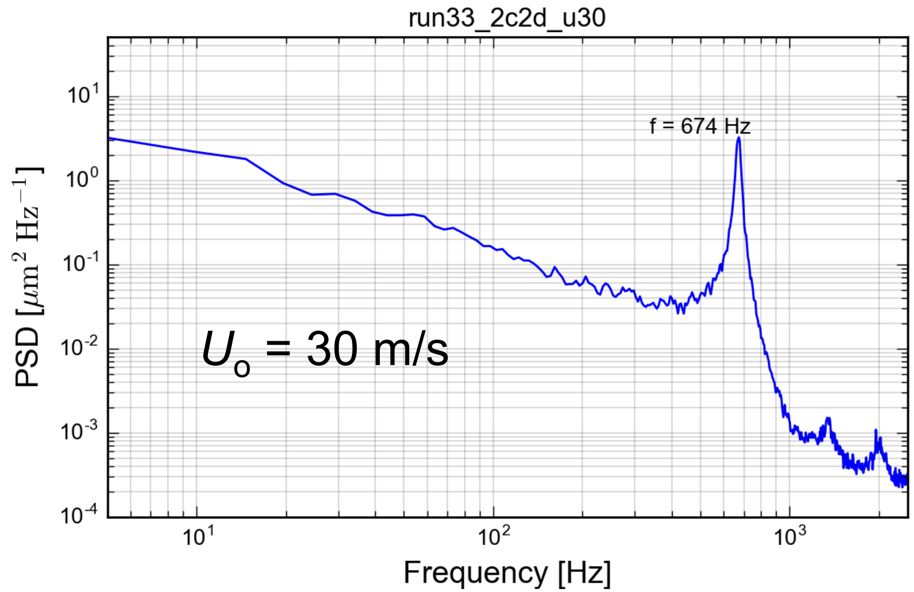
Light source:

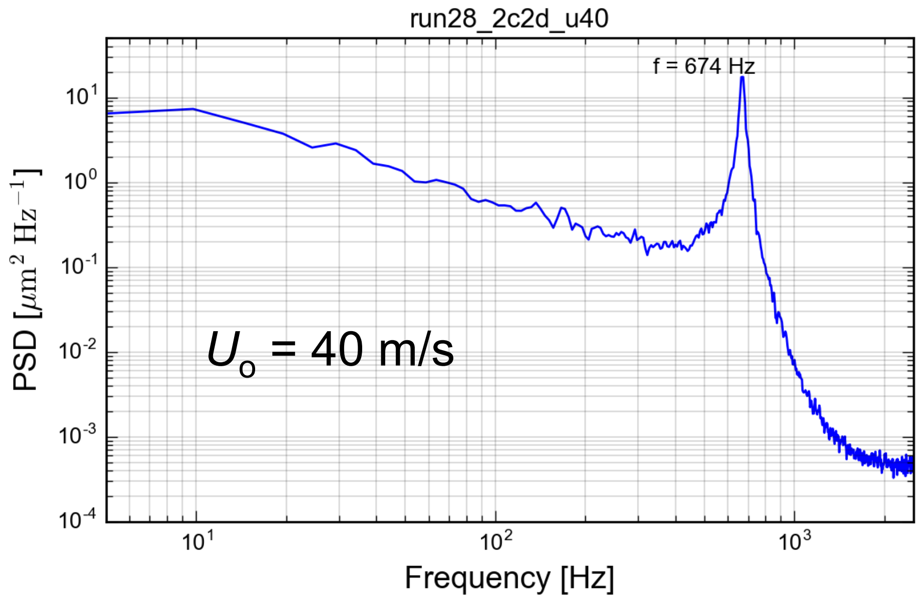
- Darwin Duo (2x40W)
- Pulse width ~300ns
- max freq. 10 kHz

Vibrations

- present at U ≥ 30 m/s
- tracked using correlation approach
- image shifting before PIV analysis



