# High-Fidelity PIV of a Naturally Grown High Reynolds Number Turbulent Boundary Layer

D. Biles, C. Klewicki, N. Mairno, C.M. White
University of New Hampshire

*Graduate Seminar*
*27th October 2017*

**High-Fidelity PIV**

↓

Sound reproduction over full range of audible frequencies with very little distortion of the original signal

**Naturally Grown High Reynolds Number Turbulent Boundary Layer**

↓

Complicated dynamic non-linear system

# Boundary Layers 101

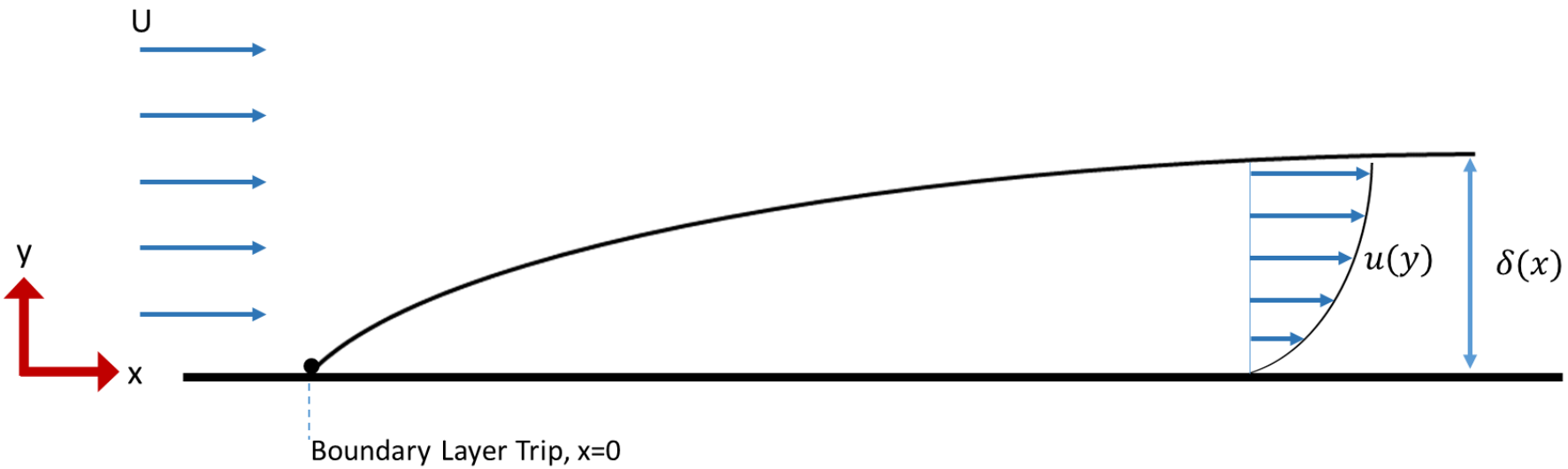



Image of mean boundary dynamics
Boundary layer thickness increasing with downstream position
Mean velocity profile staying self similar (ie when normalized indep. of position).

# Reynolds Number Scales


http://www.dkrub.com


www.boeing.com

$10^1$ $10^2$ $10^3$ $10^4$ $10^5$ $10^6$ $10^7$ $10^8$ $10^9$


http://modernistcuisine.com


http://www.eagletribune.com

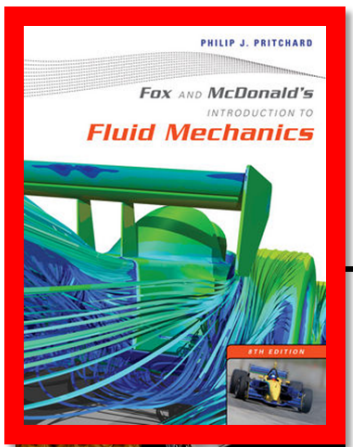

www.unh.edu

- $Re = \frac{uL}{\nu}$
- $\eta = Re^{-3/4}L$

  $\eta$ = small scales

  $L$ = large scales

# Reynolds Number Scales

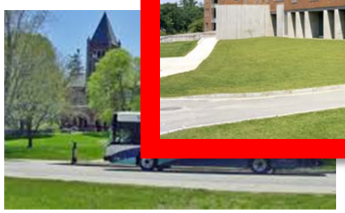



http://modernistcuisine.com

http://www.dkrub.com

$10^3$ $10^4$ $10^5$ $10^6$

http://www.eagletribune.com



www.unh.edu

- $Re = \frac{uL}{\nu}$

- $\eta = Re^{-3/4}L$

  $\eta$ = small scales

  $L$ = large scales

# Reynolds Number Scales


http://www.dkrub.com


www.boeing.com

$10^1$ $10^2$ $10^3$ $10^4$ $10^5$ $10^6$ $10^7$ $10^8$ $10^9$


http://modernistcuisine.com


http://www.eagletribune.com


www.unh.edu

- $Re = \frac{uL}{\nu}$
- $\eta = Re^{-3/4}L$

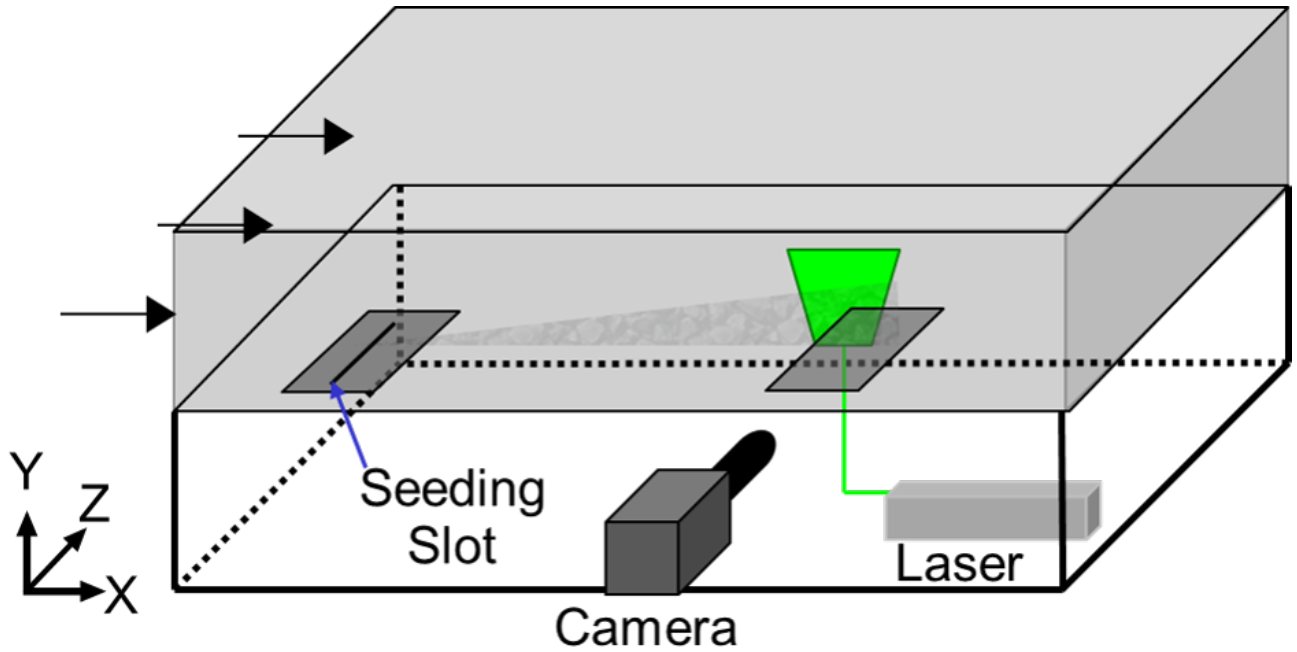
  $\eta$ = small scales

  $L$ = large scales

# Flow Physics Facility

- $2.8m$ x $6m$ x $72m$
- Driven by two $2.6m$ fans
  -Each $400hp$
- Velocity: $3m/s$ - $14.5m/s$
  -Vol. flow rate: $252m^3/s$
- Floor deviations: .26mm/m

# PIV System: Overview



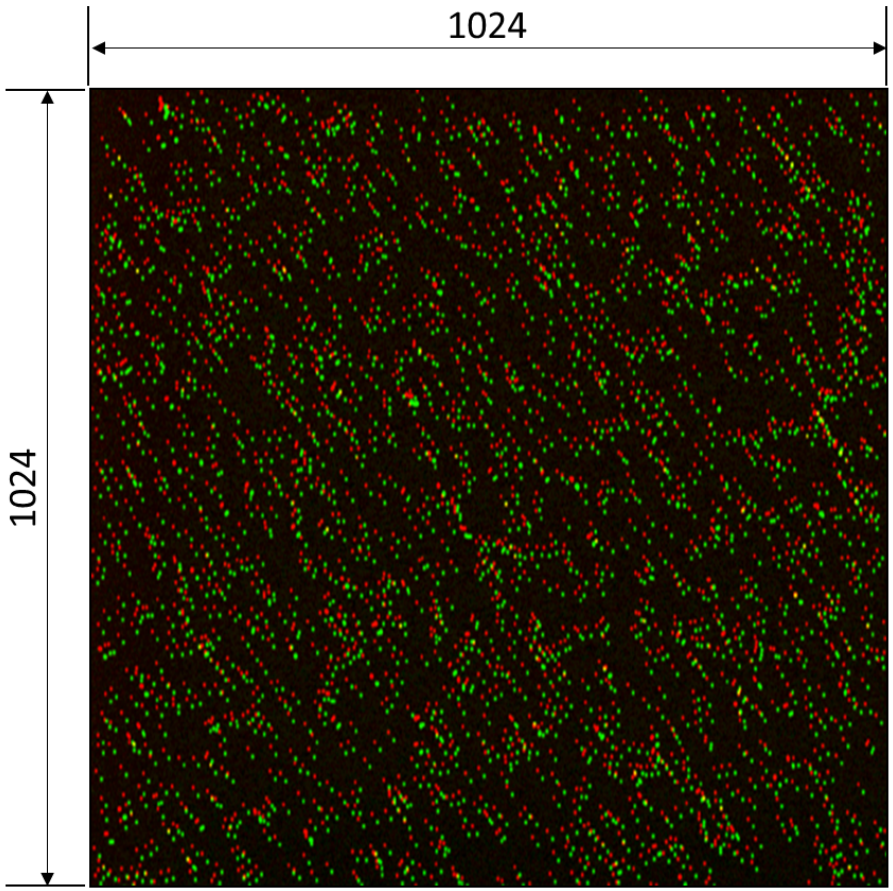

## Photron Fastcam Camera

- 12bit
- CMOS
- 1024 x 1024 pixels
- $20\mu m$ pixel width
- $3.6kHz$ at full FOV

