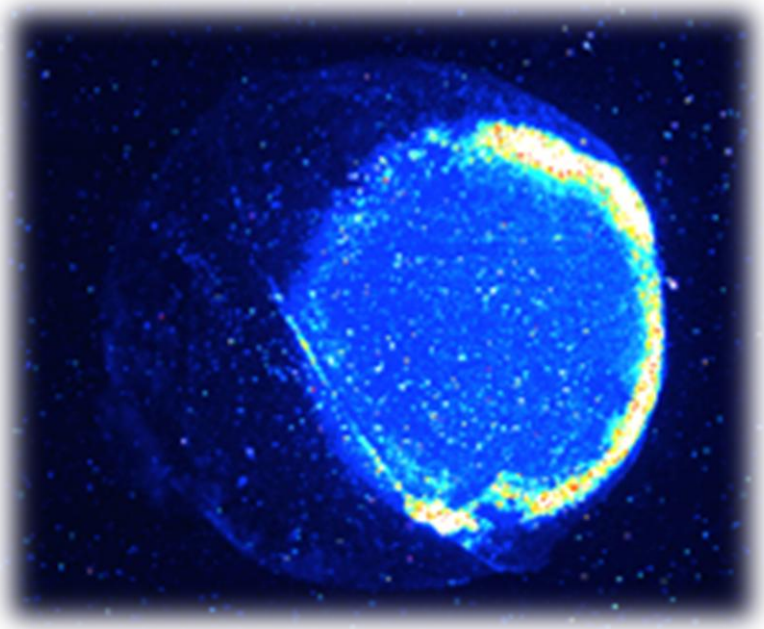
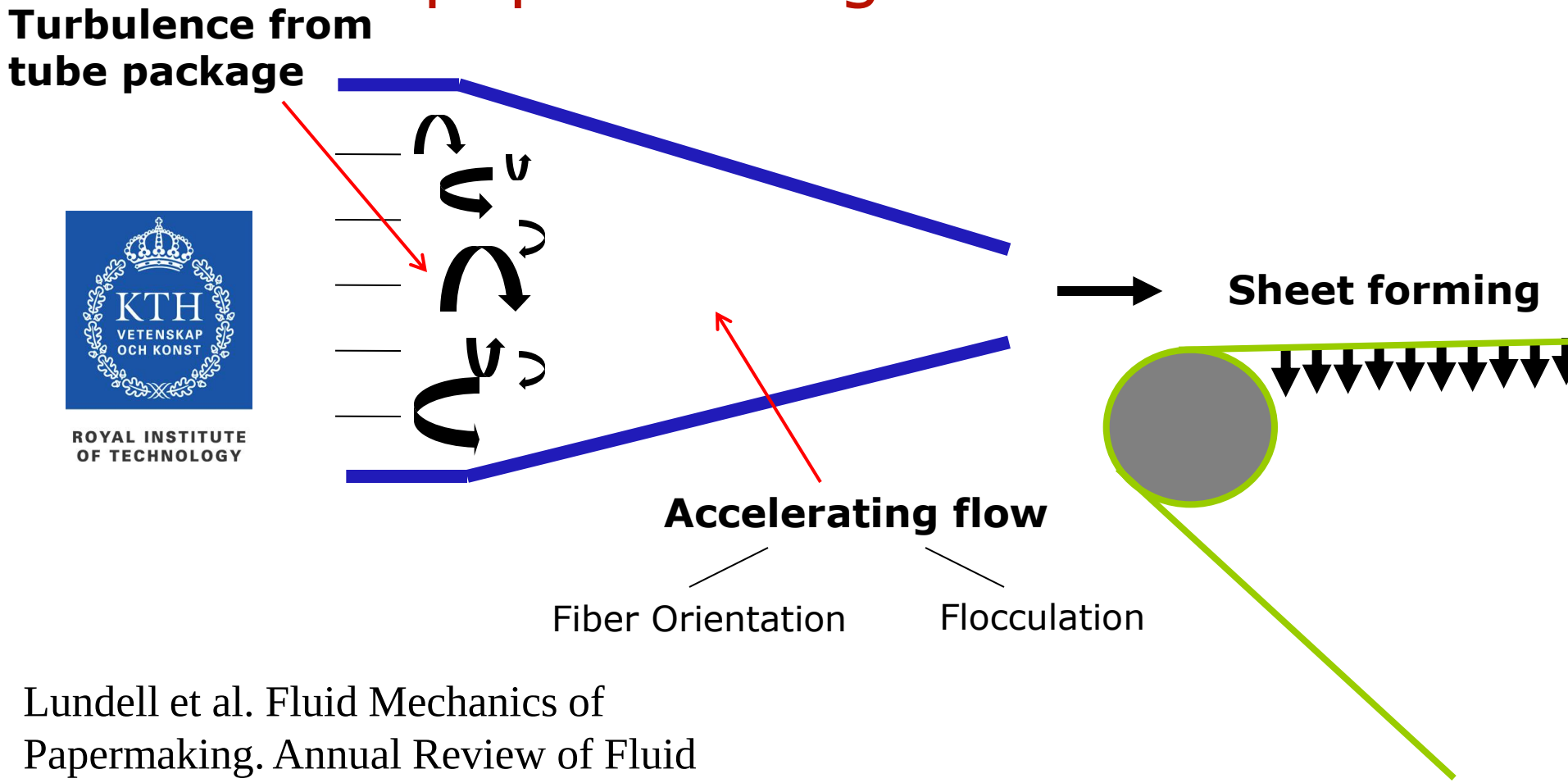
Experimental study of large particles in Homogeneous Isotropic Turbulence



Gabriele Bellani,
KTH Mechanics, Sweden
@UC Berkeley, CA

Turbulence particle interaction in papermaking



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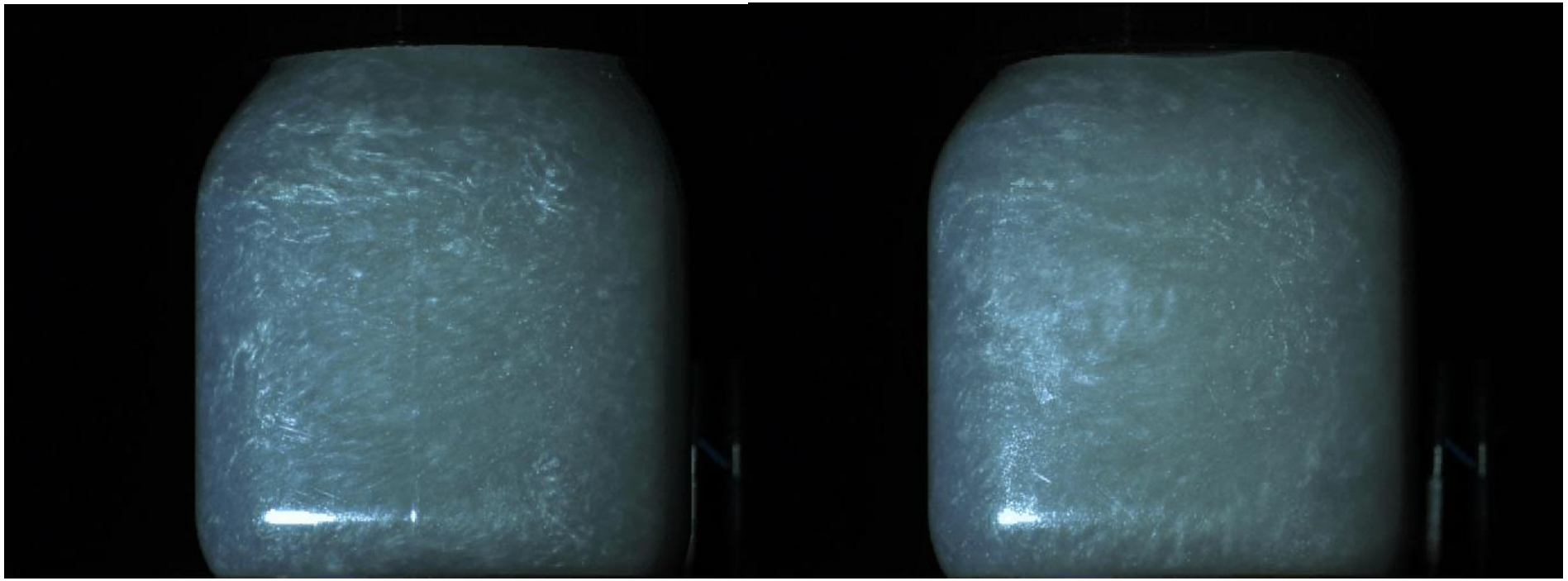
Lundell et al. Fluid Mechanics of Papermaking. Annual Review of Fluid Mechanics (2010) (43) pp. 195-217

Decay of turbulence



Without pulp

With 0.2% bleached softwood pulp

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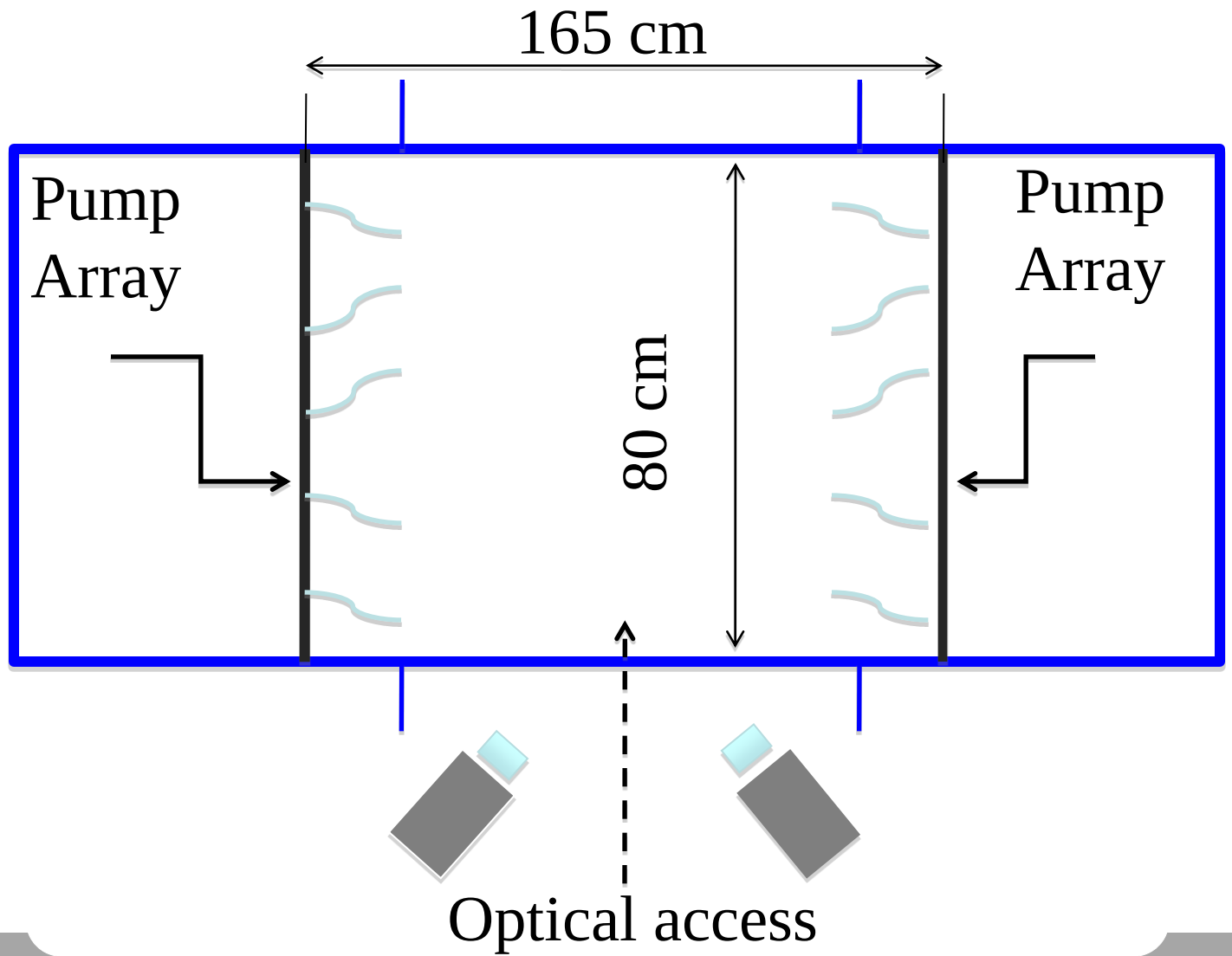
Turbulence generation: experimental setup

ENGINEERING LABORATORY FOR FLUID MOTION IN THE ENVIRONMENT

Stirred Tank

Top view



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Pump Array: Stochastic algorithm

- 2 Synthetic Jet Arrays
- 64 Jets per Array
- Jets Fire in Pattern(Algorithm based on: Variano&Cowen2008, JFM)
- Stochastic