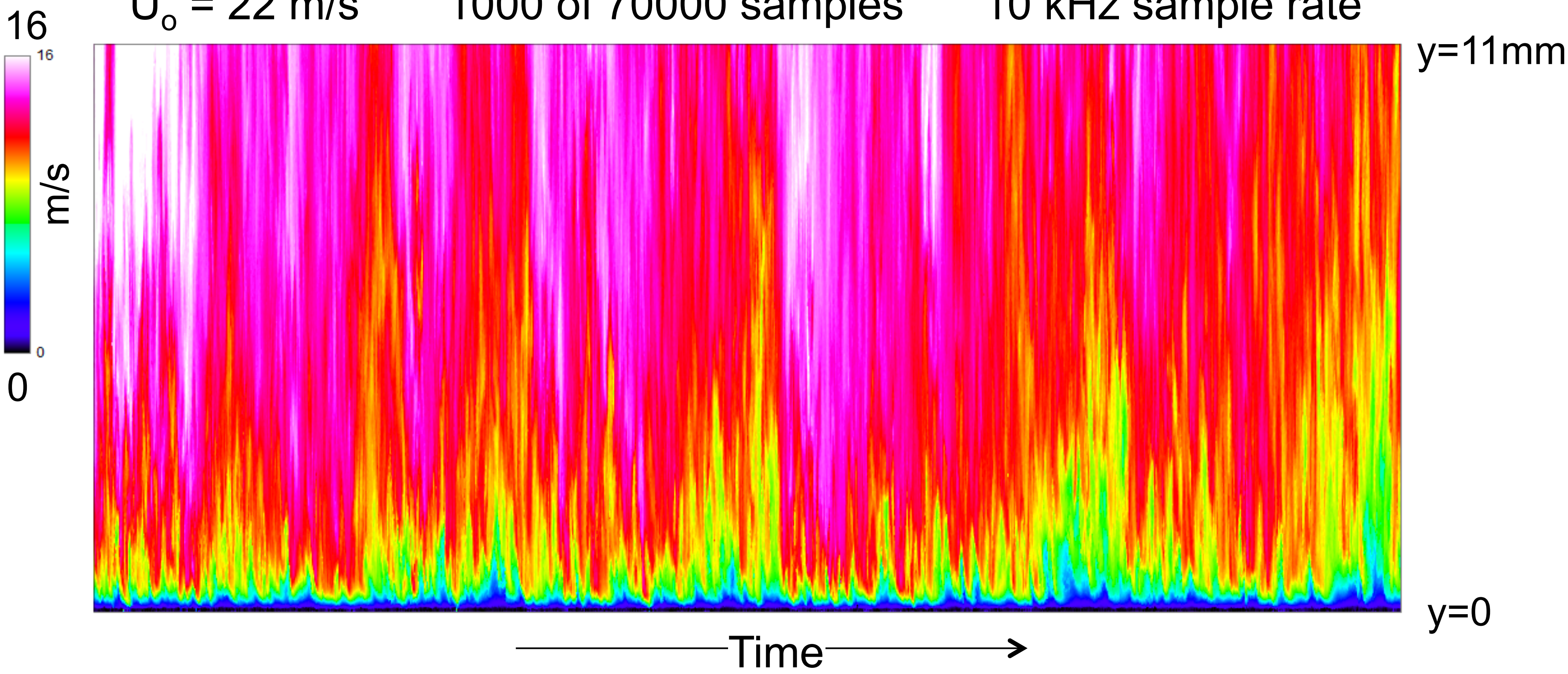




Time-record of stream-wise velocity profile

Re_τ = 20,000

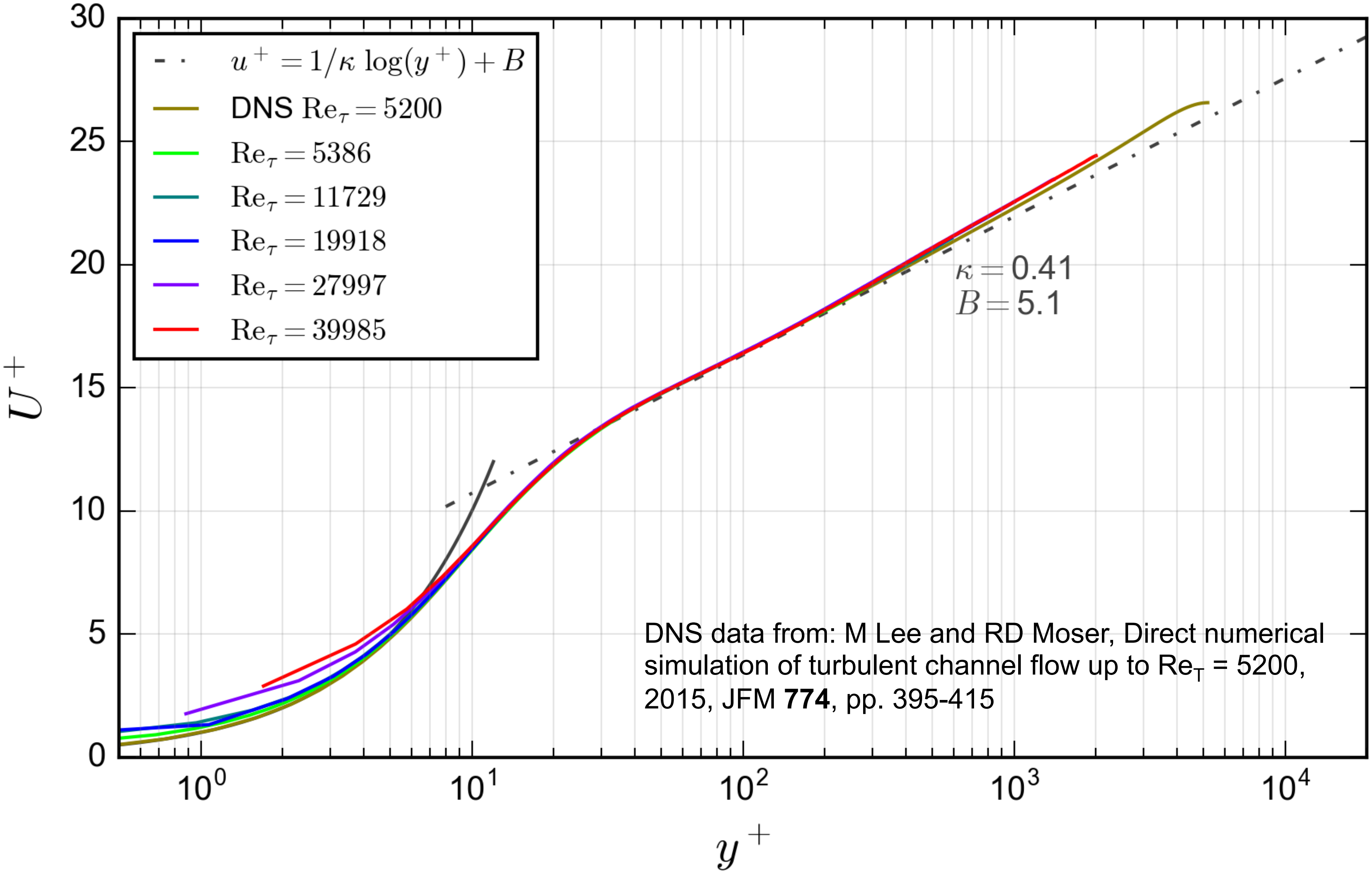
U_o = 22 m/s   1000 of 70000 samples   10 kHz sample rate