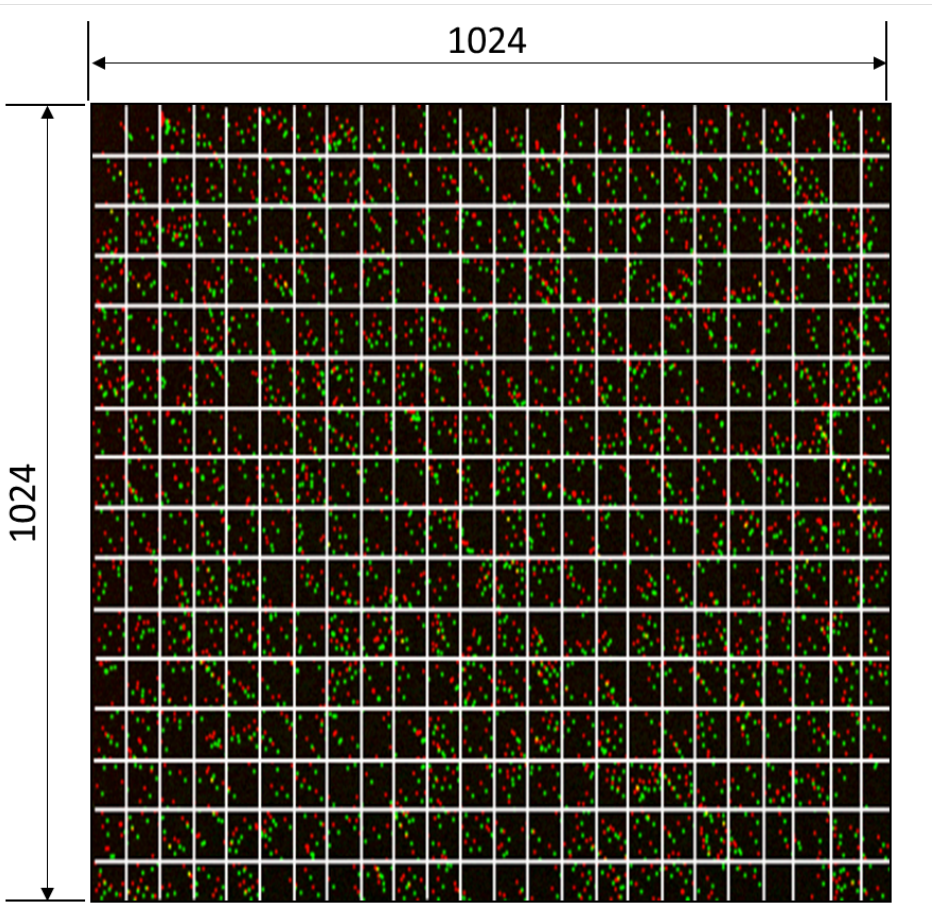
## Photonics Nd:Ylf Laser

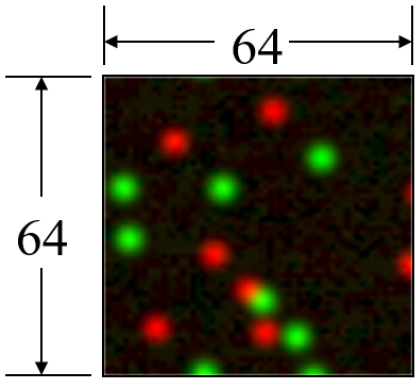
- $527nm$
- $30mJ/pulse$
- single shot - 10kHz