Side view

Idea of H.I.T. generation

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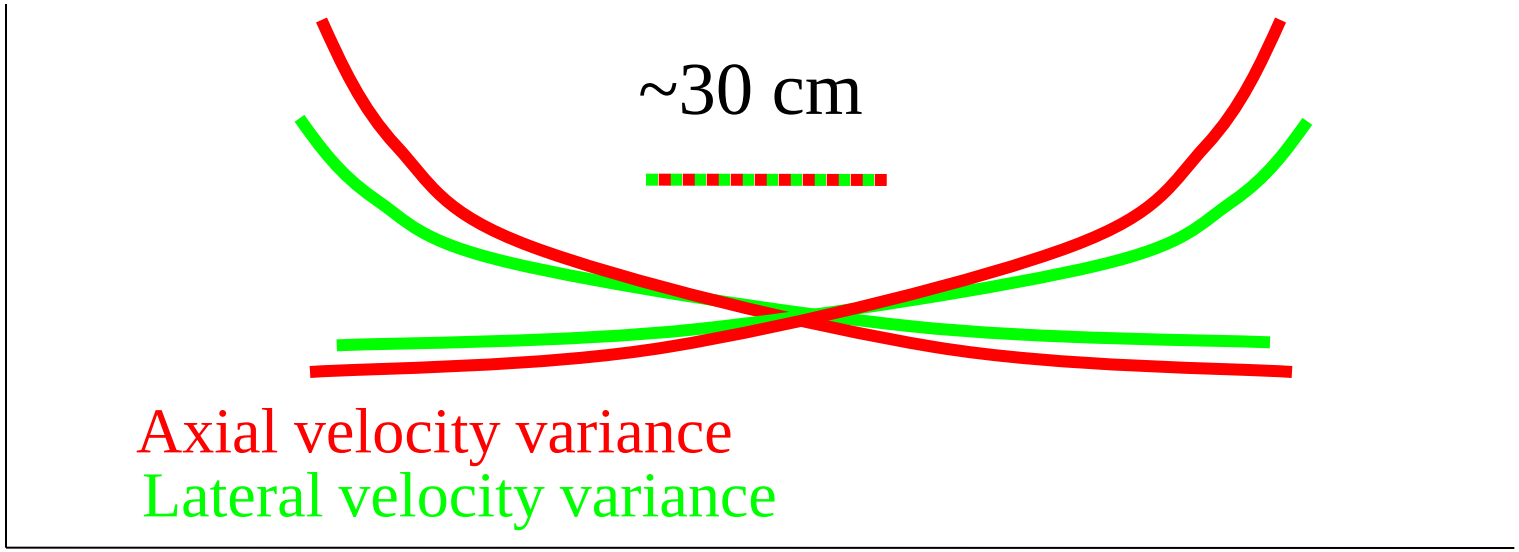
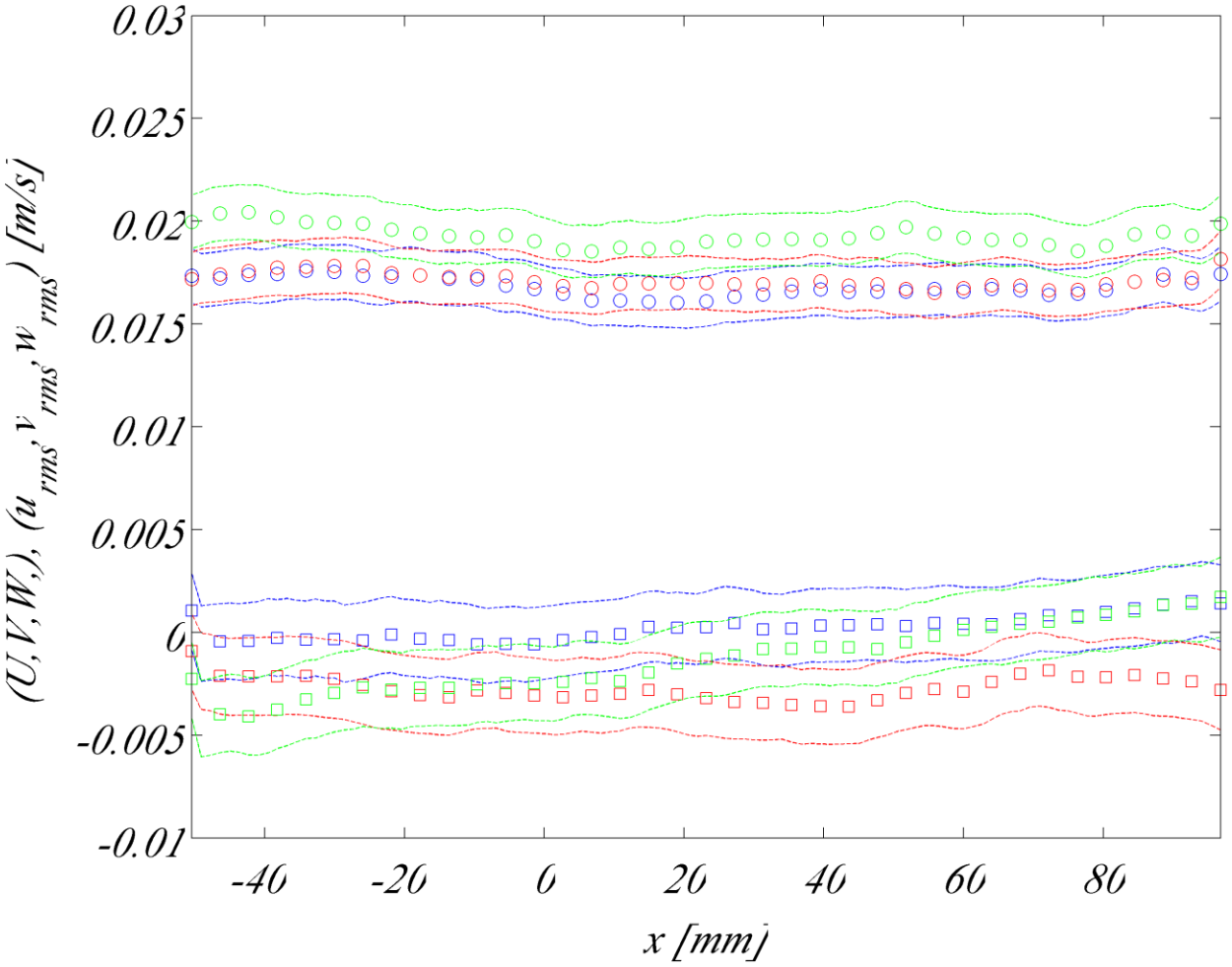


Measurements at the center of the tank



$< u^2 >^{1/2}$
$< v^2 >^{1/2}$
$< w^2 >^{1/2}$

U
V
W

Tank summary

$$Re_\lambda = 269$$

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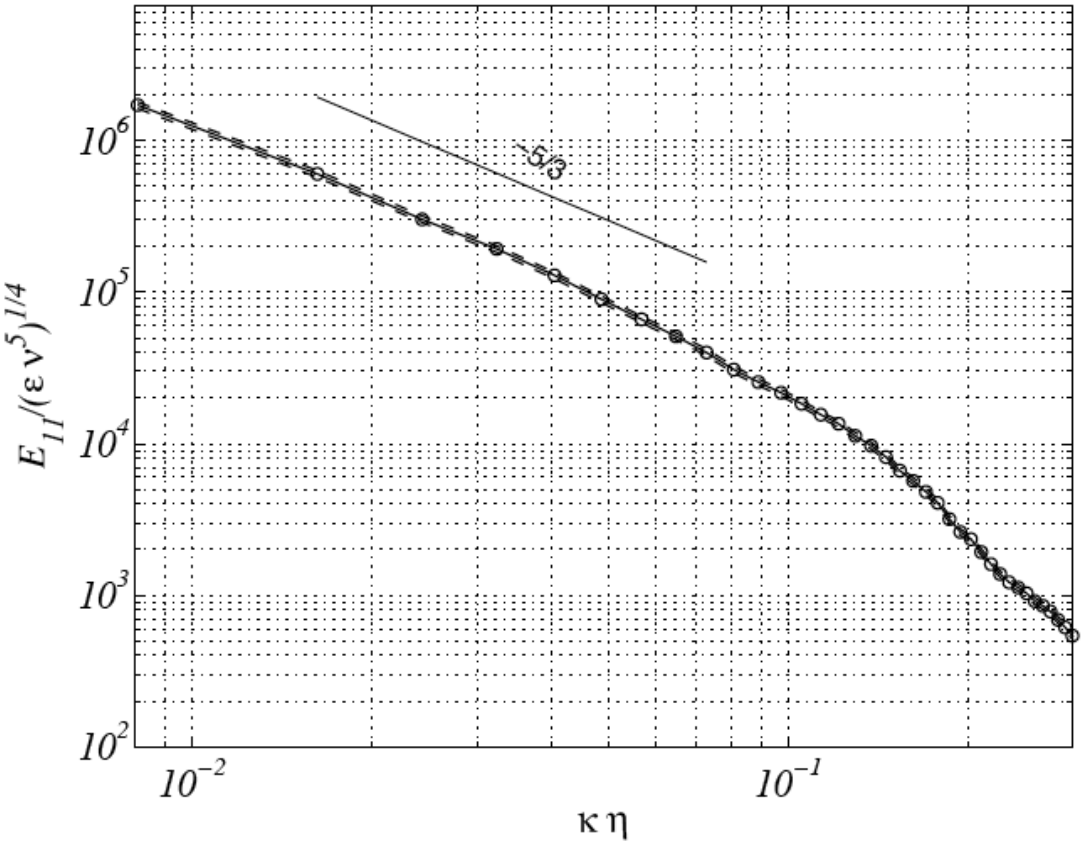
$$\frac{\Lambda}{\lambda} = \frac{\Lambda}{\eta} = 2.7\mathrm{s}$$



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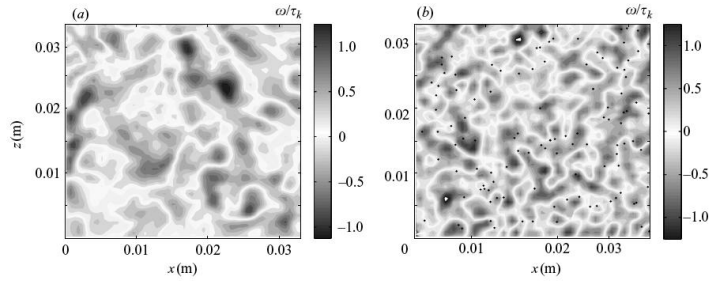
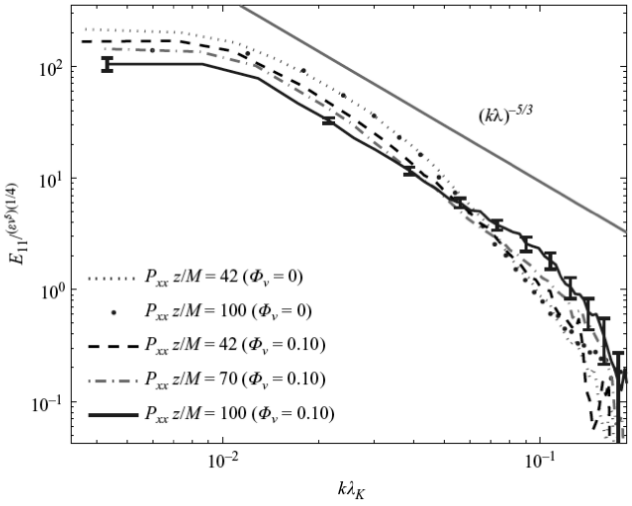
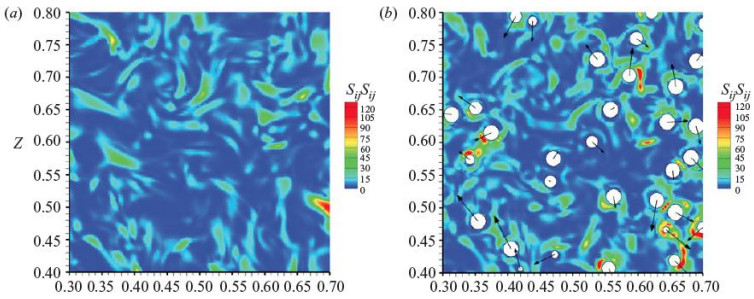
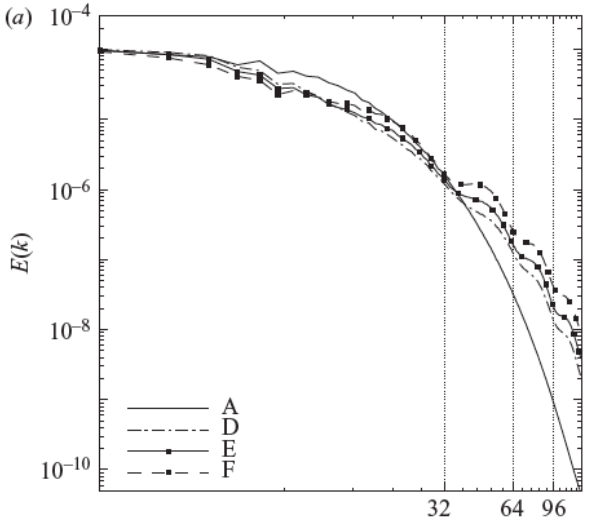
Turbulence-particle interactions