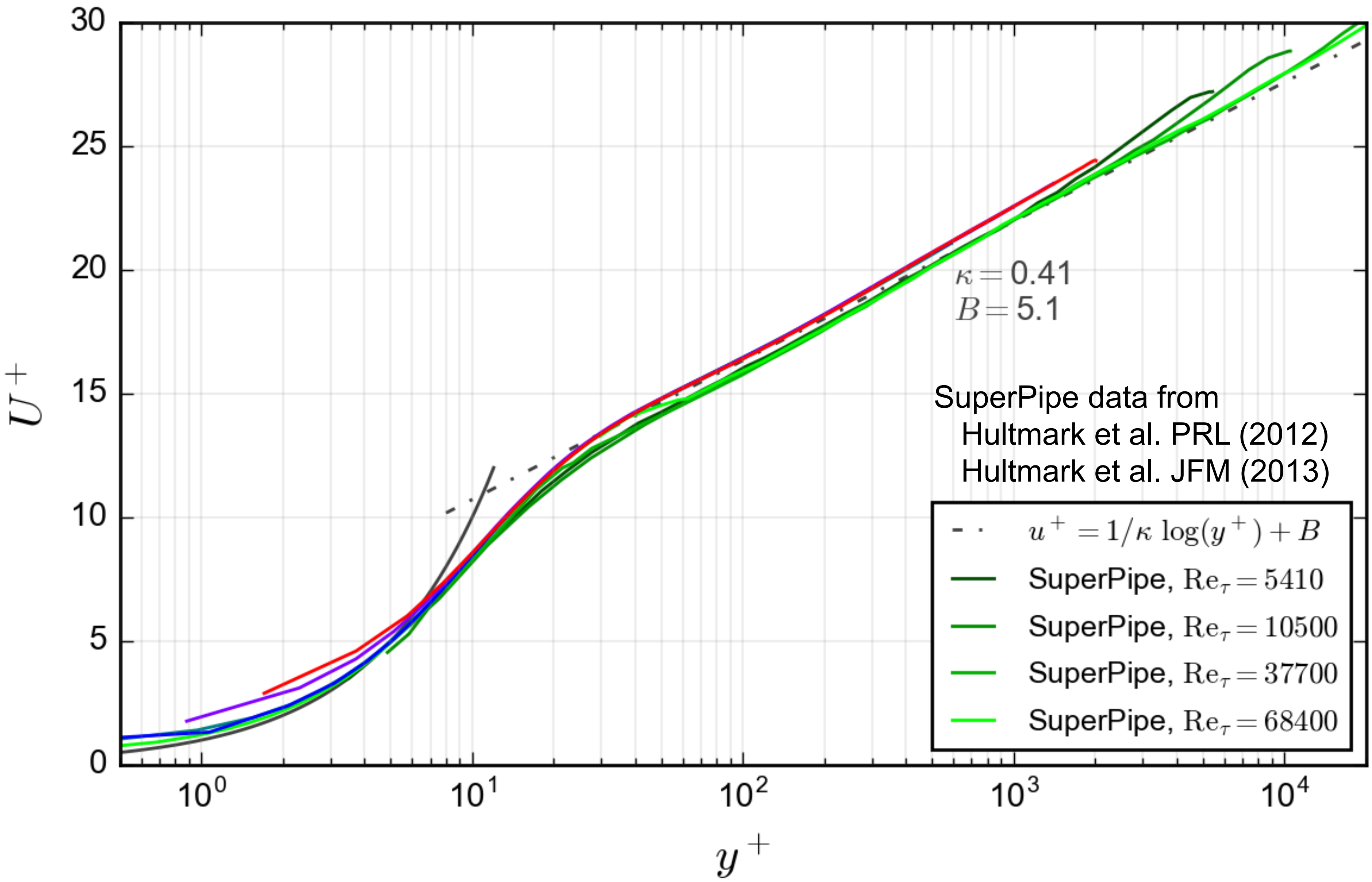
also have wall-normal velocity component (and vorticity ω_z)