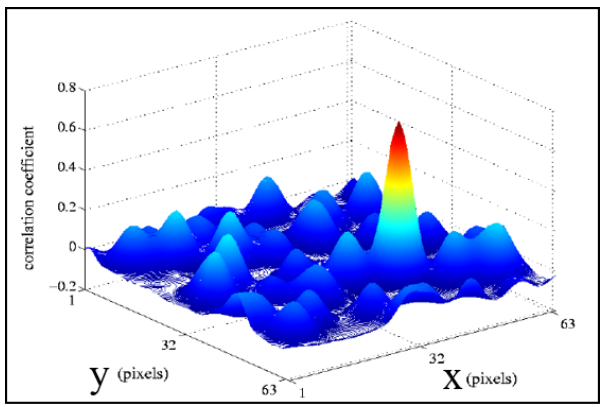
# Processing Sequence



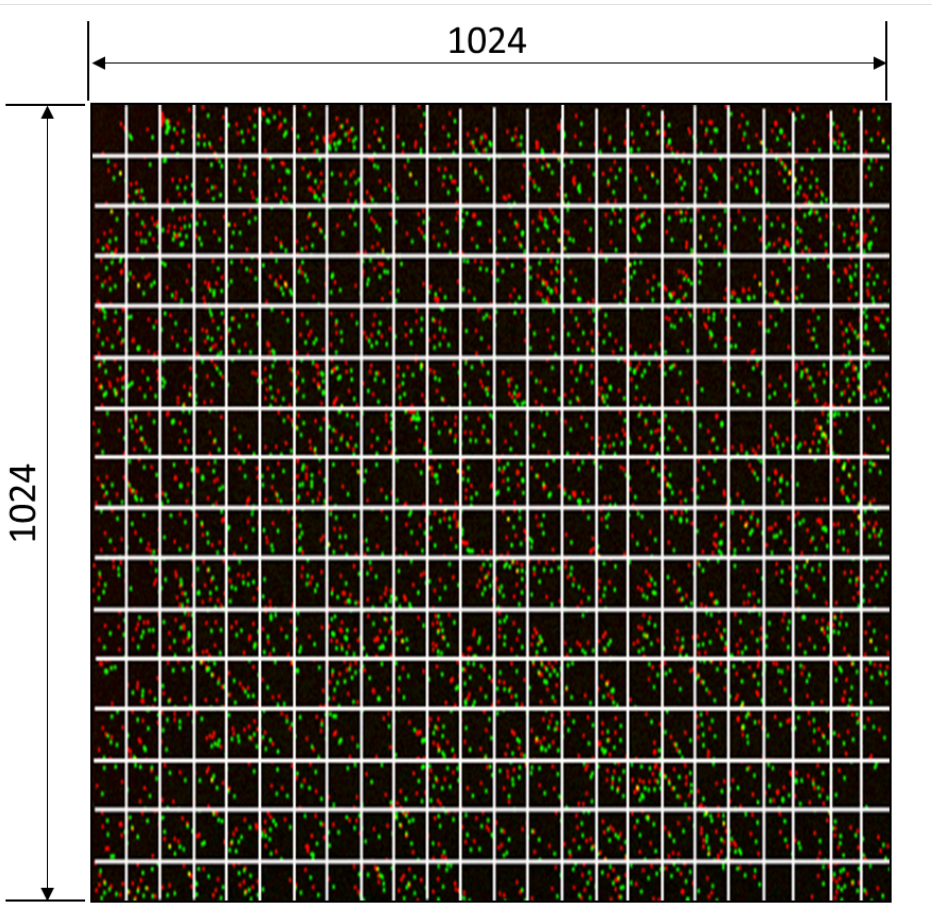
# Processing Sequence

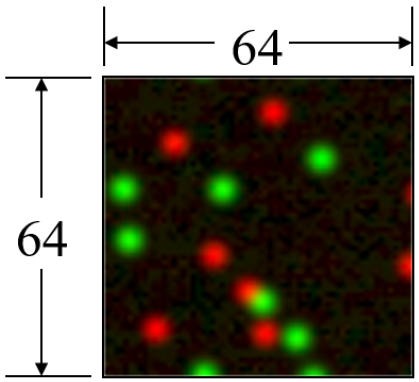


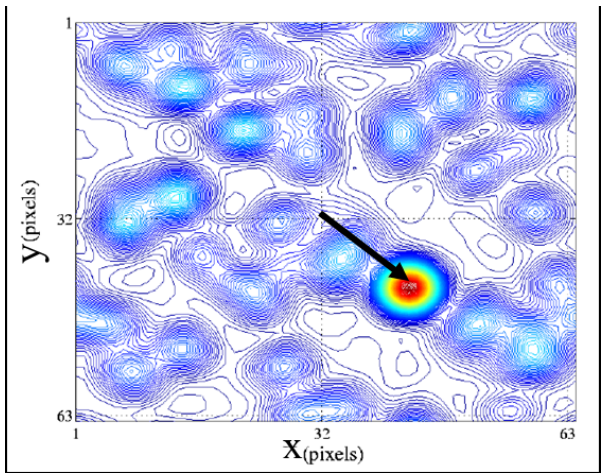



# Processing Sequence



# Imaging Sequence

Image A

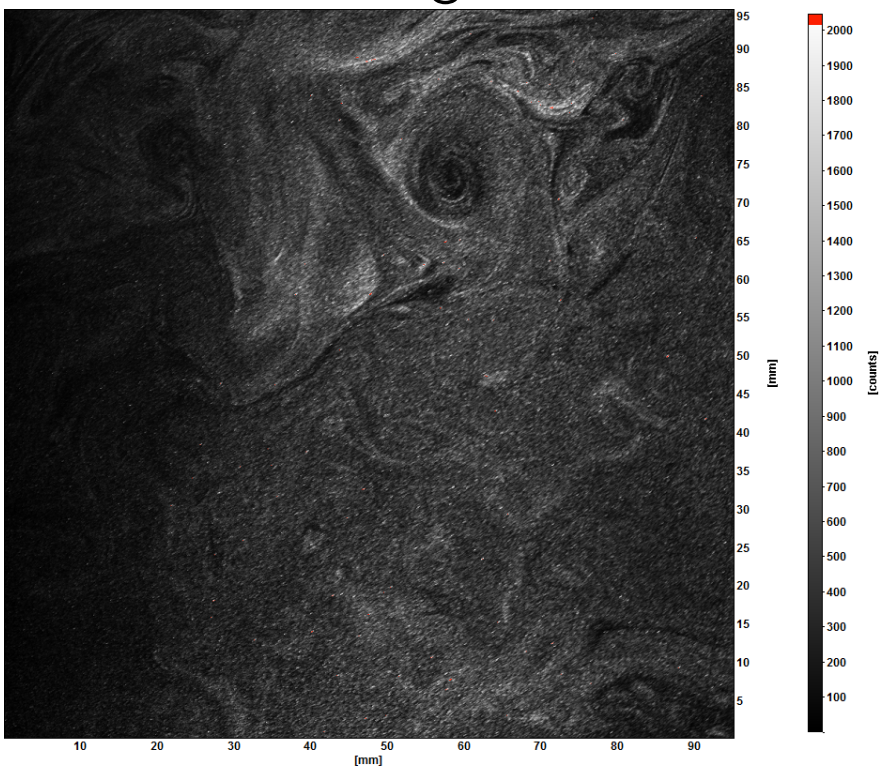
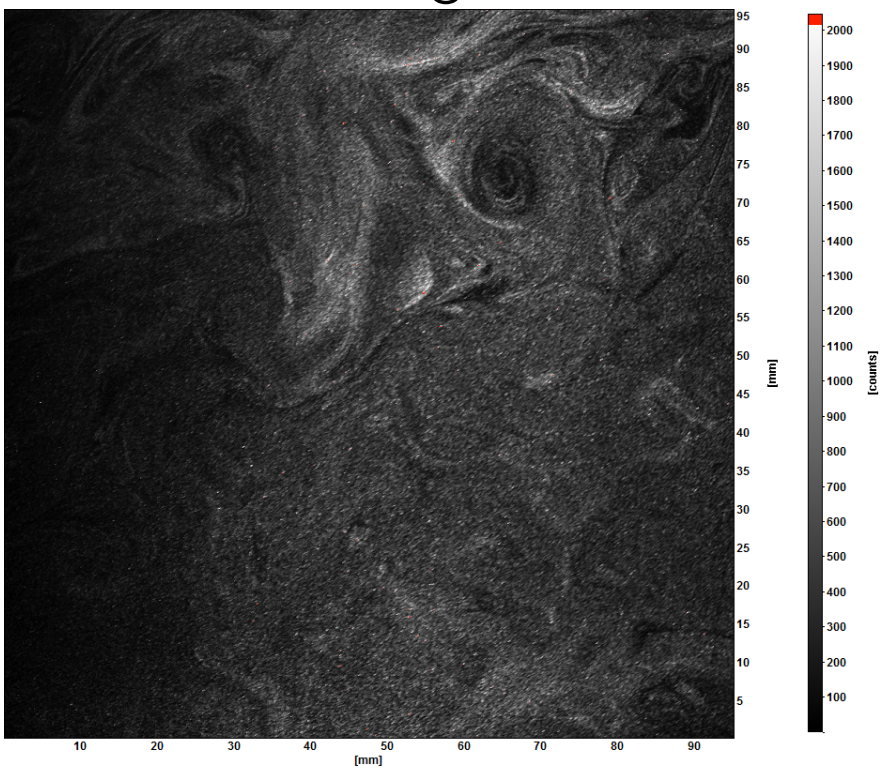