Small Vs Large particles





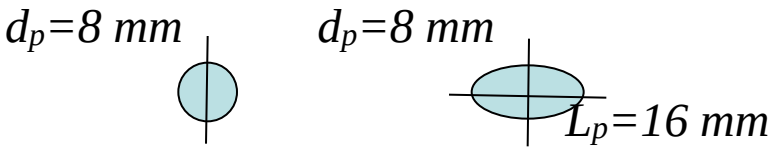




Experiments: Poelma, C. & Ooms, G. ,Particle-fluid interactions in grid-generated turbulence, JFM (2007) vol. 589, pp 315-351

DNS: Lucci et al. Modulation of isotropic turbulence by particles of Taylor length-scale size. JFM (2010) vol. 650 pp. 5

Non spherical particles?



$$\rho_p/\rho_{H_2O} \approx 1$$

$$d_p/\eta \approx 21$$

$$d_p/\lambda \approx 0.65$$

$$\tau_p/\tau_\eta \approx 26$$

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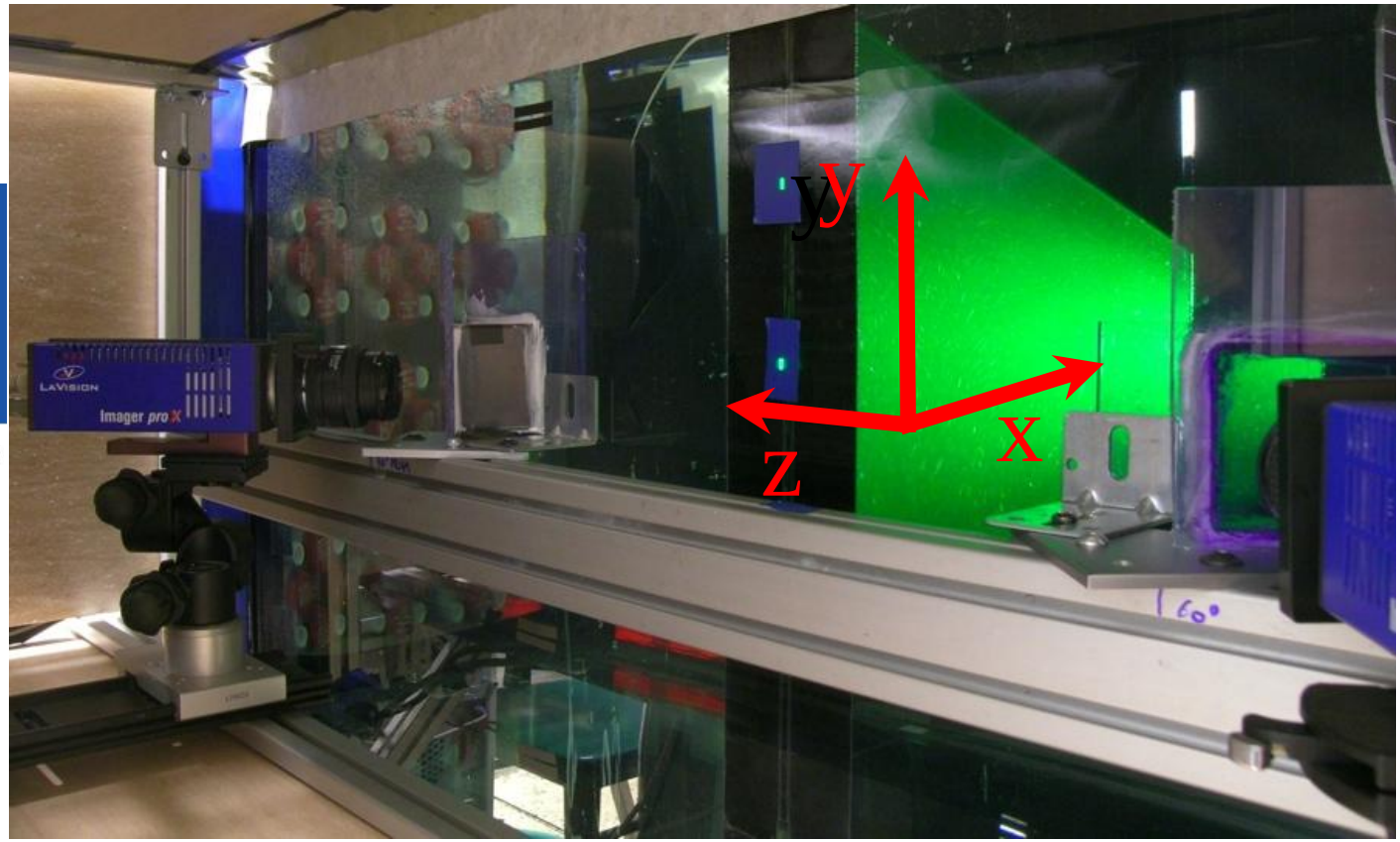
Experimental technique

Stereoscopic PIV



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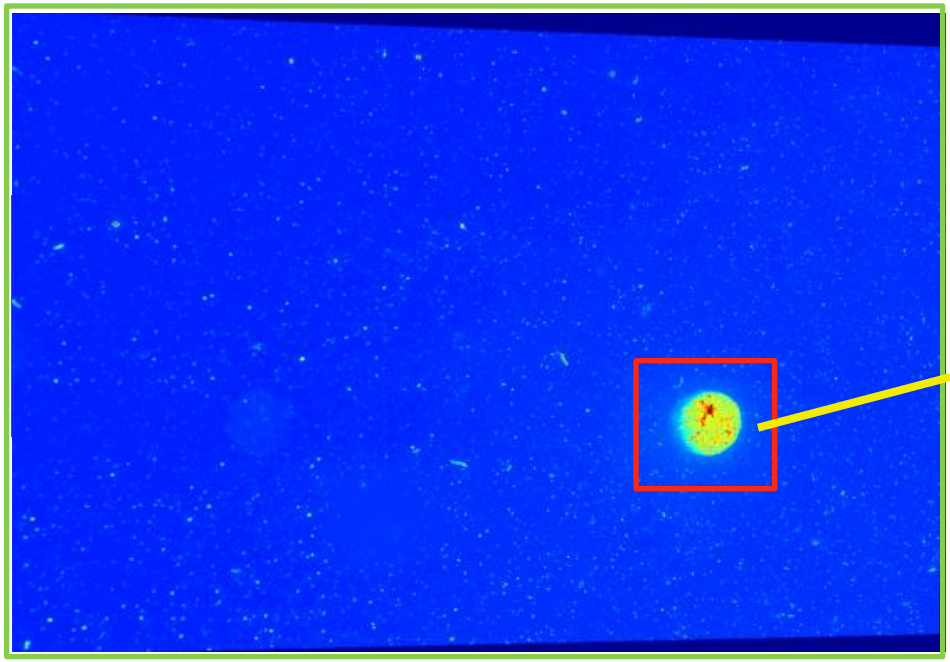
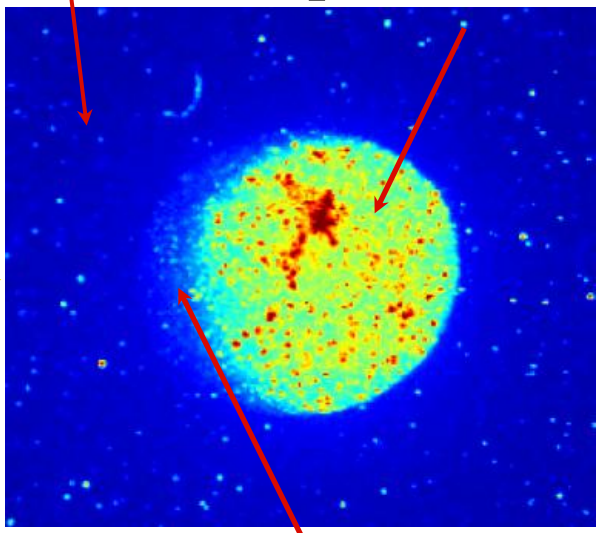
Fluid-particle phase velocity measurements