DLR

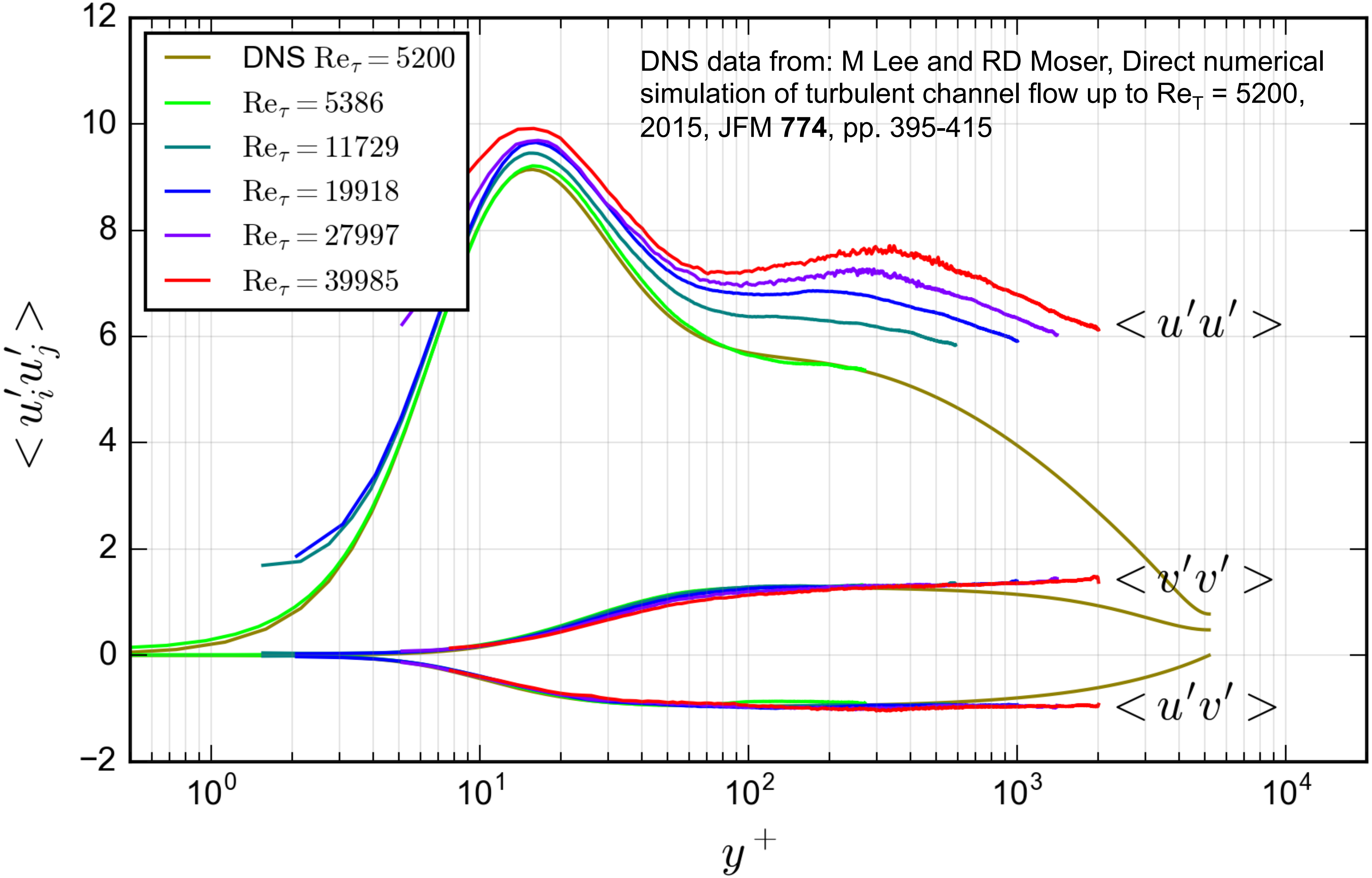
Mean velocity profiles