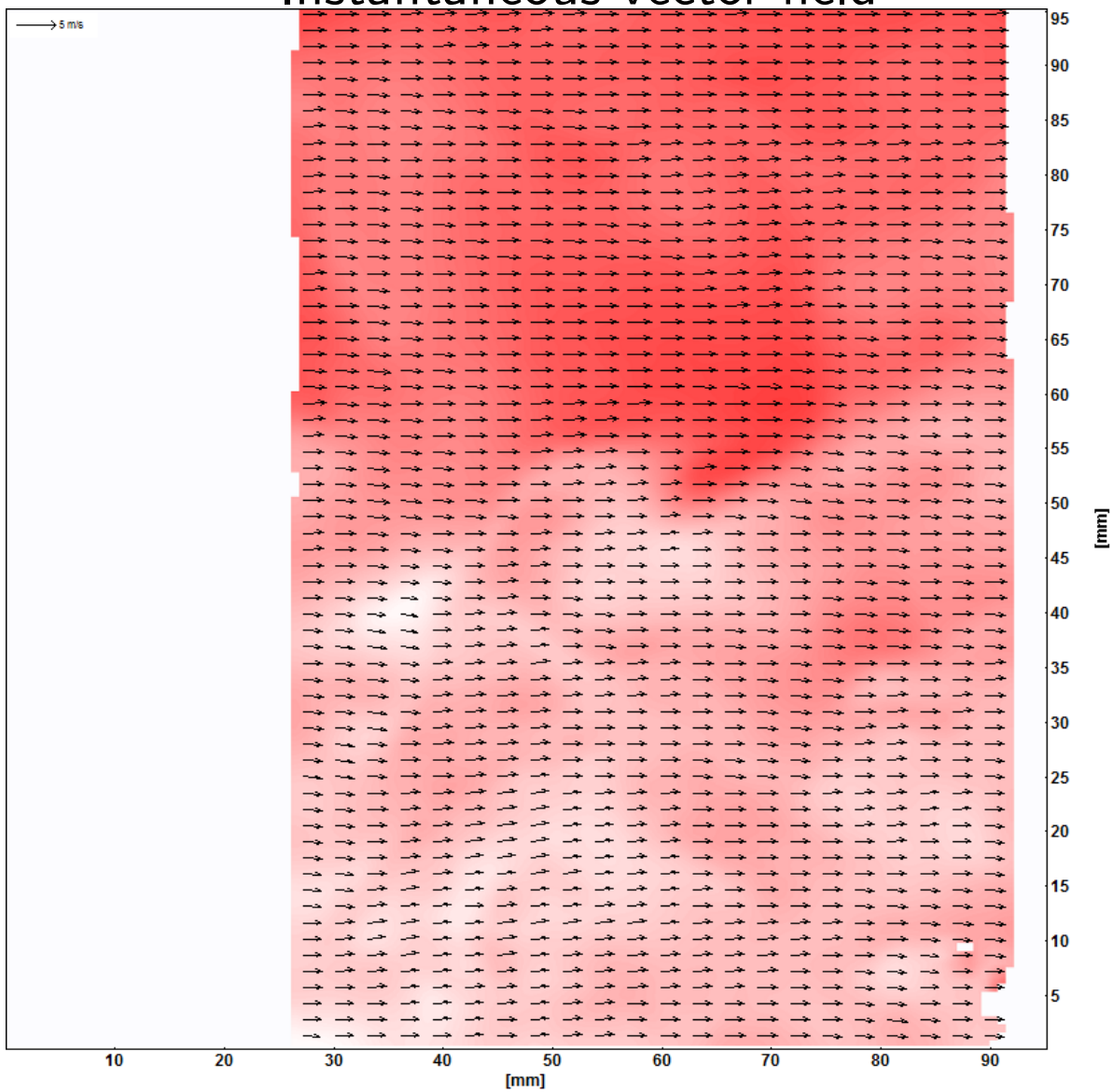

Image B




- images processed on multiloop scheme with decreasing interrogation window size

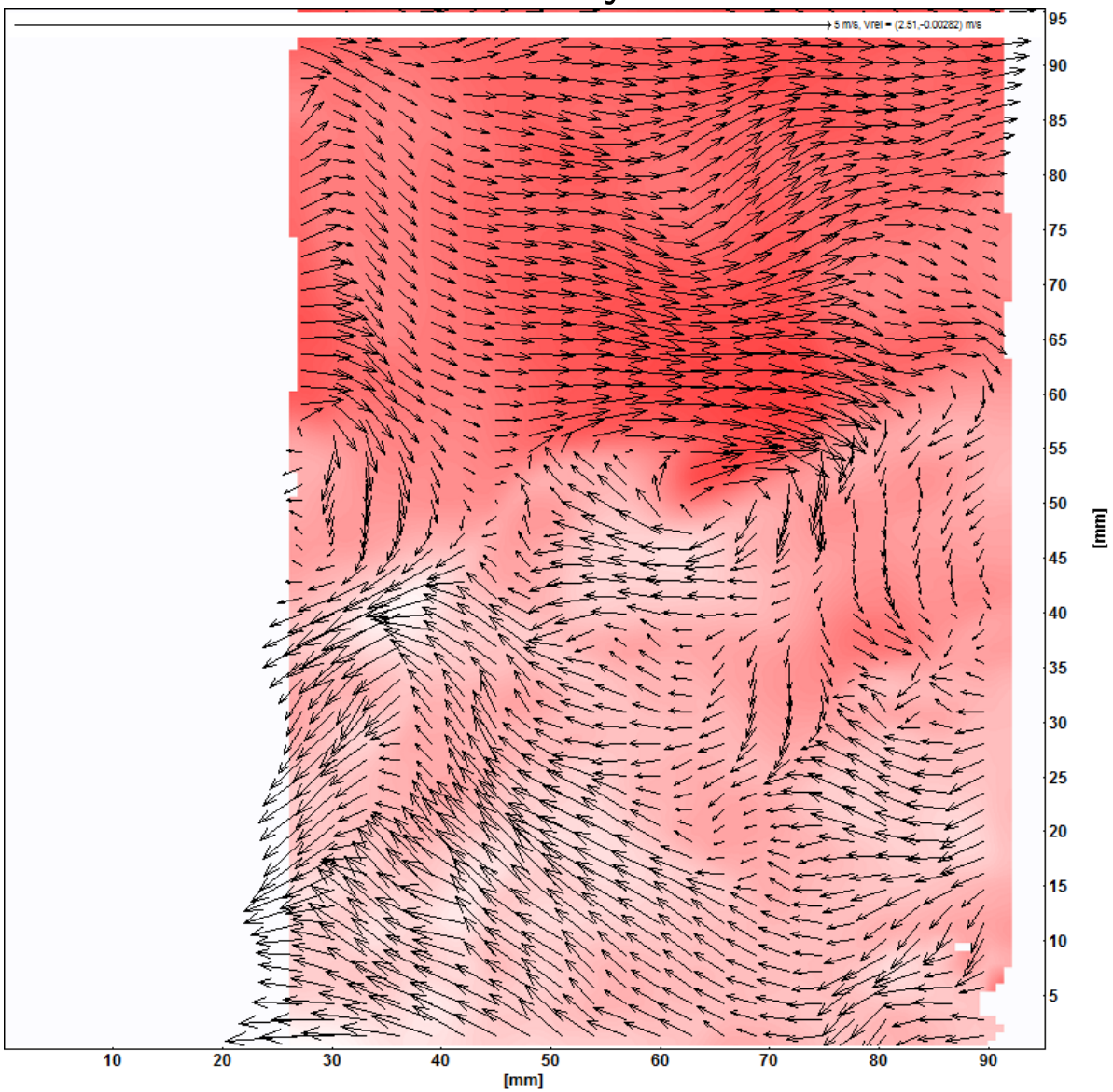
# Imaging Sequence

## Instantaneous vector field

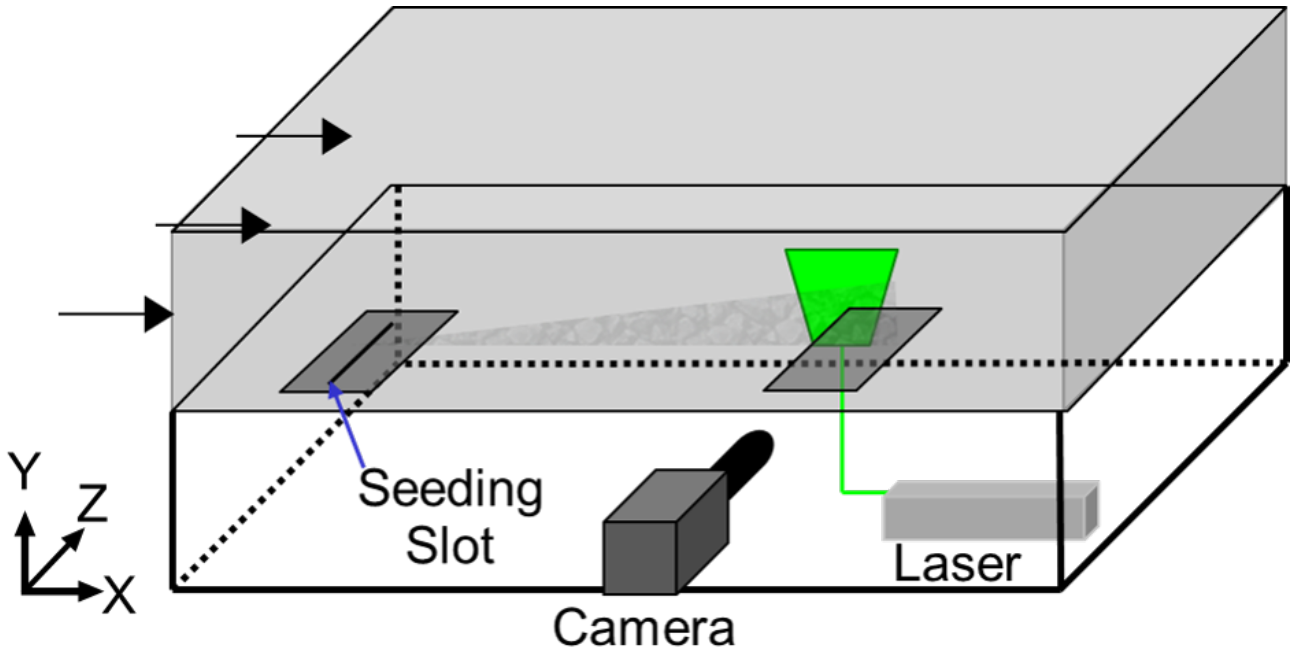


# Imaging Sequence

## Relative velocity vector field



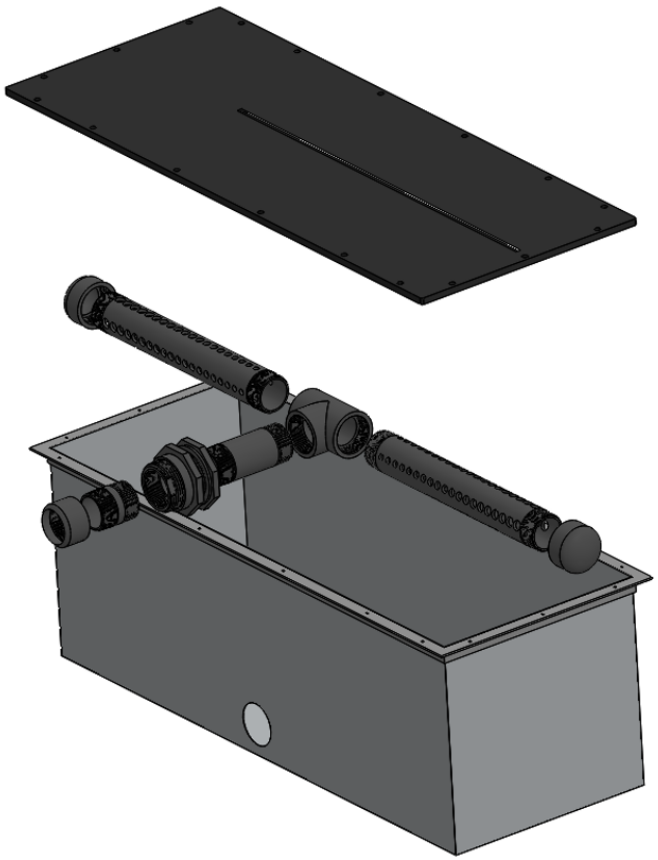
# PIV System: Measurement Details



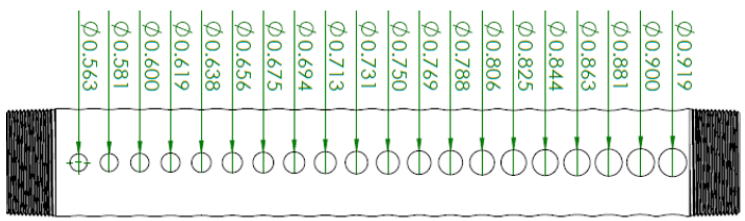

- Oil droplets :$1 - 5\mu m$
- Image plane $60m$ downstream
- $1m$ from laser sheet to camera
- $1.5mm$ laser sheet width

- $14m$ from injection slot to FOV
- FOV: $95mm$ x $95mm$
- Magnification: 4.6 : 1

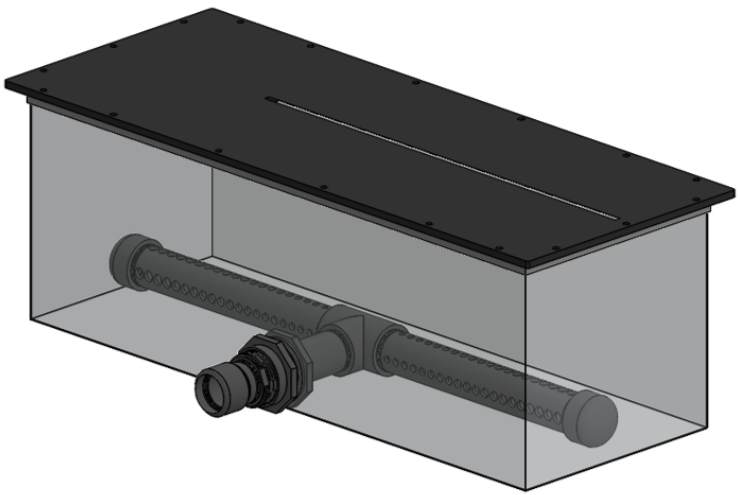
# Seeder Mechanism



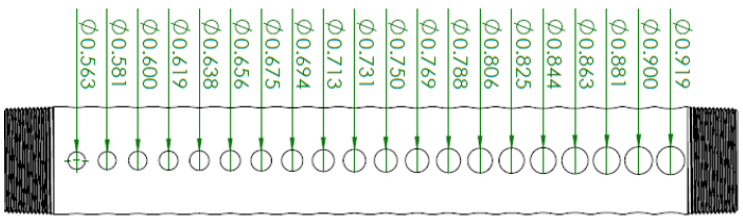
- $6mm$ slot width
- $1m$ slot length
- Slot angle $60^o$
- Inlet manifold to disperse fog
- Rosco fog machine