Fluid fase

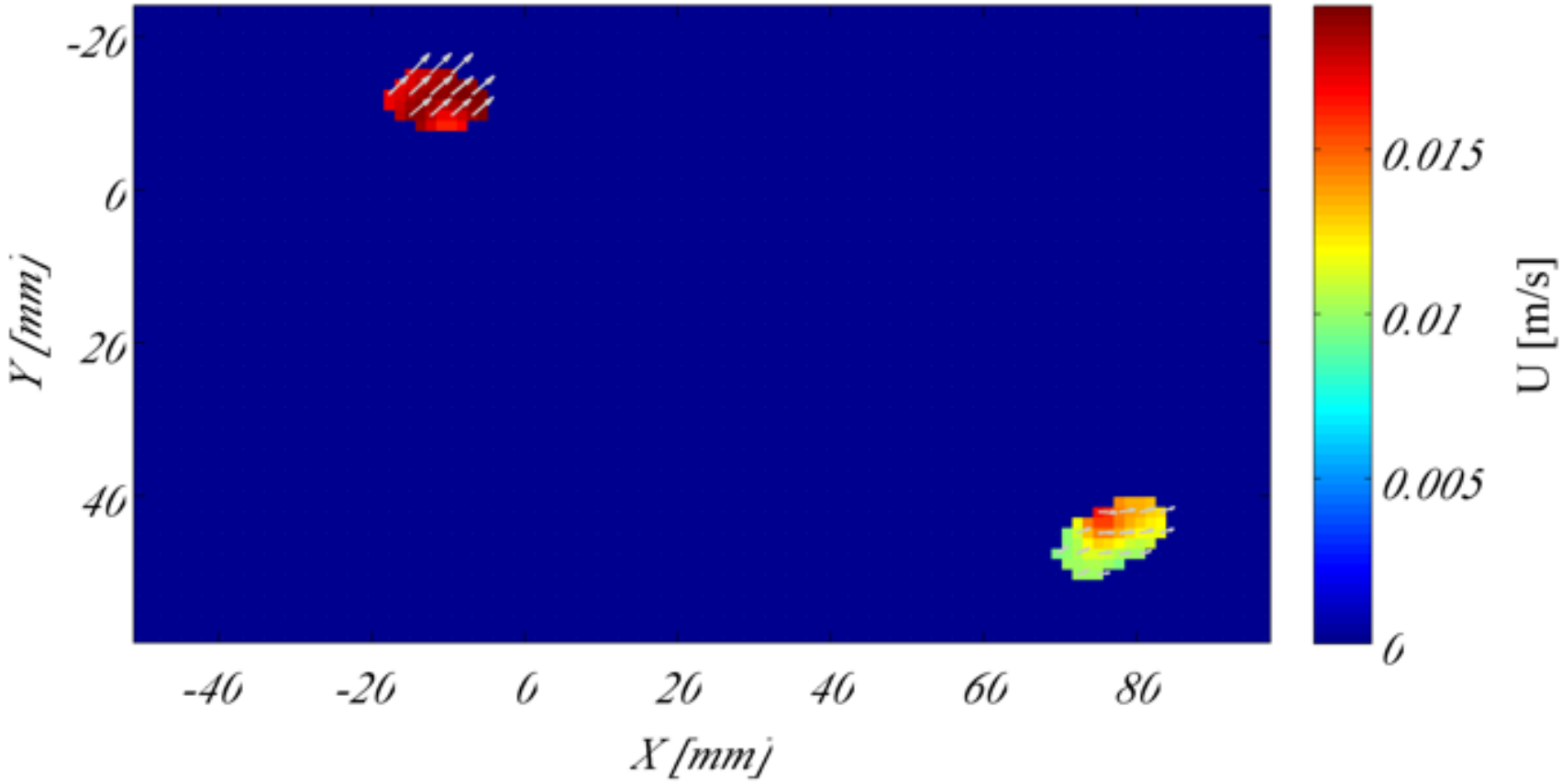
In-plane particle slice



Out-of-plane particle slice

15

Example velocity field



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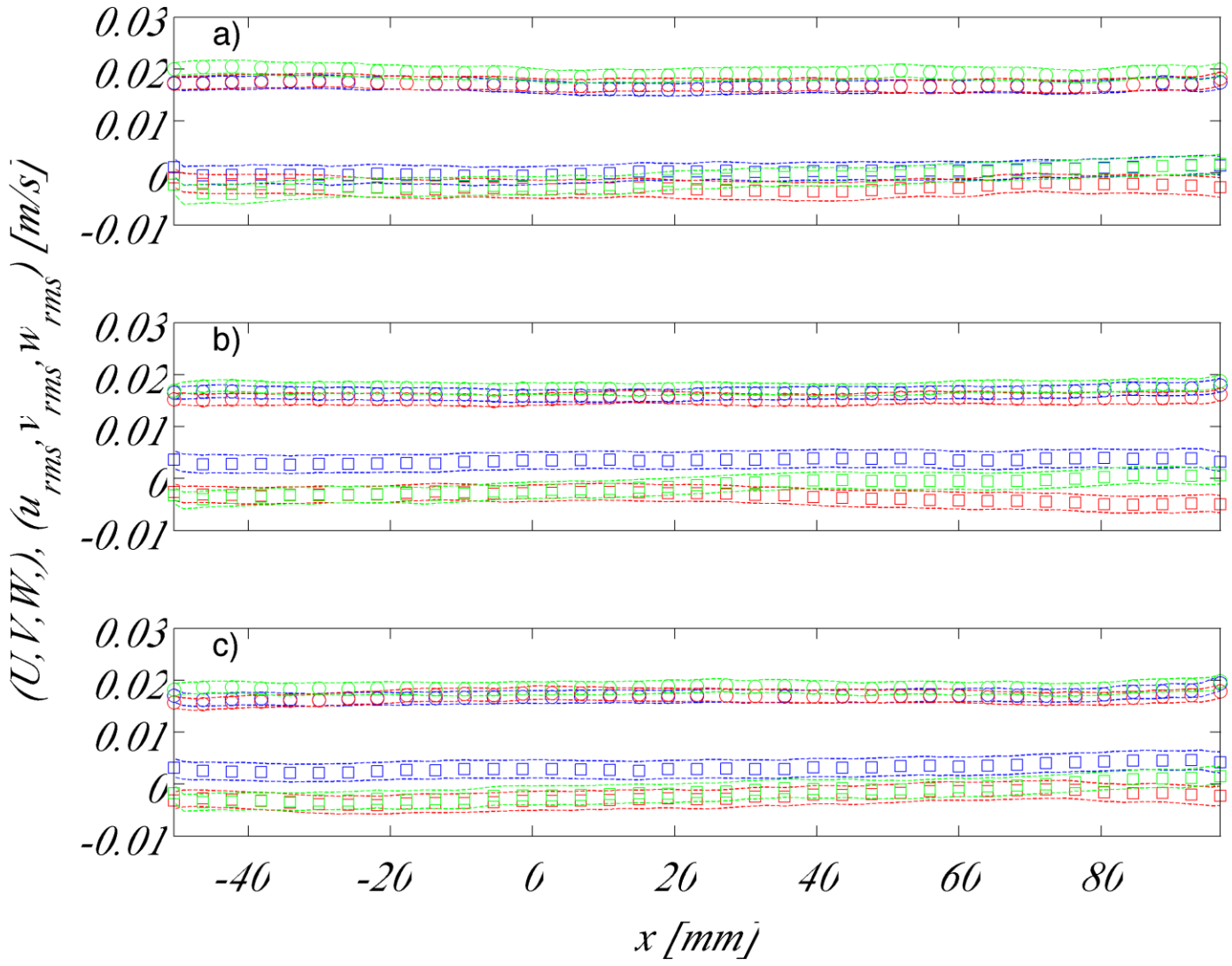
Results
– turbulence modulation -