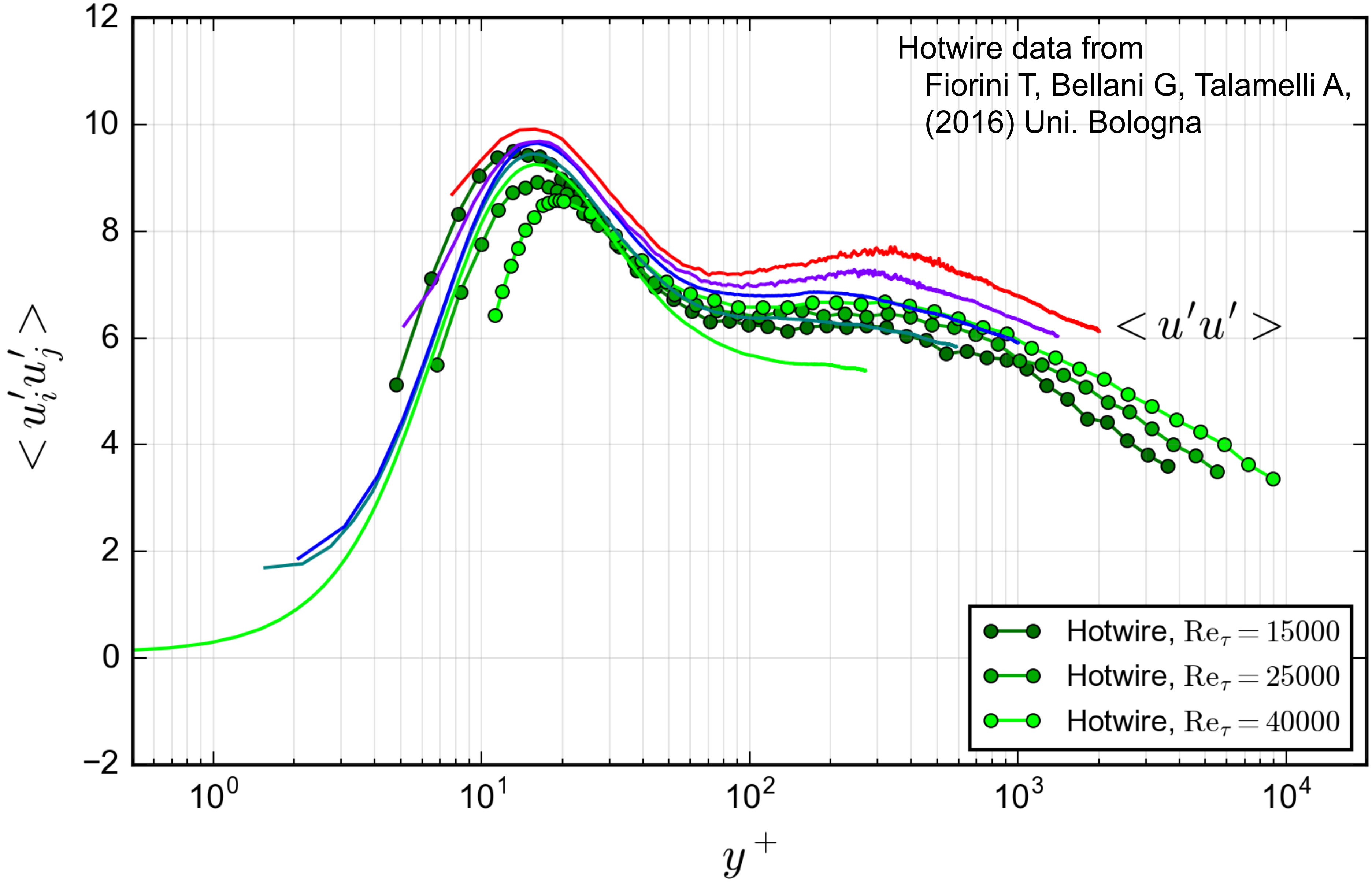
Mean velocity profiles – incl. hotwire data