# Seeder Mechanism

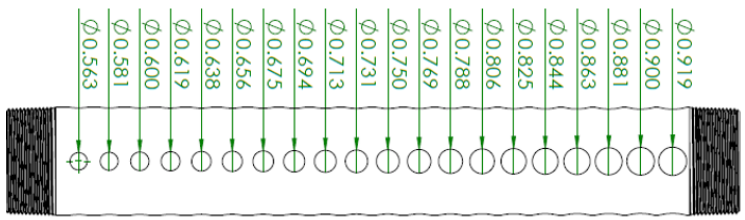


- $6mm$ slot width
- $1m$ slot length
- Slot angle $60^o$
- Inlet manifold to disperse fog
- Rosco fog machine

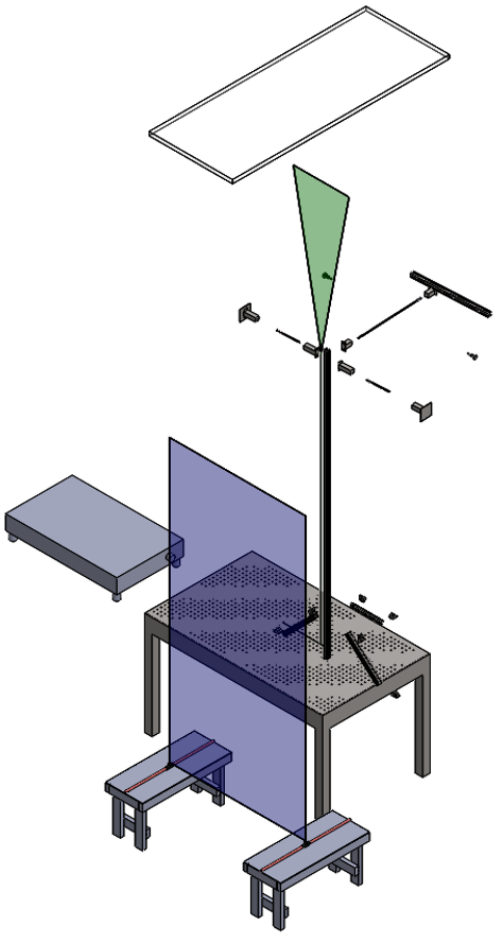


# Seeder Mechanism


- 6$mm$ slot width
- 1$m$ slot length
- Slot angle 60$^o$
- Inlet manifold to disperse fog
- Rosco fog machine

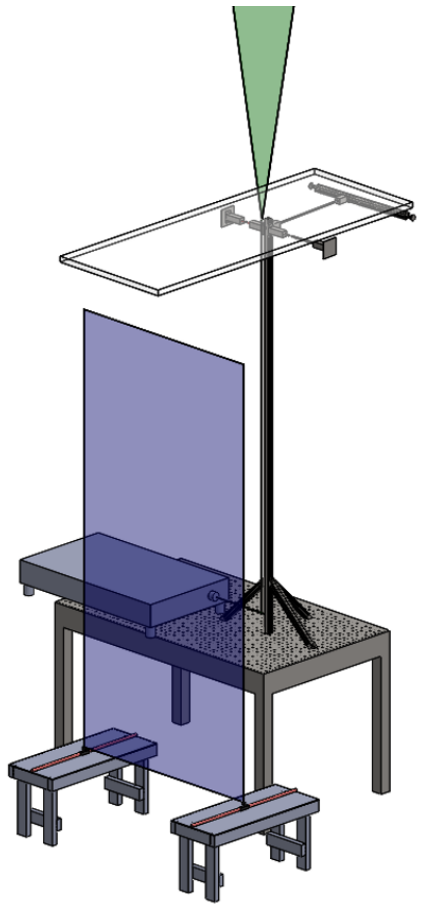


# Laser / Optics Train



- Spherical focusing lens
- Cylindrical lens to create laser sheet
- Focused in center of FOV
- Adjustable to any window position

# Laser / Optics Train



- Spherical focusing lens
- Cylindrical lens to create laser sheet
- Focused in center of FOV
- Adjustable to any window position

# Camera Setup

- Lowest wall normal position
- 200mm lens
- Magnification 4.6:1 (.09mm/pixel)
- Adjustable 30$cm$ in y and z

# Camera Setup

- Lowest wall normal position
- 200mm lens
- Magnification 4.6:1 (.09mm/pixel)
- Adjustable $30cm$ in y and z