Single phase

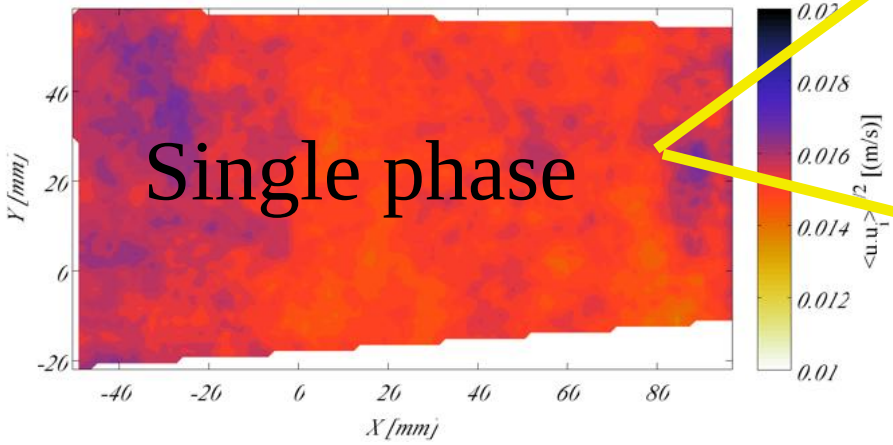
● Spheres

$\Phi_v = 0.1 \cdot 10^{-2}$

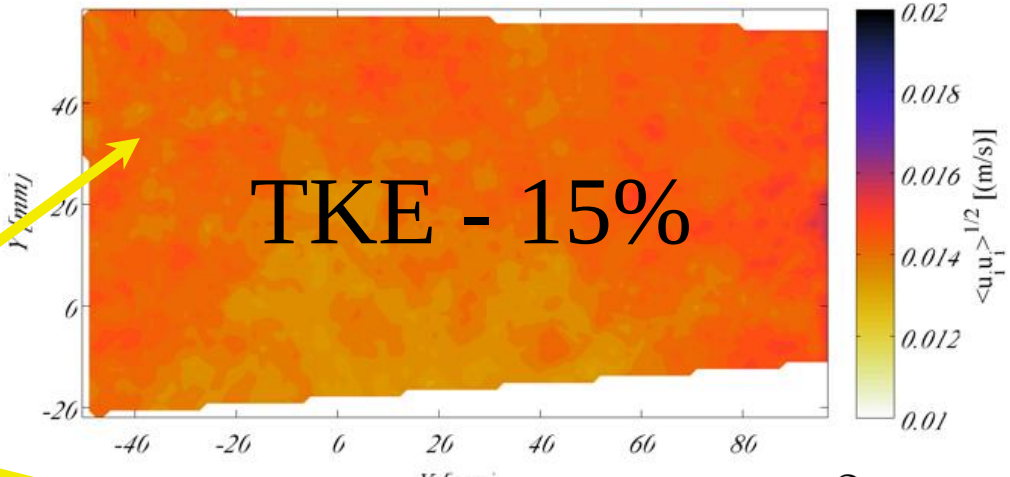
● Ellipsoids

$\Phi_v = 0.1 \cdot 10^{-2}$

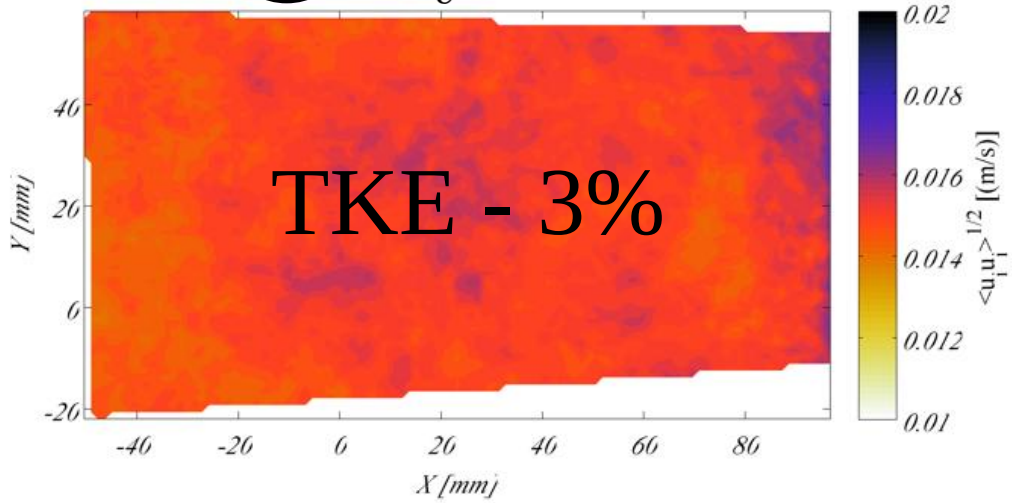
Turbulent Kinetic Energy



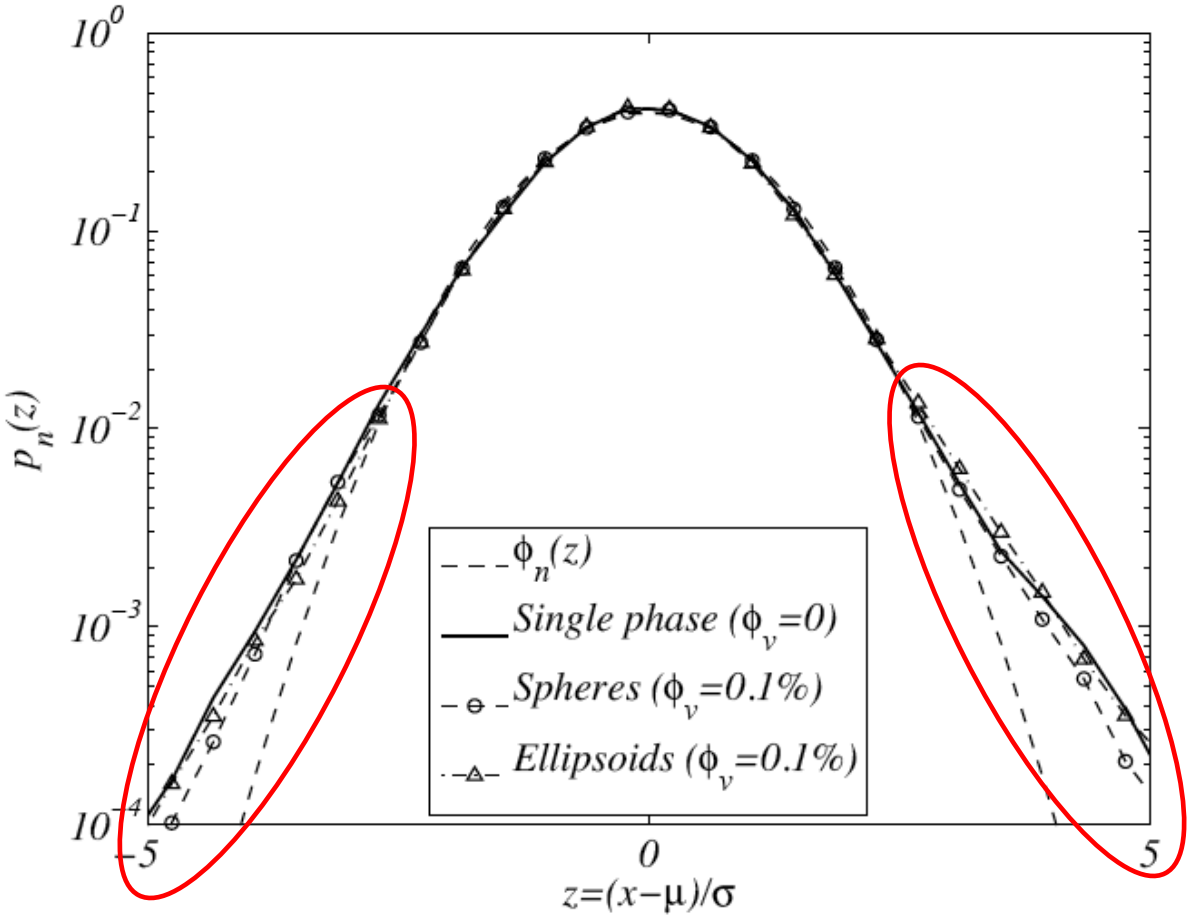
● $\Phi_v = 0.1 \cdot 10^{-2}$



● $\Phi_v = 0.1 \cdot 10^{-2}$



Probability density functions of velocity fluctuations



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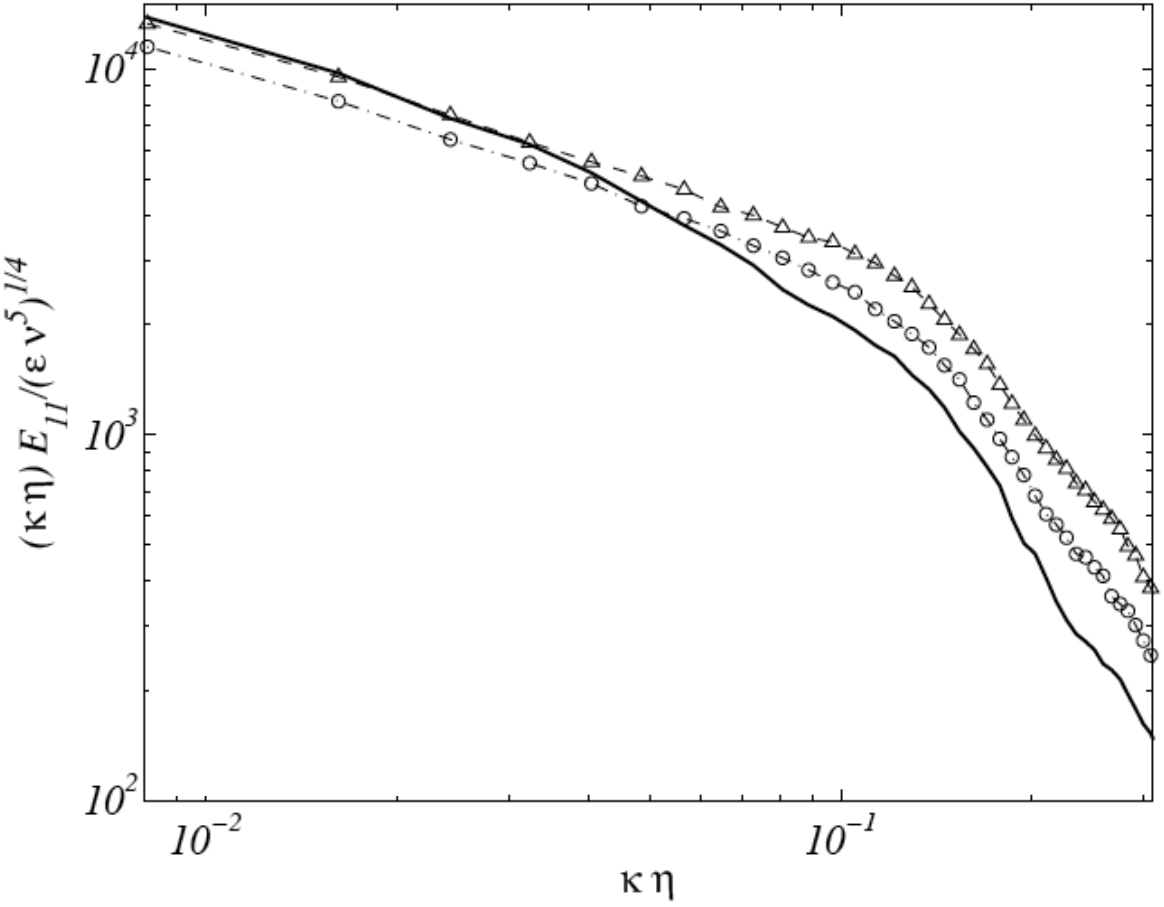
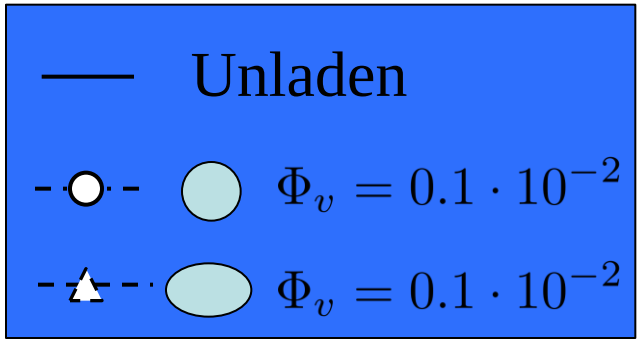
Spectral Pivot





Spectra from of two-point correlation as described in: Poelma, C. et al. (2006) Exp. in Fluids 40:347-363

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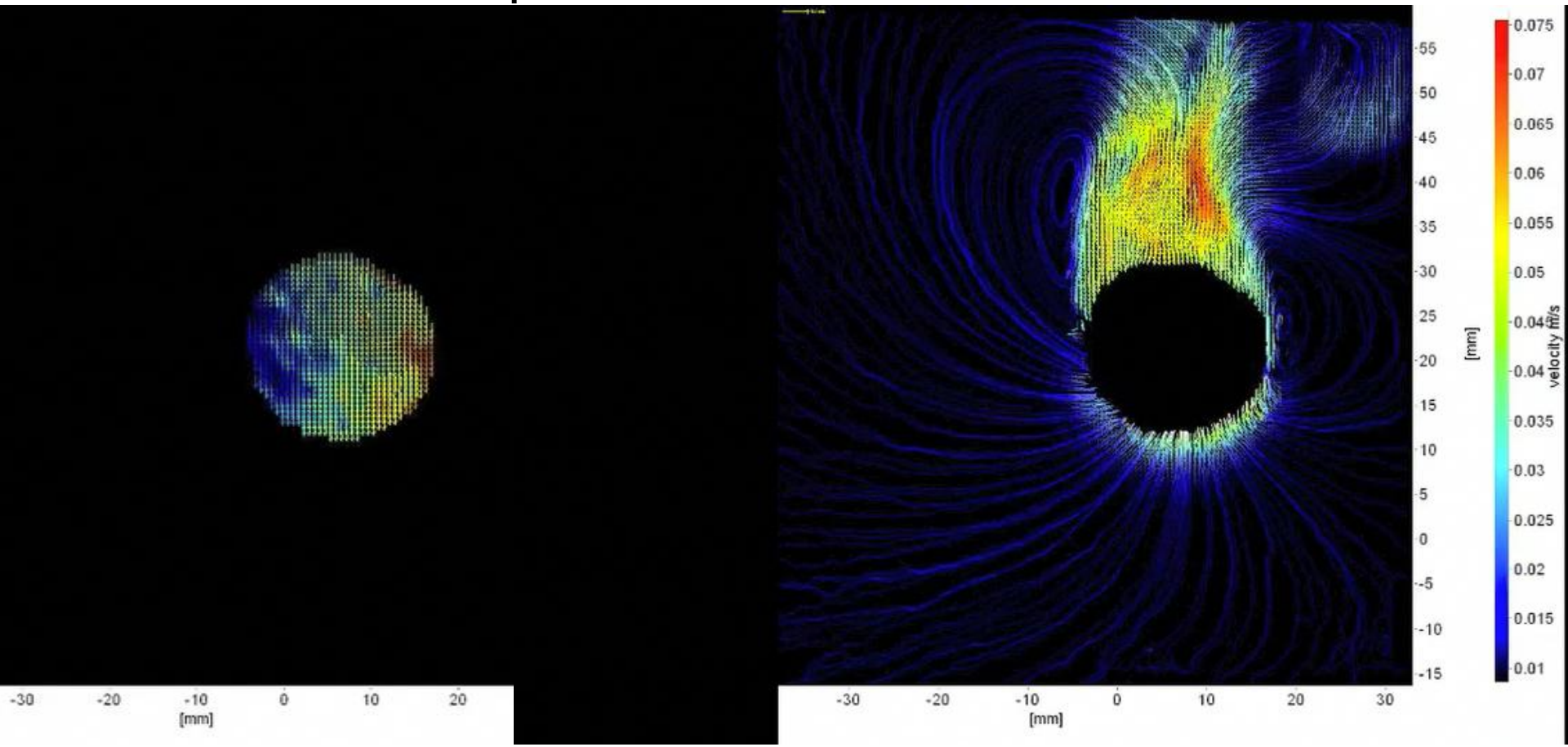
Open question:

less dissipation around ellipsoidal particles or additional production mechanism due to rotation?

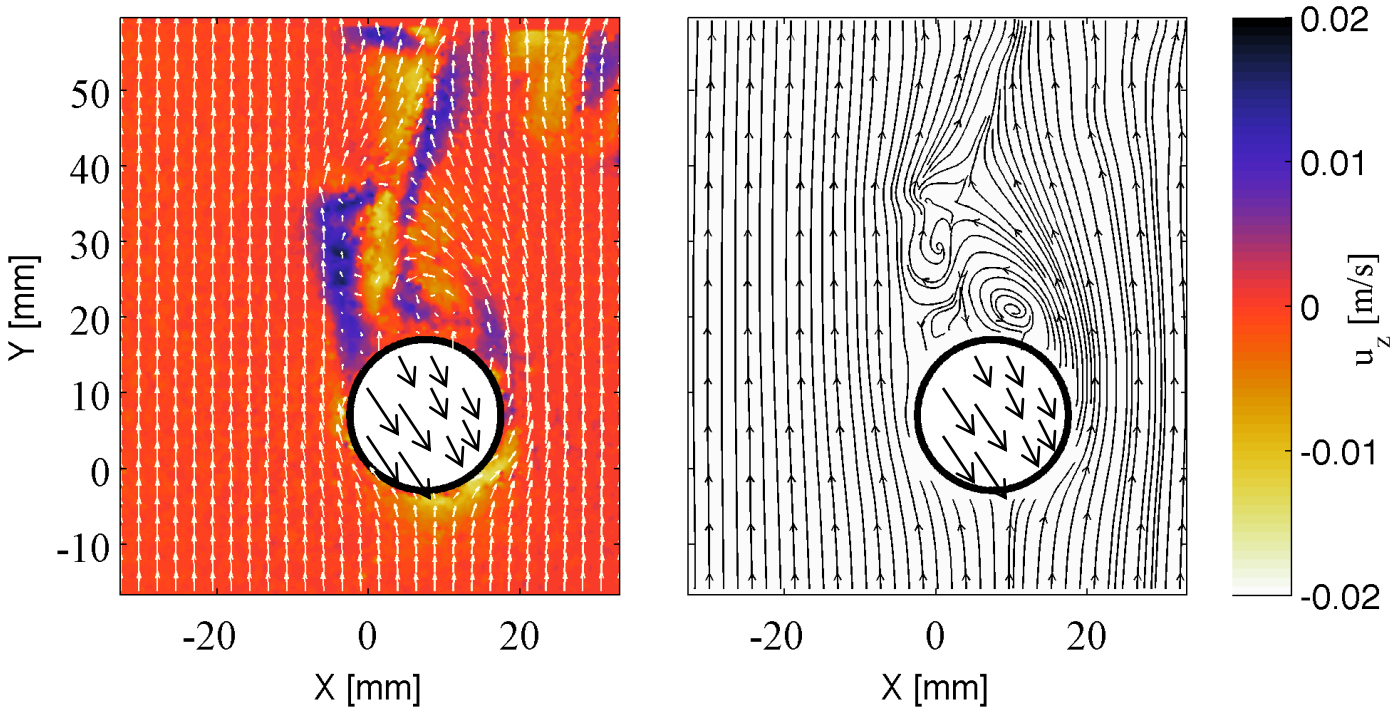
Future work:

combine fluid and particle velocity and rotation measurements to analyze local dissipation and production mechanisms



Future work:

combine fluid and particle velocity and rotation measurements to analyze local dissipation and production mechanisms



Falling sphere, Re=180 (G. Bellani, 2010)

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Conclusions

Experimental technique to measure fluid phase and particle velocity (and rotation rates) in stationary H.I.T. is presented

Spectral Pivoting observed for large-neutrally buoyant particles in dilute regime

Ellipsoids provide lower TKE reduction and a exhibit a more pronounced Pivoting than spherical particles at the same volume fraction

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Acknowledgements

Financial support from UC Berkeley and KTH Mechanics

Thanks to: Audric Collignon – UC Berkeley

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Steve Anderson - LaVision Inc.

Matt Ritter– UC Berkeley

Margaret Byron – UC Berkeley

Colin Meyer - UC Berkeley

Fredrik Lundell – KTH Mechanics

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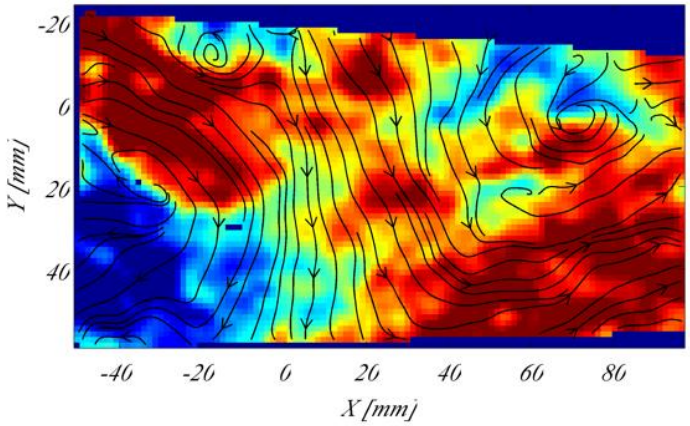
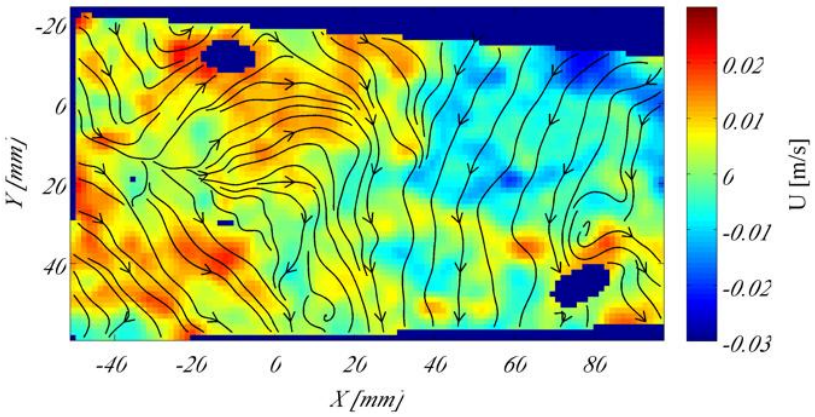
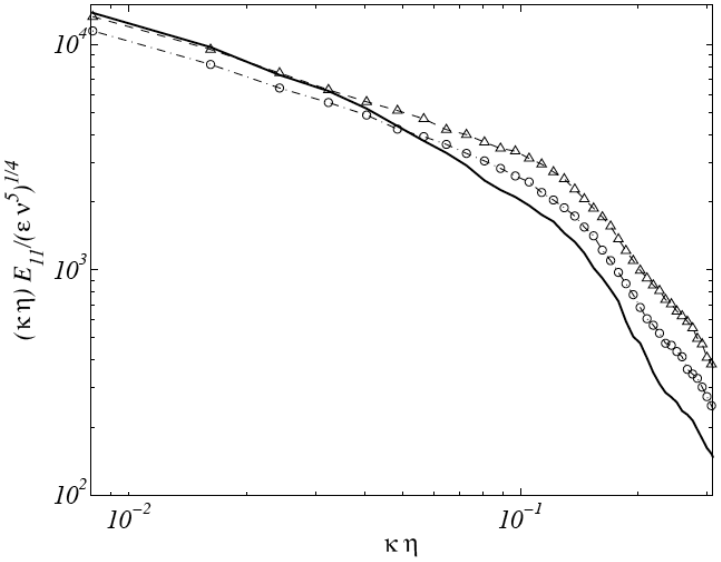
Thank you!