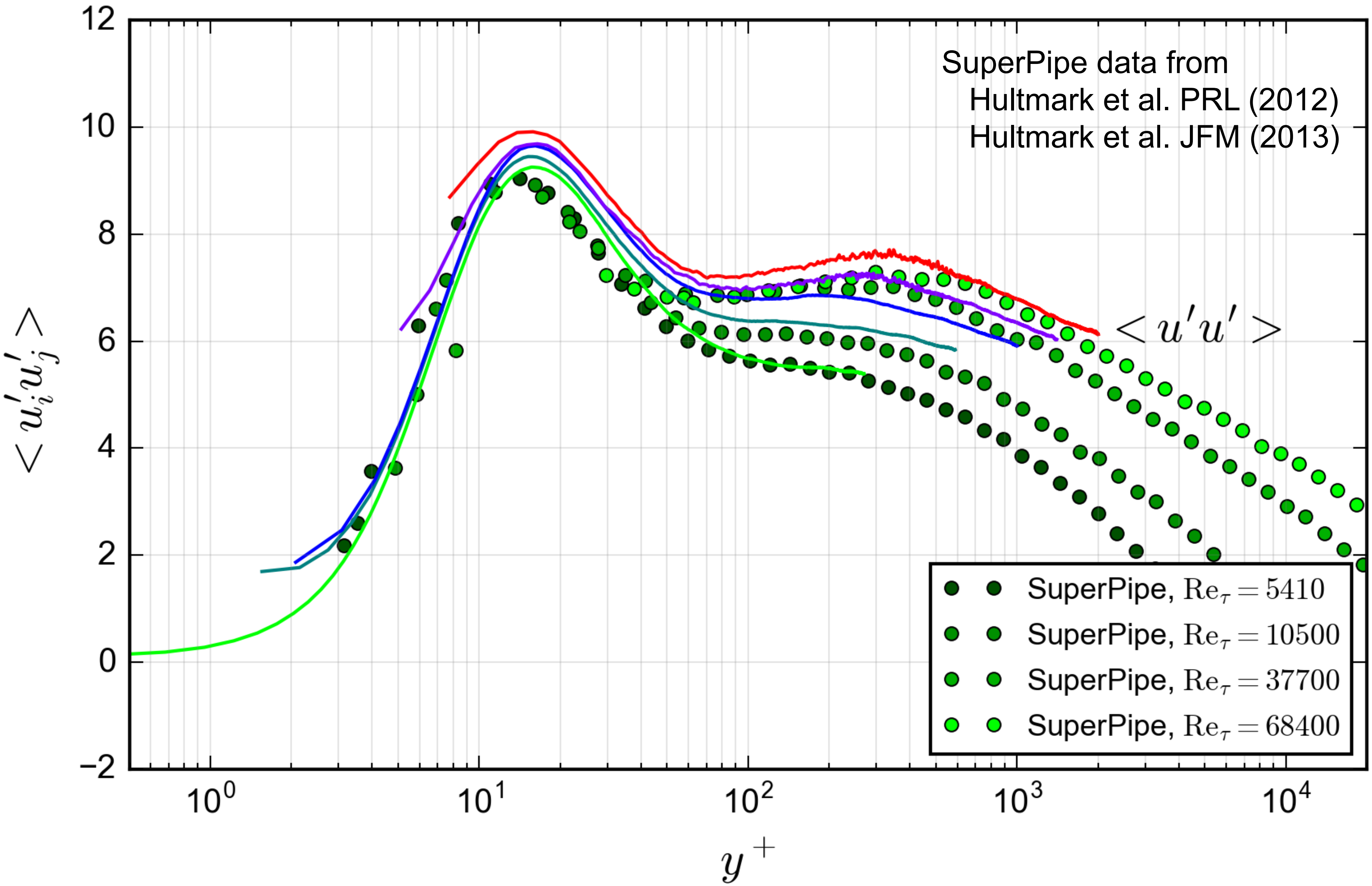
Reynolds stress profiles



Reynolds stress profiles, incl. hotwire data



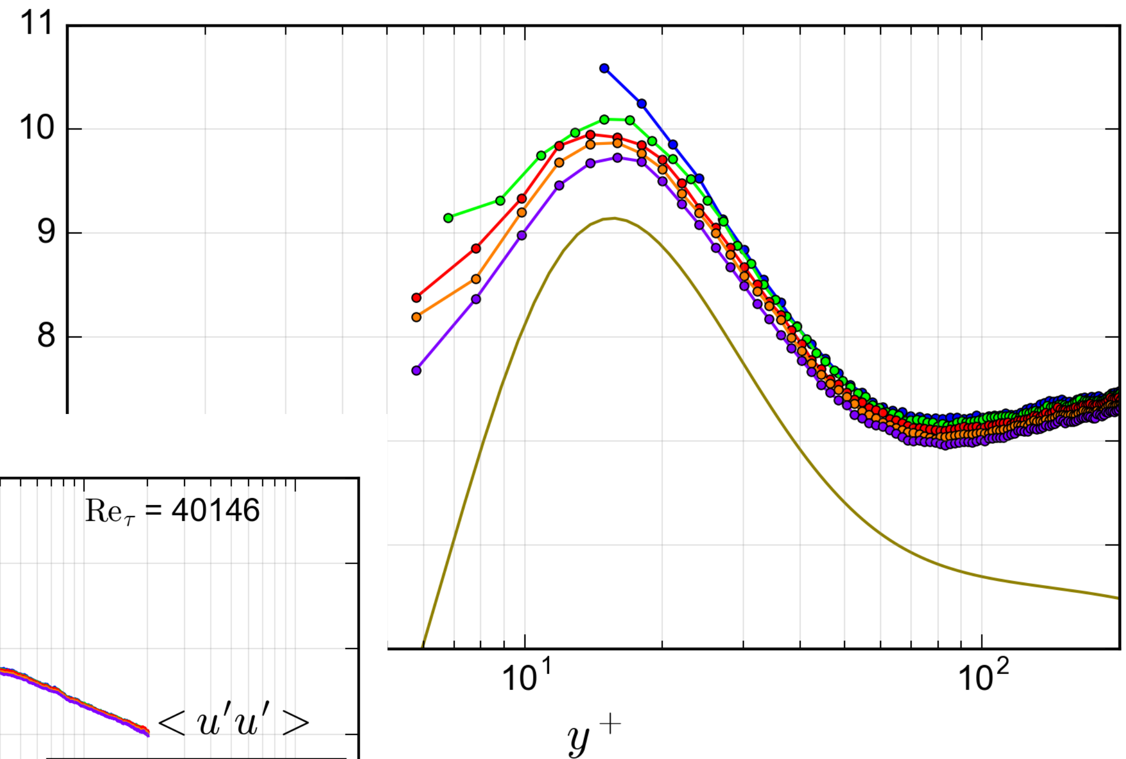
Reynolds stress profiles, incl. SuperPipe data