# Flow Physics Facility

# PIV Details and Processing

- 10,918 images at $600Hz$
- final int. area: $16x16pixels$
- $U_\infty = 4m/s$

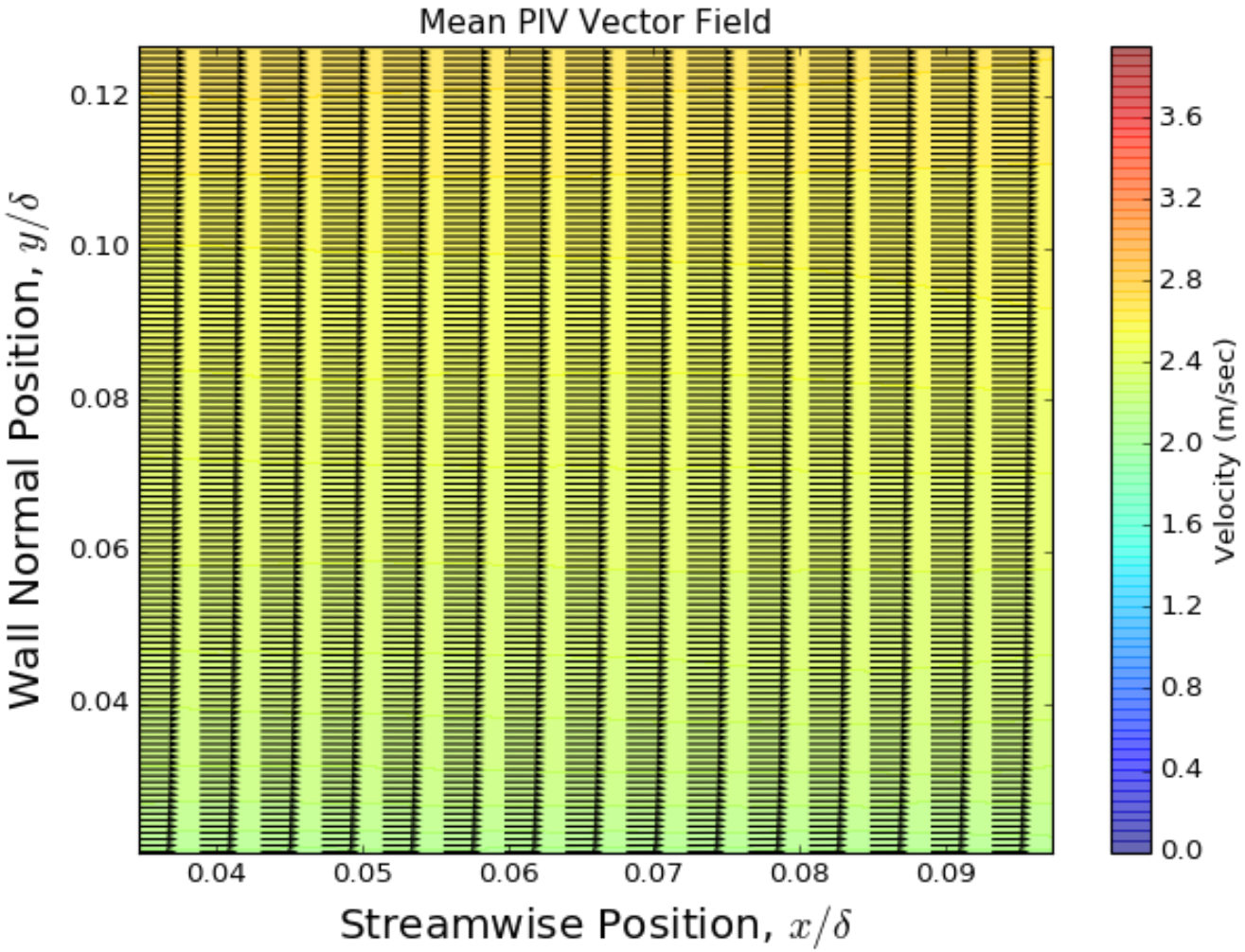
# PIV Details and Processing

- 10,918 images at $600Hz$
- final int. area: $16x16pixels$
- $U_\infty = 4m/s$

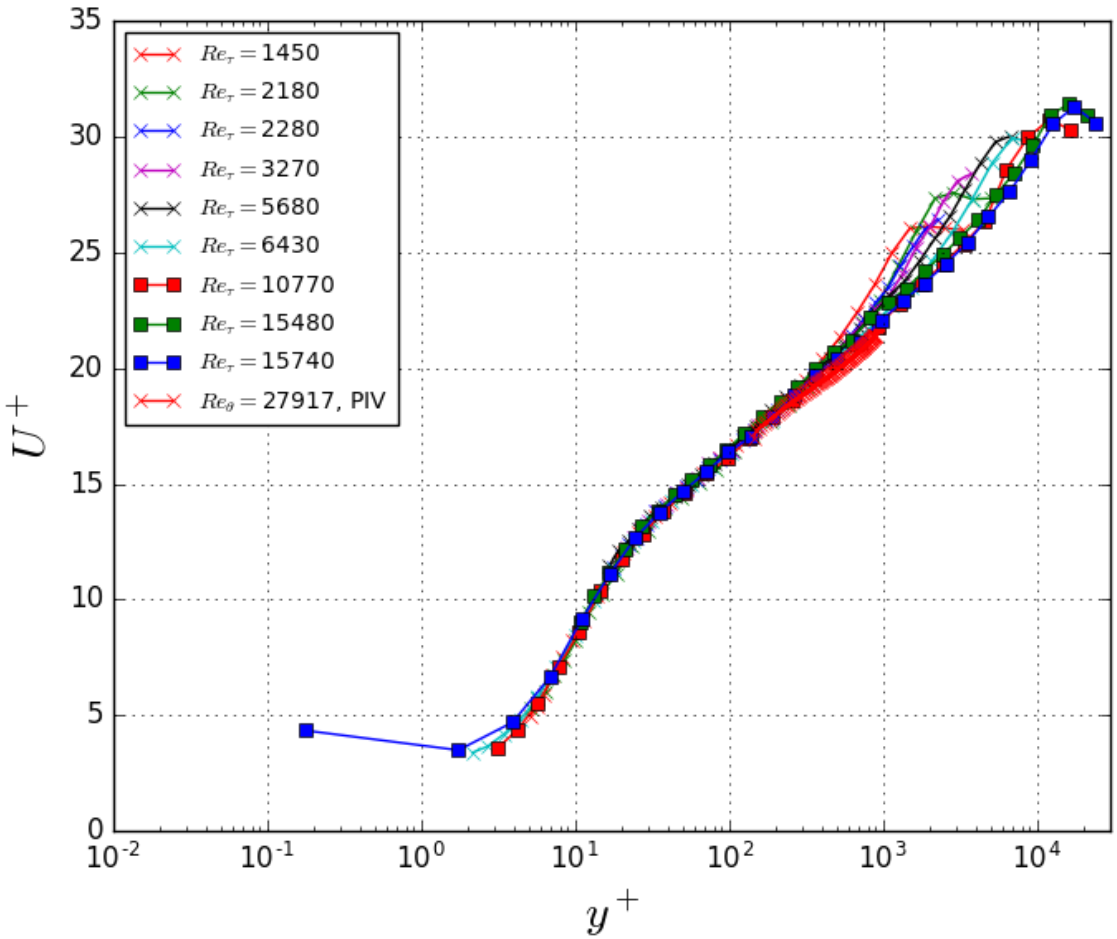
# PIV Details and Processing

- 10,918 images at $600Hz$
- final int. area: $16x16pixels$
- $U_\infty = 4m/s$

# Mean Velocity field

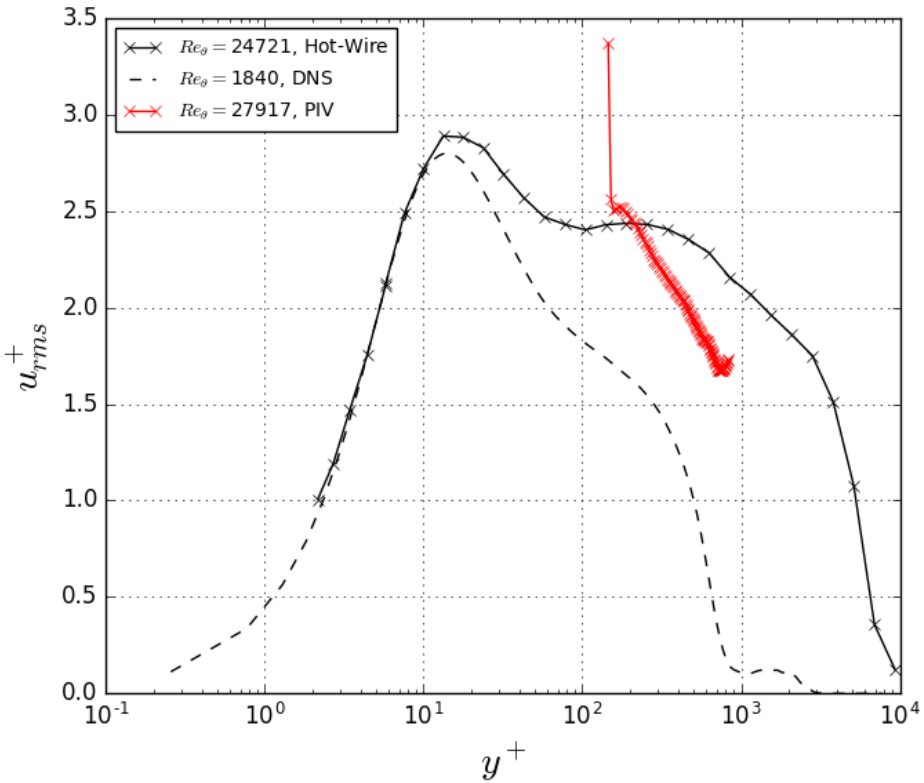


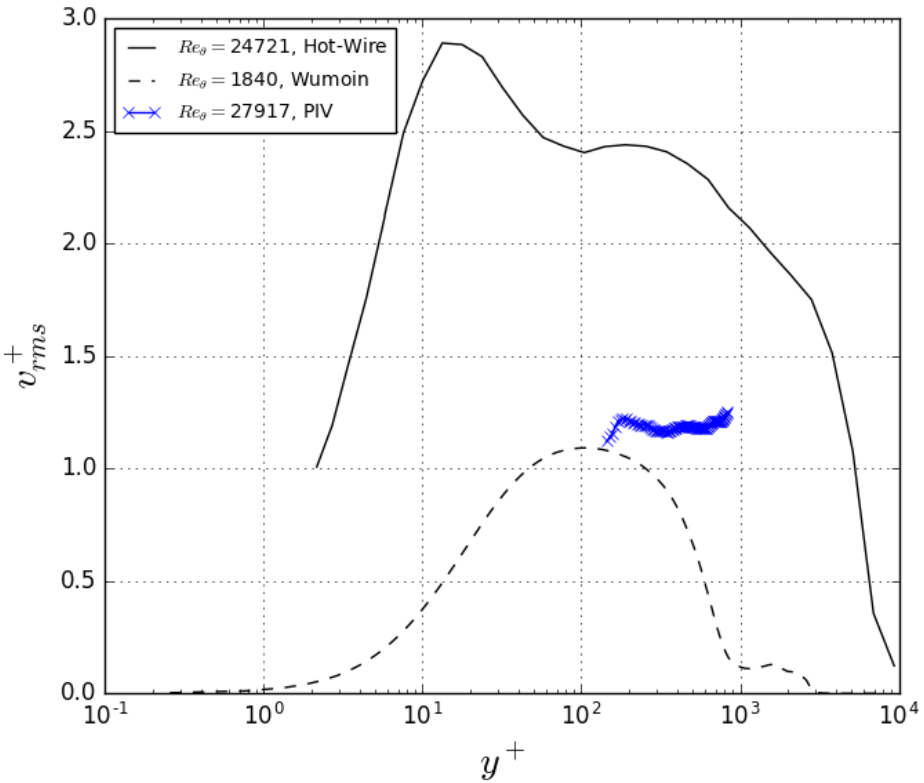