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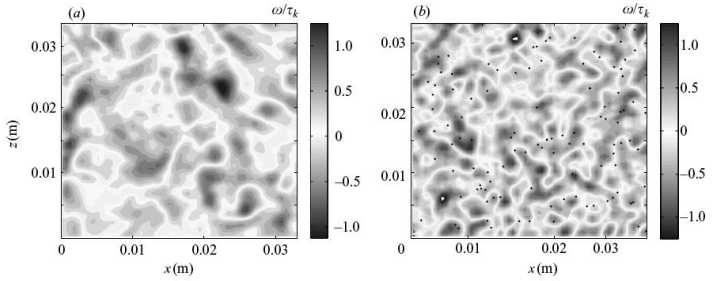
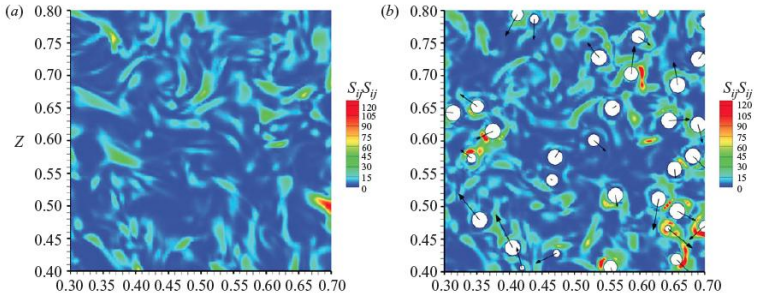
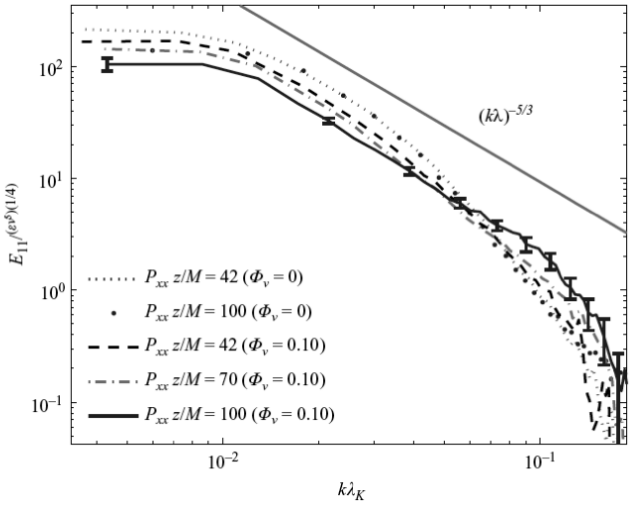
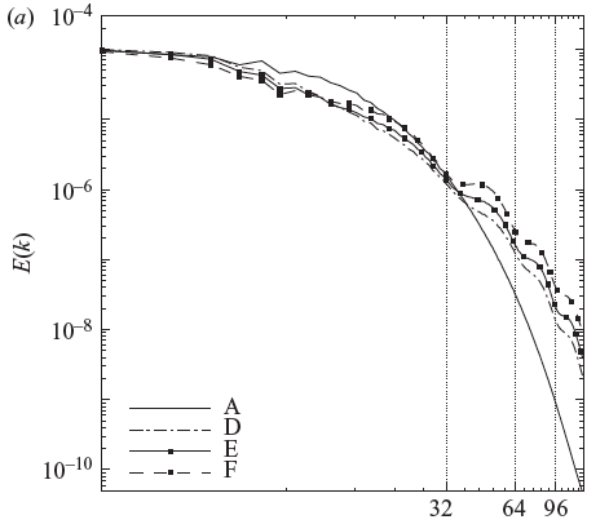
Small Vs Large particles









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DNS: Lucci et al. Modulation of isotropic turbulence by particles of Taylor length-scale size. Journal of Fluid Mechanics (2010) vol. 650 pp. 5

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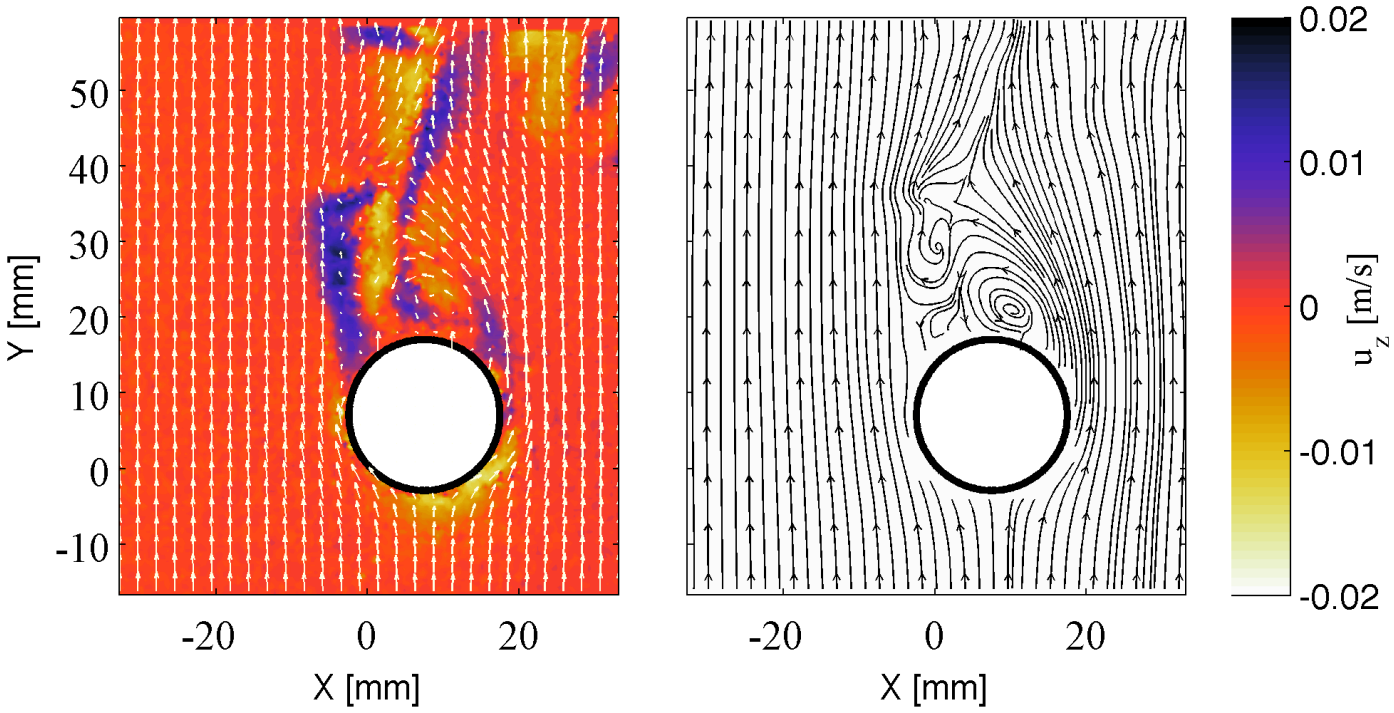
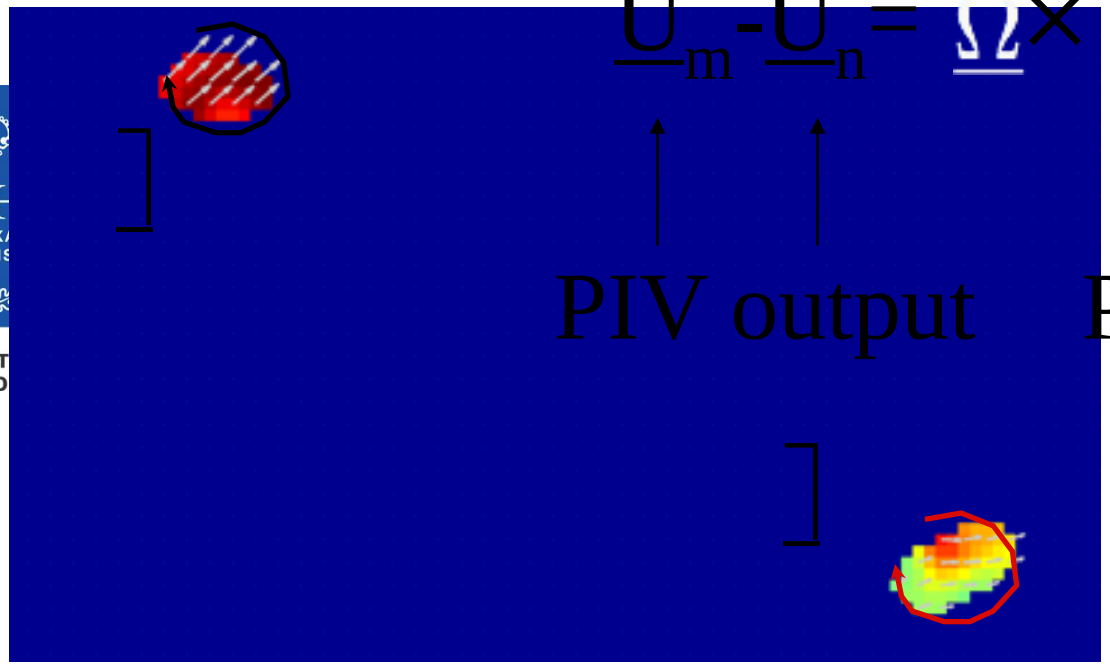


Rotation measurement

From S-PIV we get ω_z than ω_x and ω_y :

$$\underline{U}_m - \underline{U}_n = \underline{\Omega} \times (\underline{X}_m - \underline{X}_n)$$

PIV output PIV input



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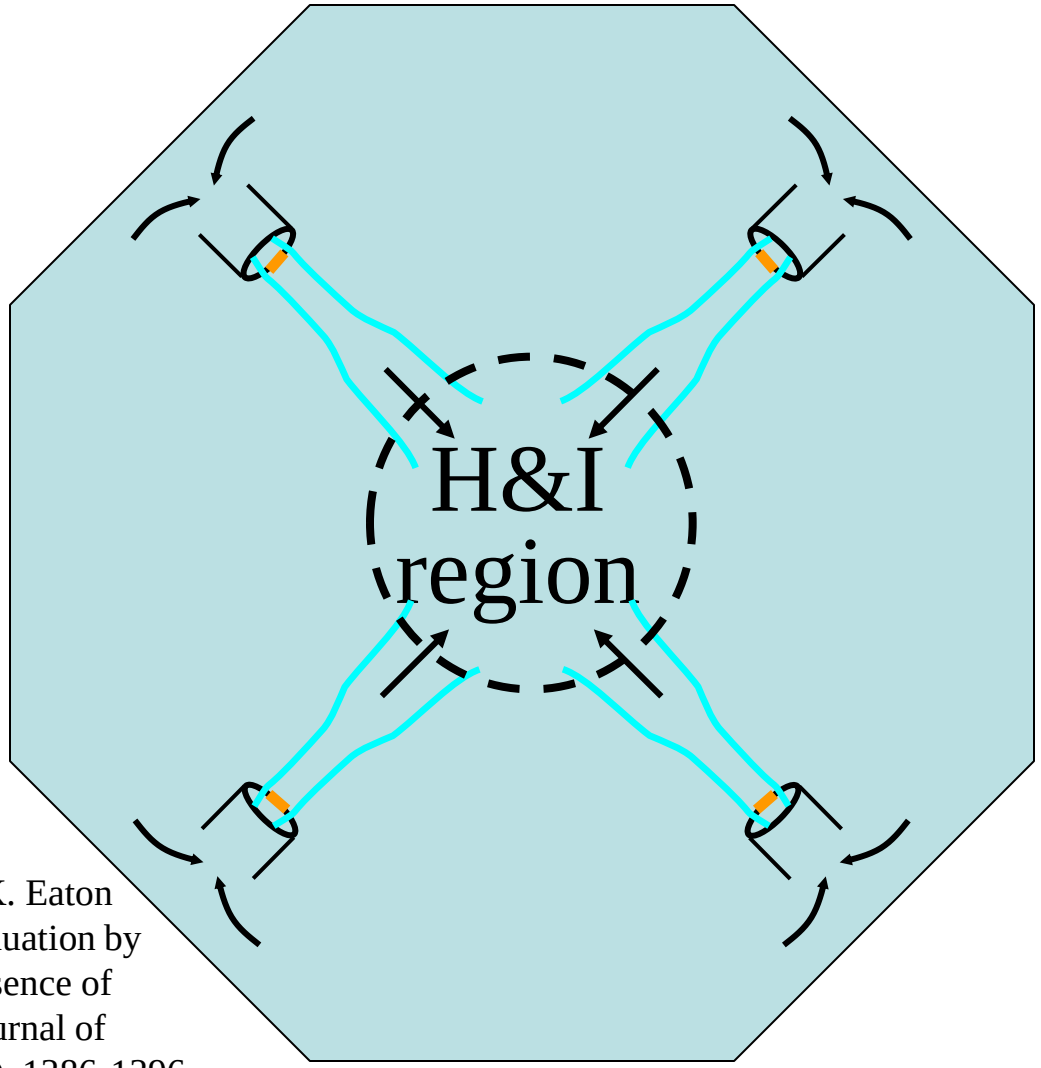
H&I Turbulence over large region