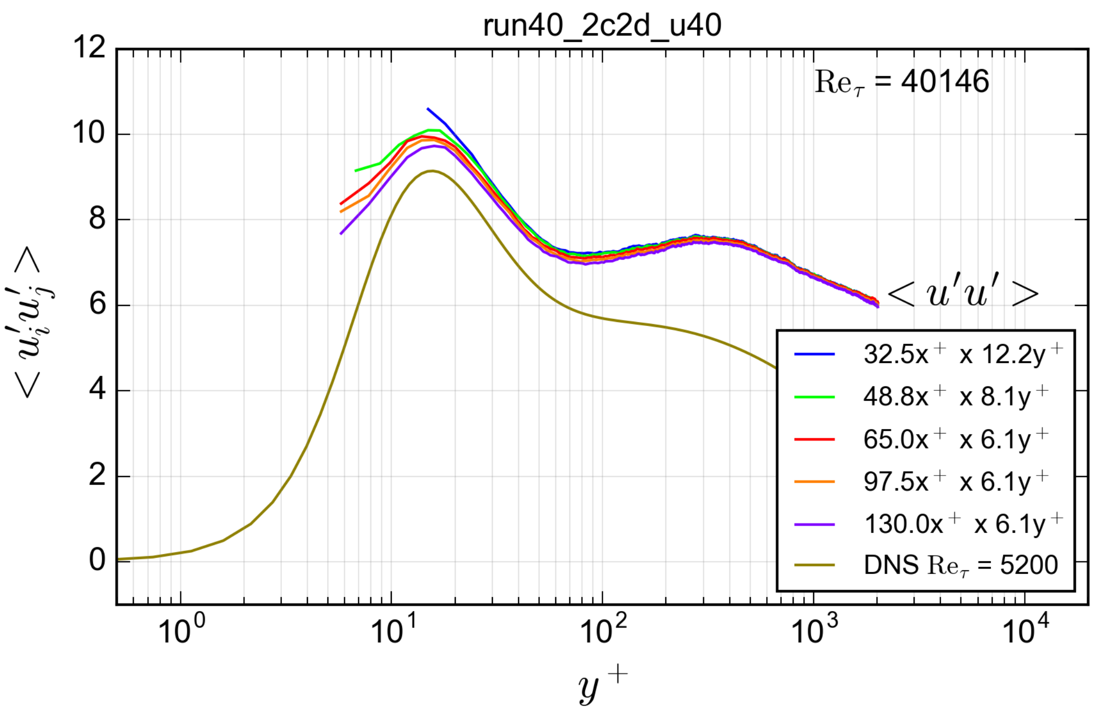


Influence of sampling window on inner peak height

PIV sample size

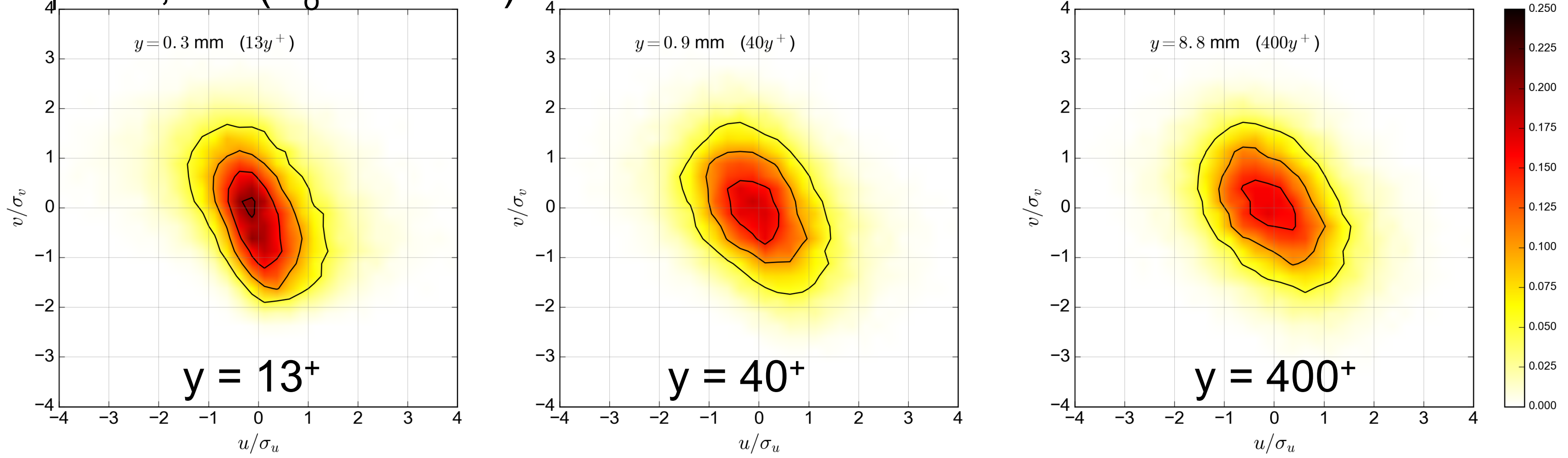
- 32 x 12 pixel
- 48 x 8 pixel
- 64 x 6 pixel
- 96 x 6 pixel
- 128 x 6 pixel



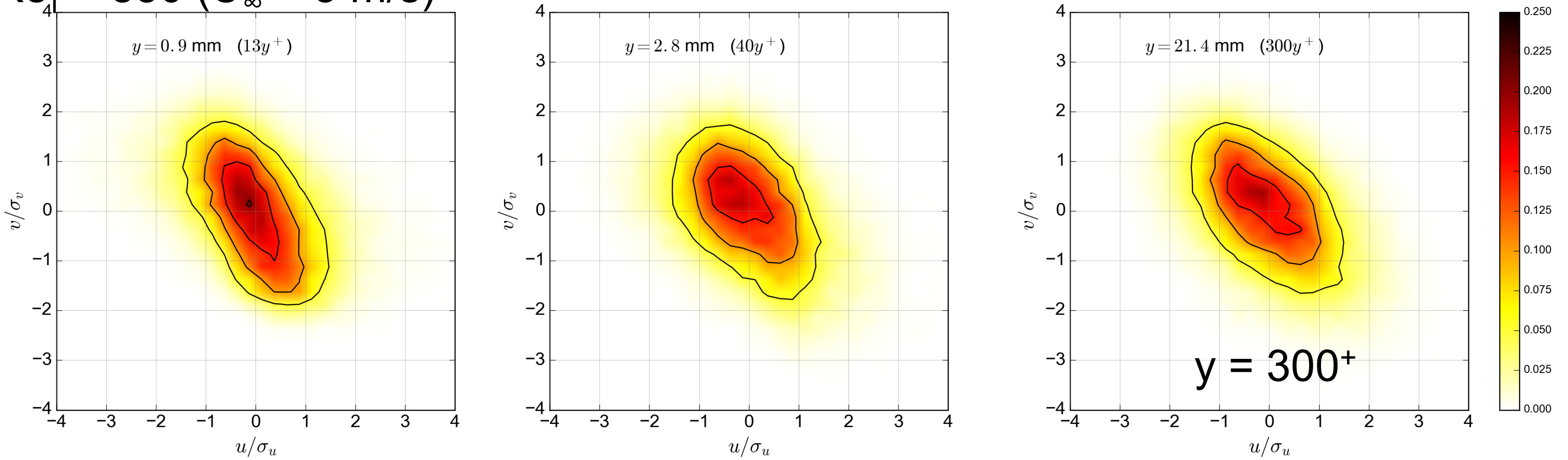


Joint-PDFs : Pipe vs. Flat Plate Turbulent BL

Re_τ = 20,000 (U_o = 22 m/s)



Re_τ = 830 (U_∞ = 5 m/s)



Summary – High-*Re* turbulent pipe flow measurements

- first application of PIV in new pipe flow facility CICLoPE
  (in operation since 2015)
- PIV measurements at Reynolds number range Re_T = 5,000 … 40,000
- imaging with spatial resolution of O(10µm) → resolves viscous sublayer
- statistical convergence through multiple time-records
  with each up to 70,000 samples
- inner peak grows with Re_T (similar to ZPG-Turb. BL)

- work in progress:
  - extract unsteady wall-shear stress from images
  - detailed spectral analysis, space-time-correlations, length scales,…
  - …