# Mean Velocity field




$$y^+ = \frac{yu_\tau}{\nu},\ U^+ = U/u_\tau$$

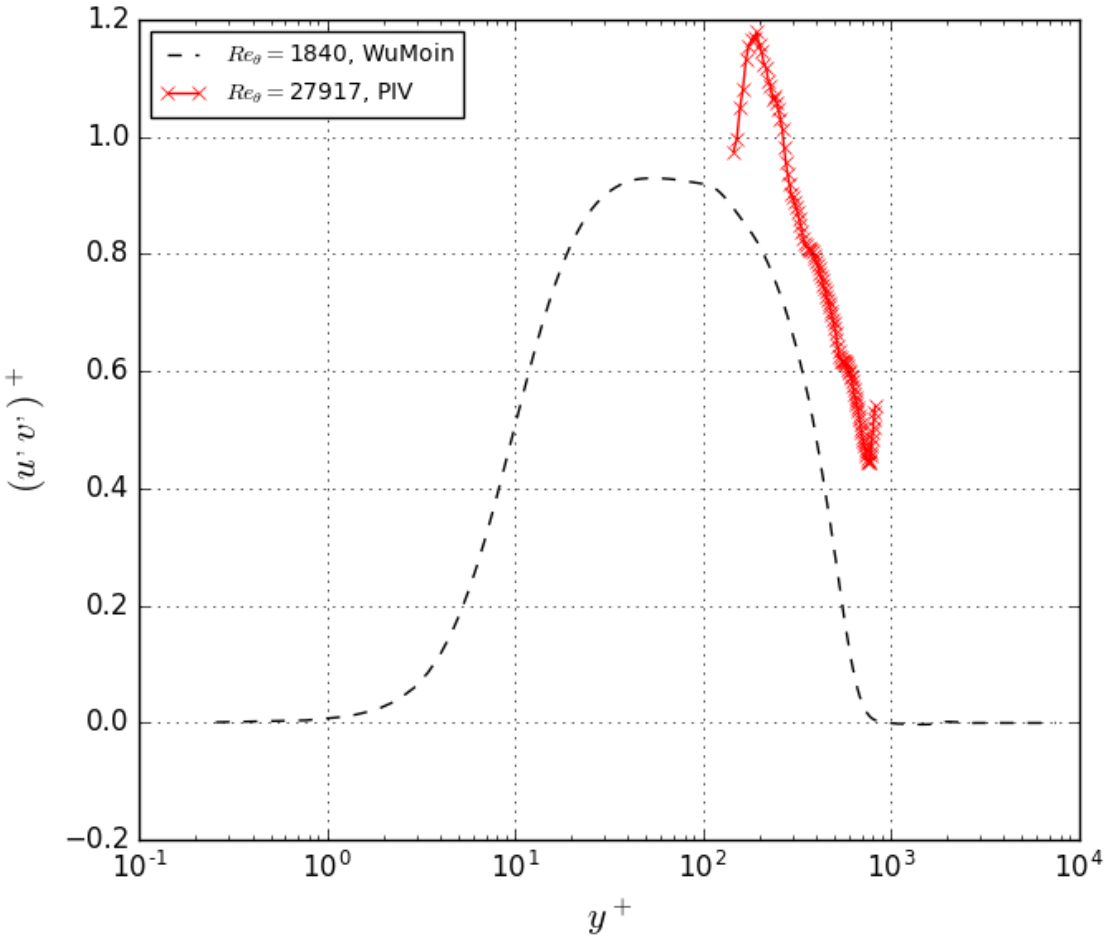
# Mean Velocity field



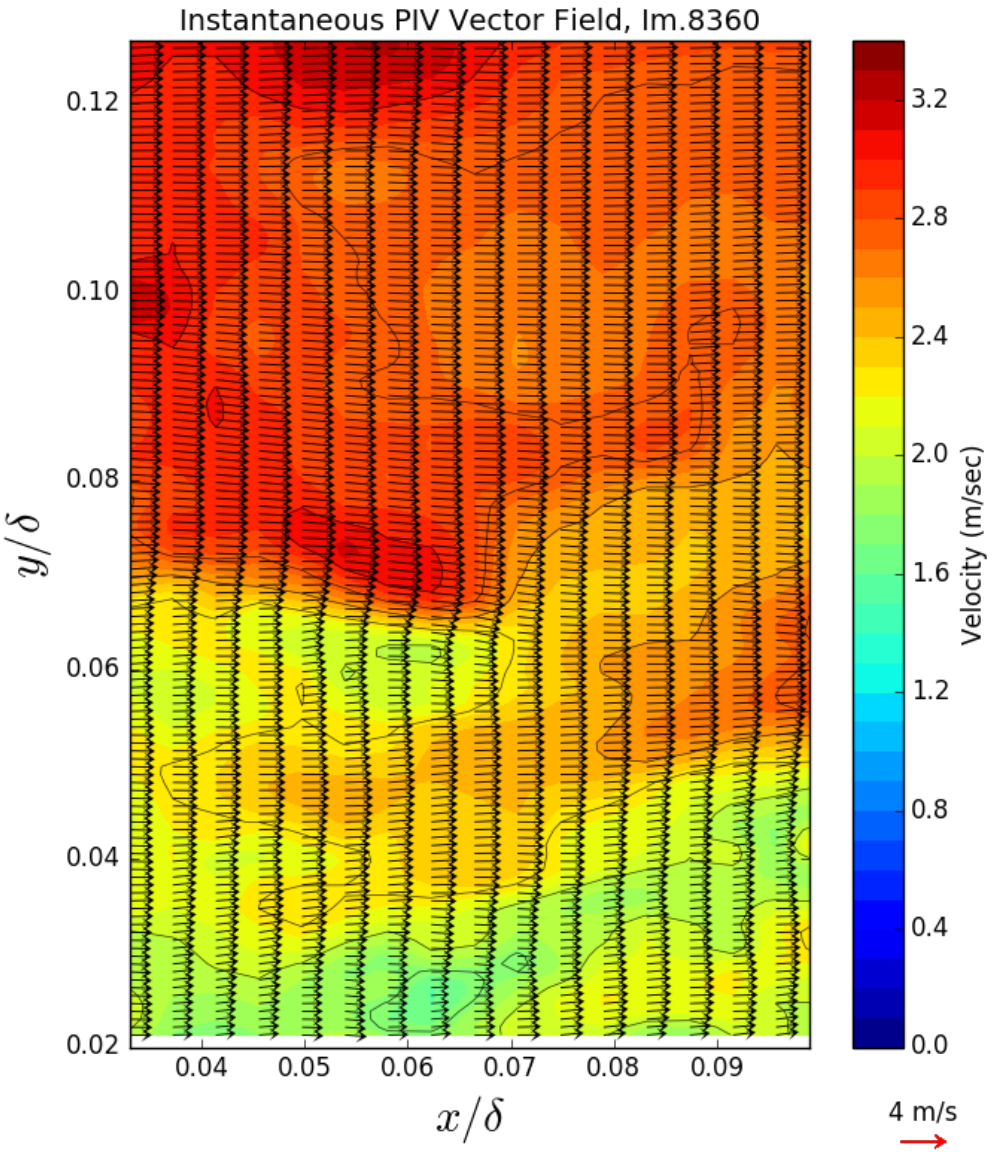




$$y^+ = \frac{yu_\tau}{\nu},\ U^+ = U/u_\tau$$

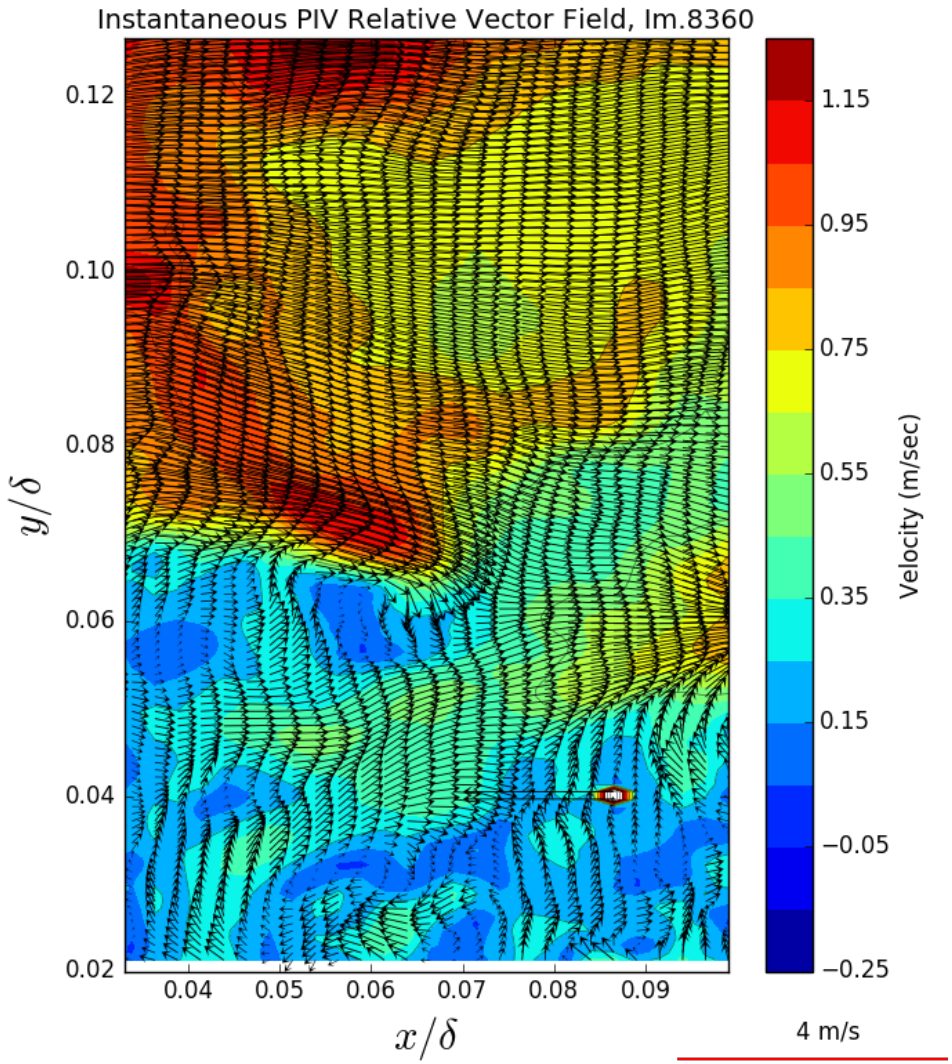
# Mean Velocity field



# Instantaneous Velocity: Structures

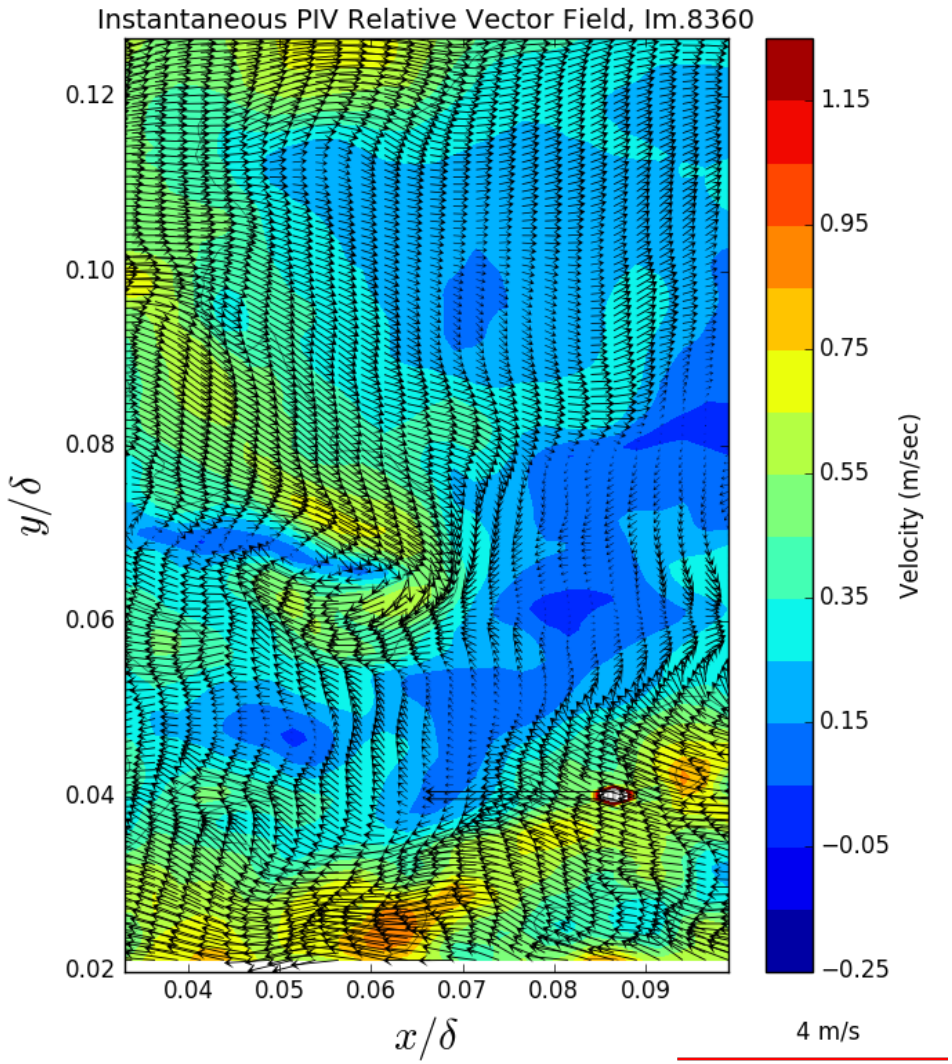


# Instantaneous Velocity: Structures



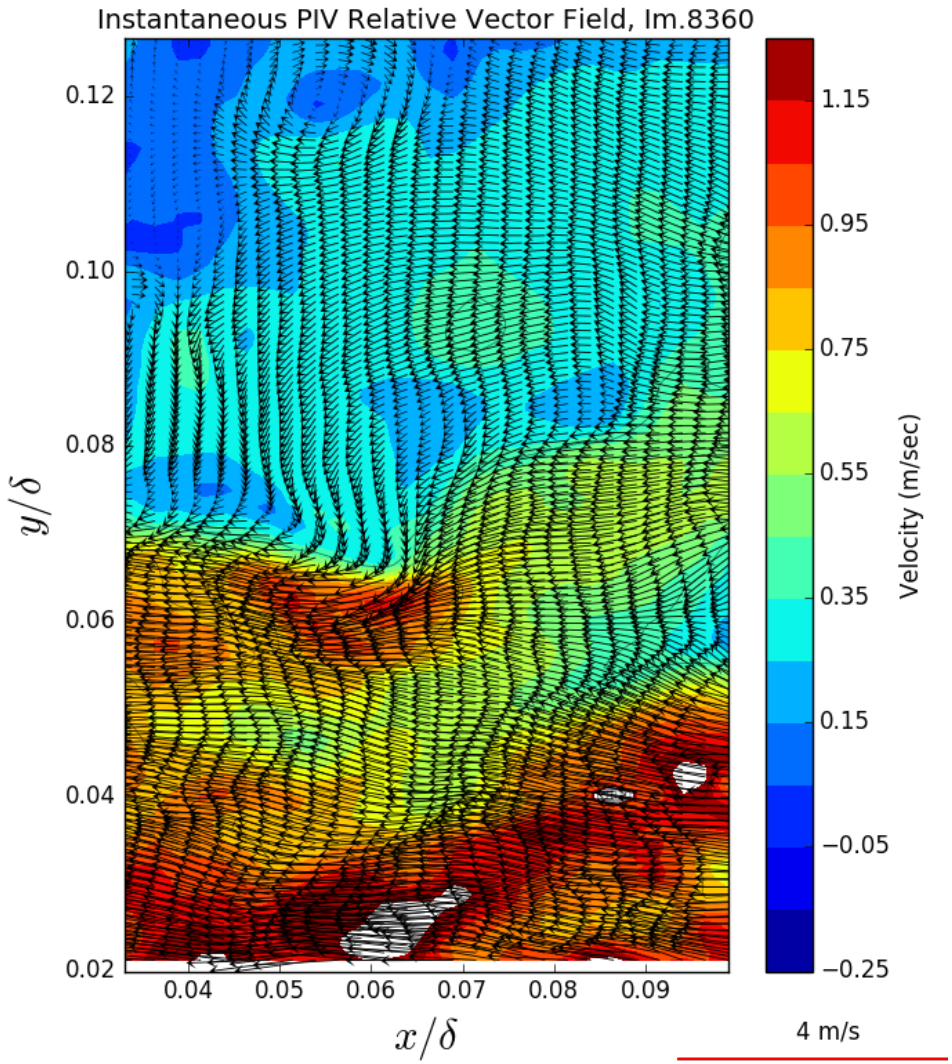

-Relative to $2m/s$

# Instantaneous Velocity: Structures



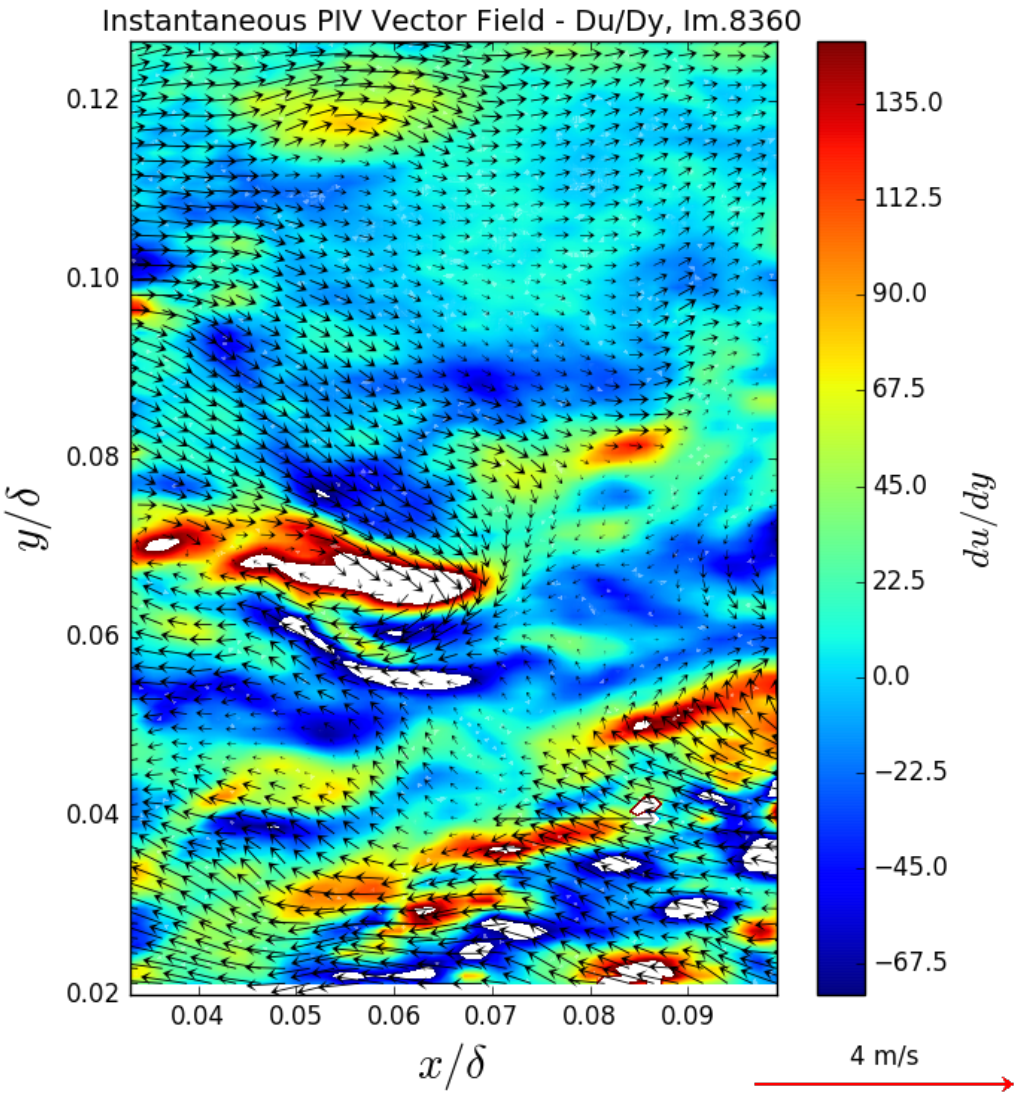

-Relative to $2.5m/s$

# Instantaneous Velocity: Structures




-Relative to $3m/s$

# Instantaneous Velocity: Structures

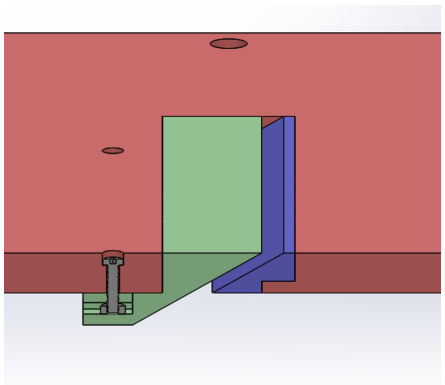


# Summary

- Developed PIV system in high Reynolds number facility
- Captured time resolved PIV which represents the mean flow and beginning to resolve the first moment
- Beginning to develop method for examining for internal structures

## To-Do

- Finish fabrication of new seeding slot



- Develop method (multi camera, stitching..) for expanded FOV

# Thanks!