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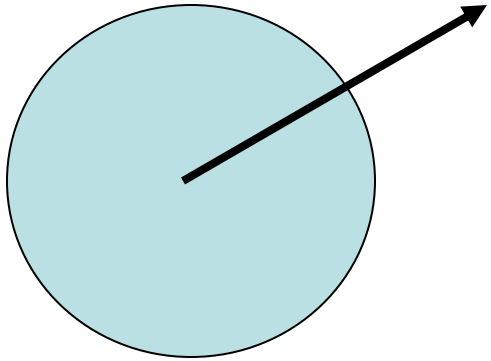
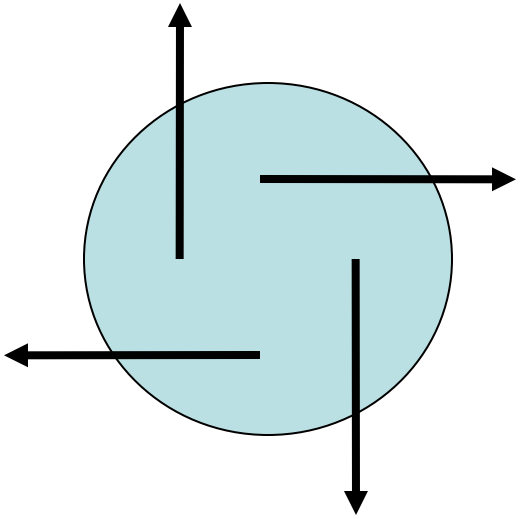
e.g. Hwang, W., and J. K. Eaton (2006), Turbulence attenuation by small particles in the absence of gravity, International Journal of Multiphase Flow, 32(12), 1386-1396.

Within-particle velocity

Velocity measurements of tracers within the particle give:

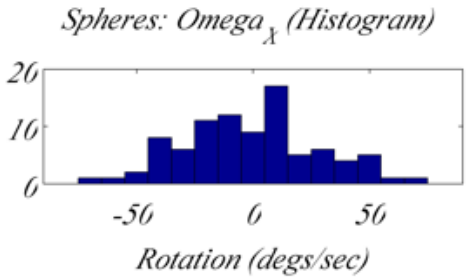


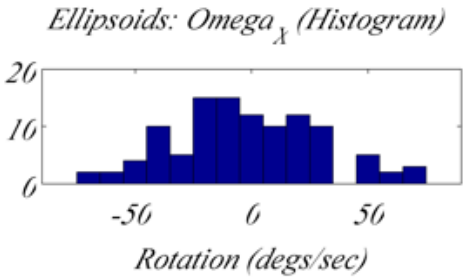
Translation

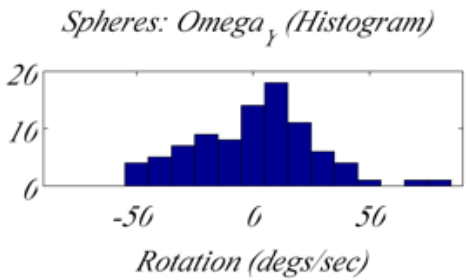


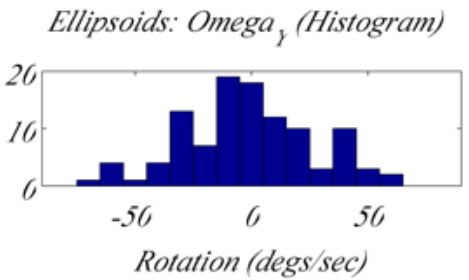
Rotation

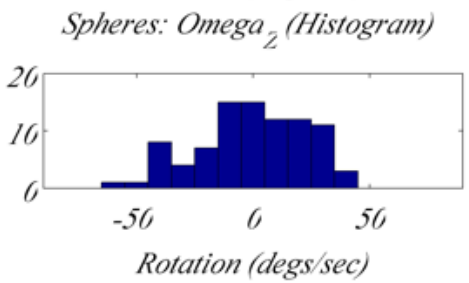
Rotational Dynamics: preliminary results

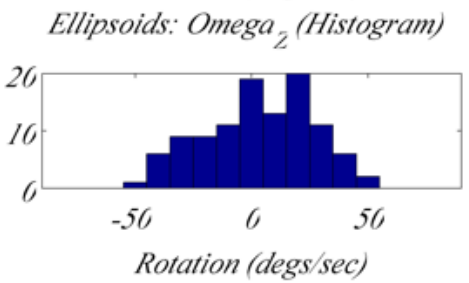












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Rotation measurement

$$\underline{U}_m - \underline{U}_n = \rceil \times (\underline{X}_m - \underline{X}_n)$$

$$\underline{U}_m - \underline{U}_p = \rceil \times (\underline{X}_m - \underline{X}_p)$$

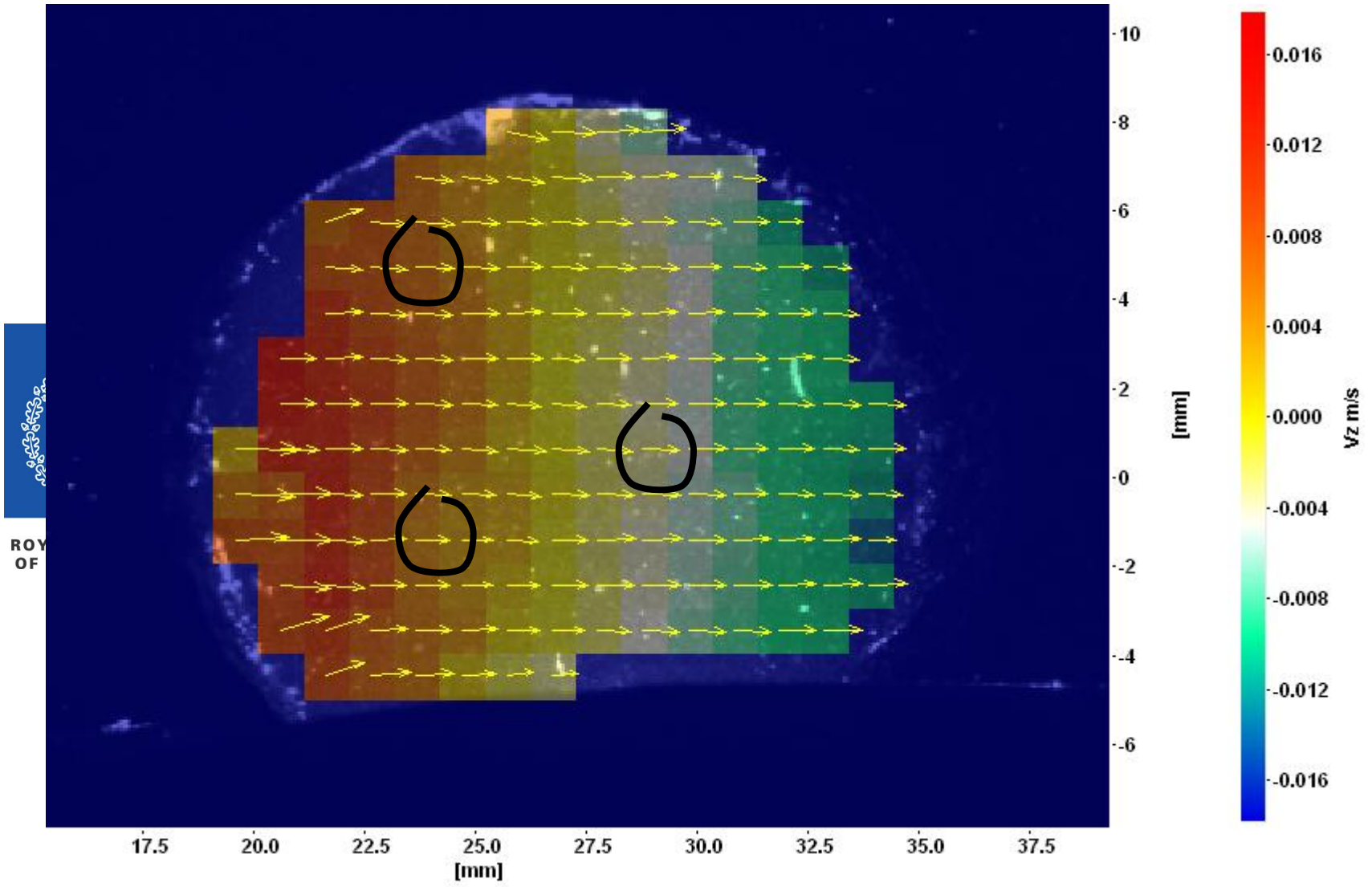
3 measured vectors within the particle give:

1 measurement of $\rceil_x$

1 measurement of $\rceil_y$

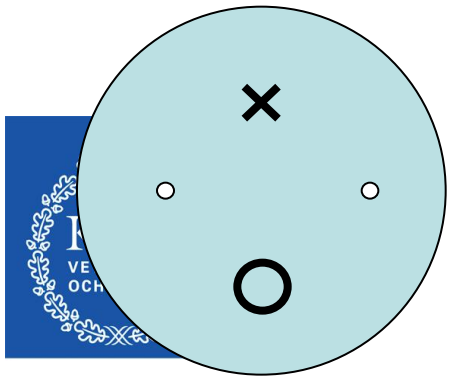
4 measurements of $\rceil_z$

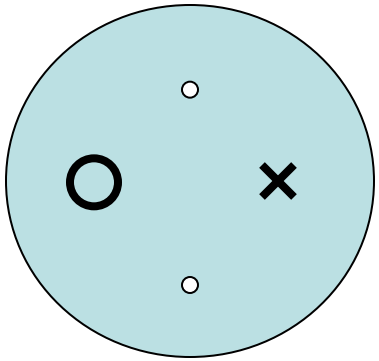
Rotation measurement – Validation

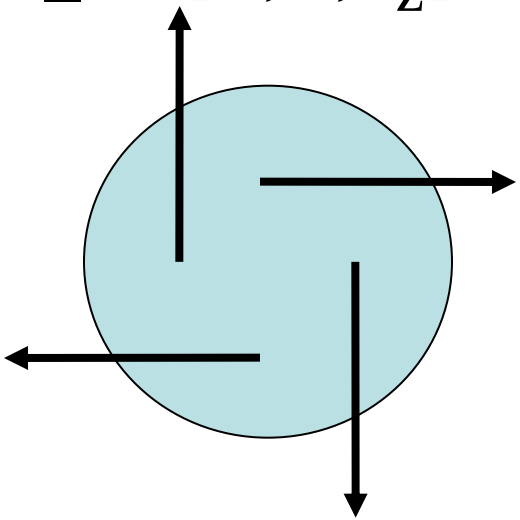


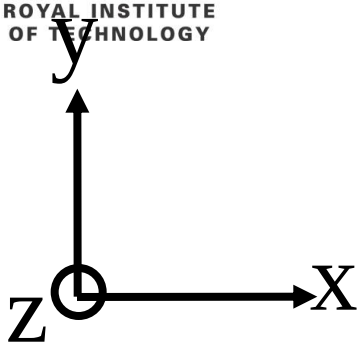
Rotation measurement – Validation

$\Omega = [\Omega_x, 0, 0]$ $\Omega = [0, \Omega_y, 0]$ $\Omega = [0, 0, \Omega_z]$









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Thank you!

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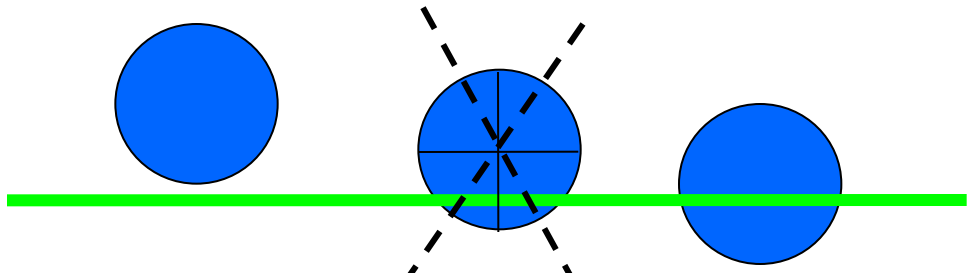
Particle Translation

Plan view:



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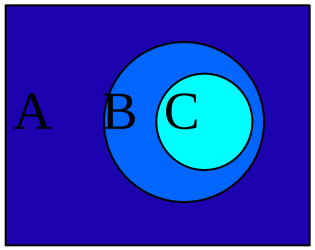
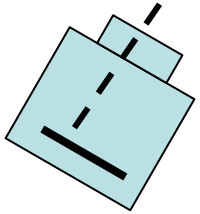
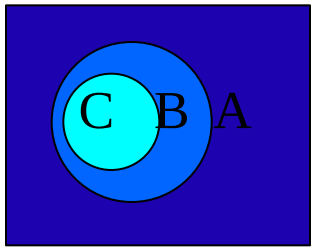
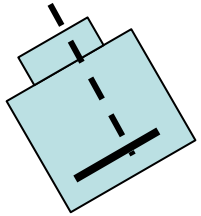
Camera 1





Camera 2





Hydrogel

Motivation

Eaton et. al. , Lucci, Ferrante etc. suggested that is important to resolve flow detail for large particles

Eaton, Lucci explained flow around spheres but what happens with non-spherical particles?

Confirm Pivoting, experimental issues.

Rotational dynamics.

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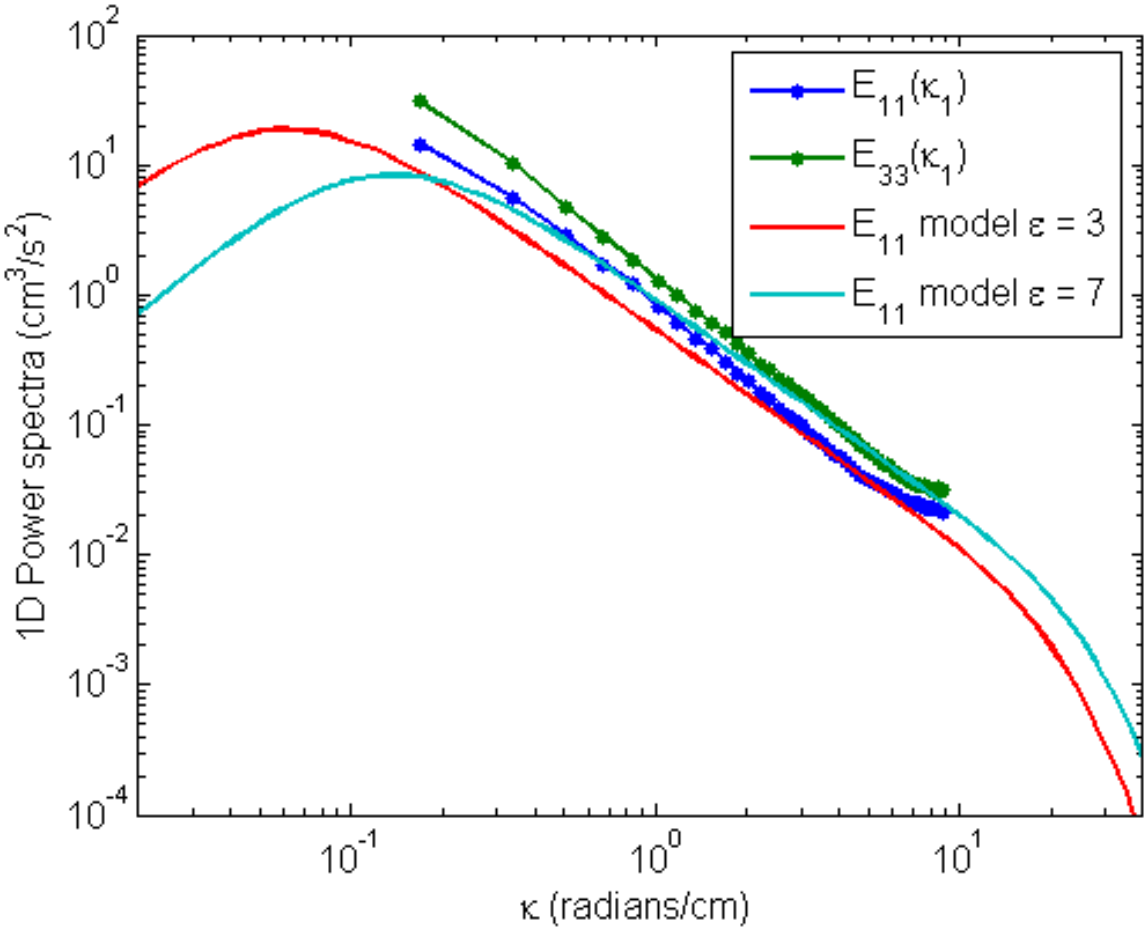
RMSPIV - Summary

Effective measurement for particle Rotation and translation

Simultaneous fluid fluid velocity

In final stages of development

Creating ideal laboratory turbulence



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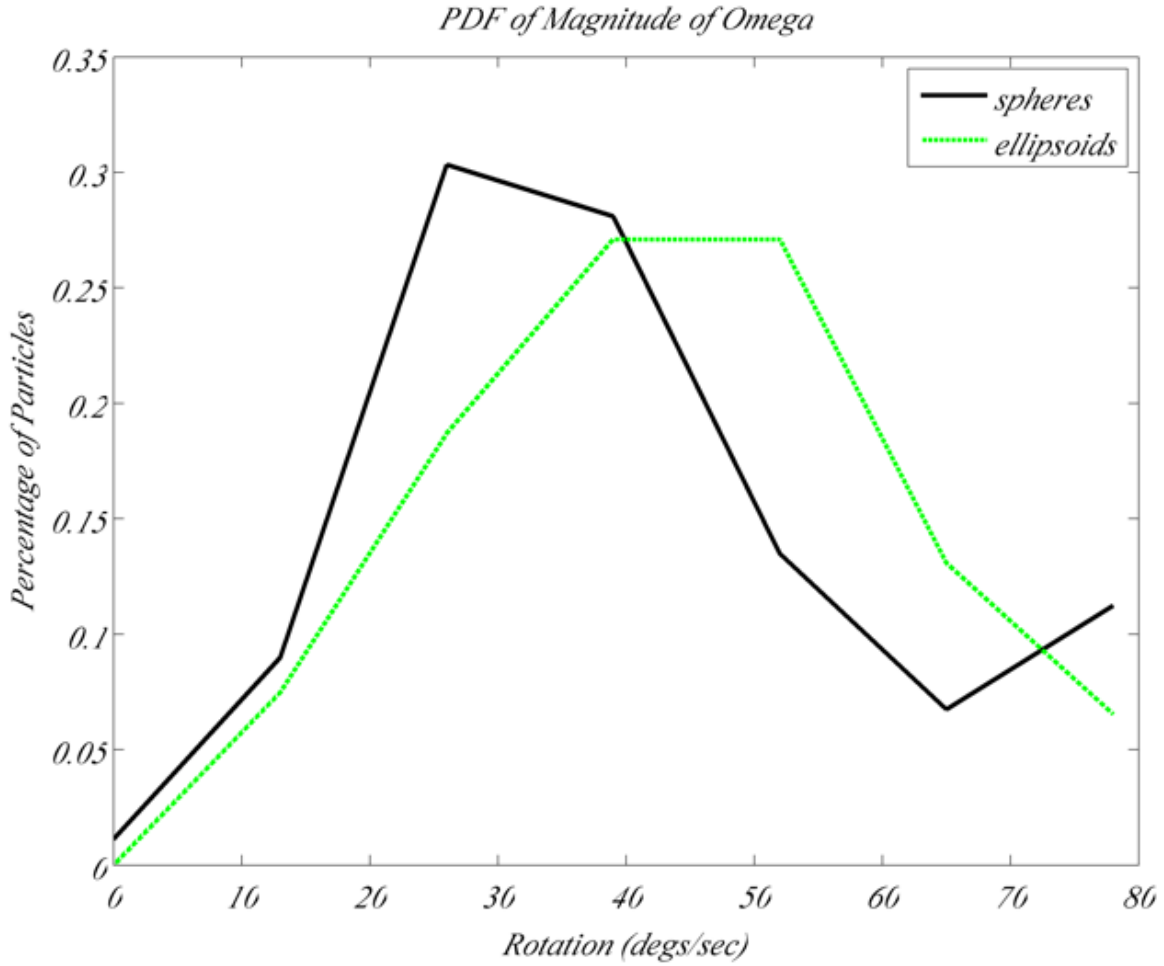
Rotational Dynamics: preliminary results

PDF of $|\Omega|$



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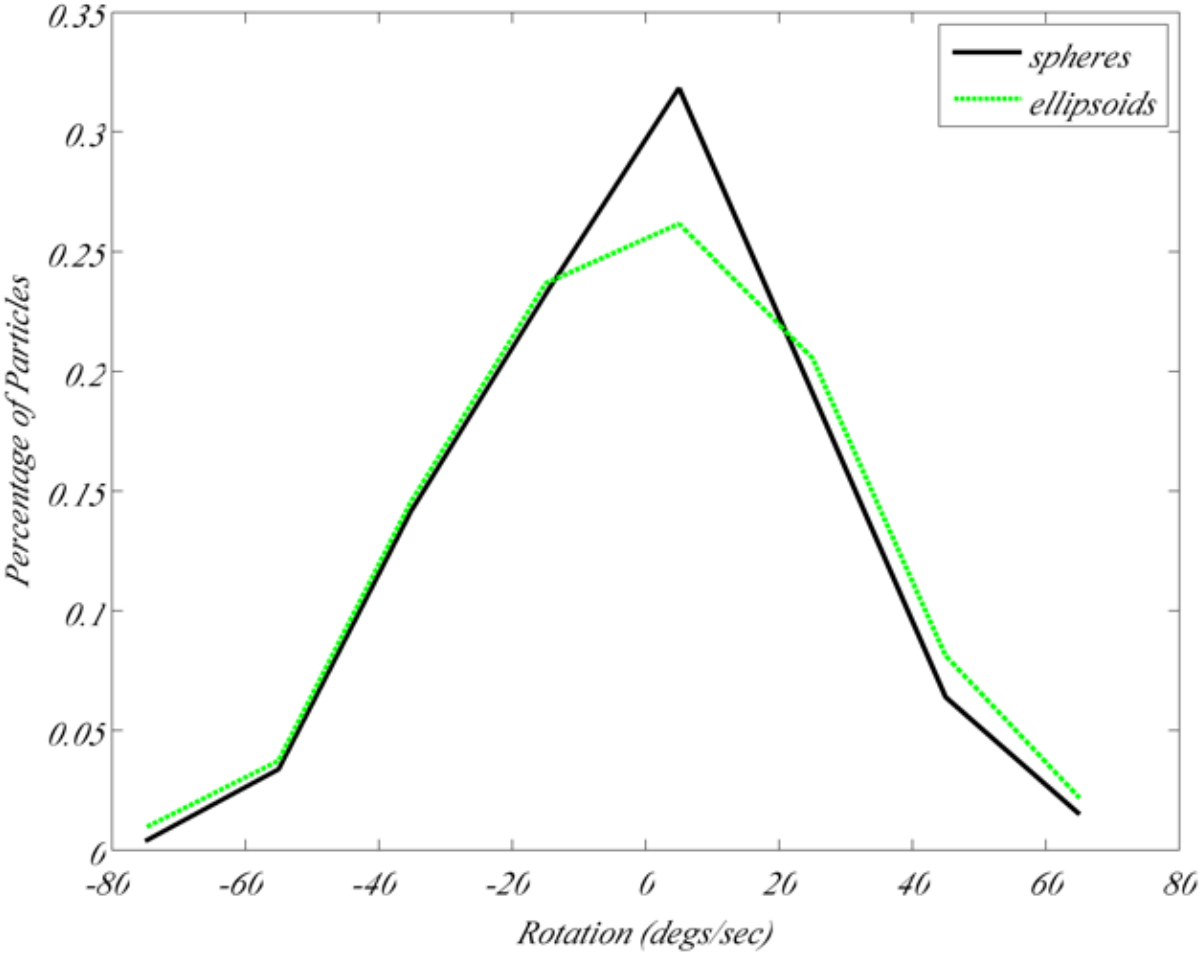
OF TECHNOL

Rotational Dynamics: preliminary results

PDF of $\Omega_x, \Omega_y, \Omega_z$



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