

# Symmetry breaking of turbulent wakes

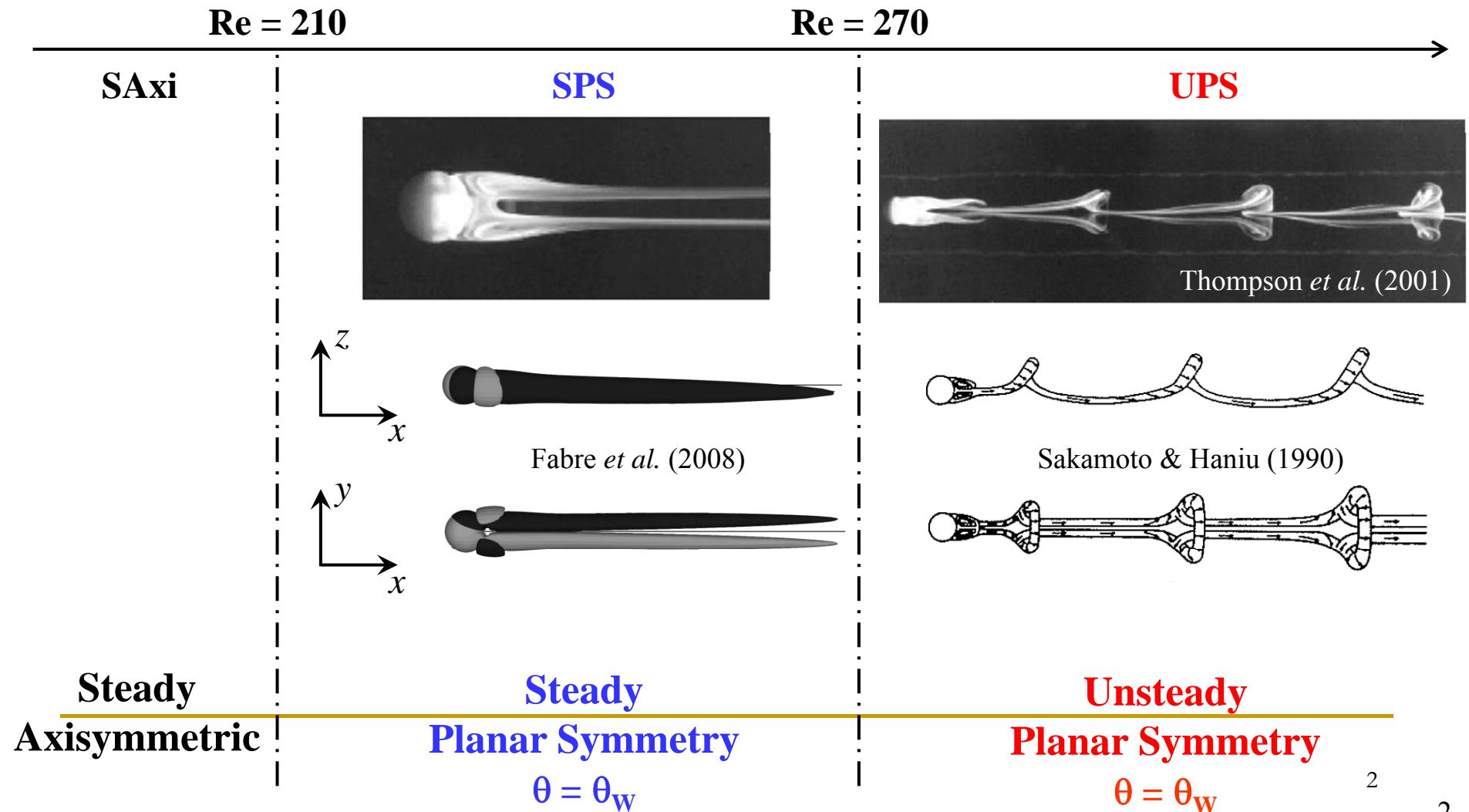
- Mathieu GRANDEMANGE (PhD UME/PSA)
- Marc GHOLKE (PSA)
- Olivier CADOT (UME)

**Unit of Mechanical Engineering  
ENSTA-ParisTech  
Palaiseau FRANCE**



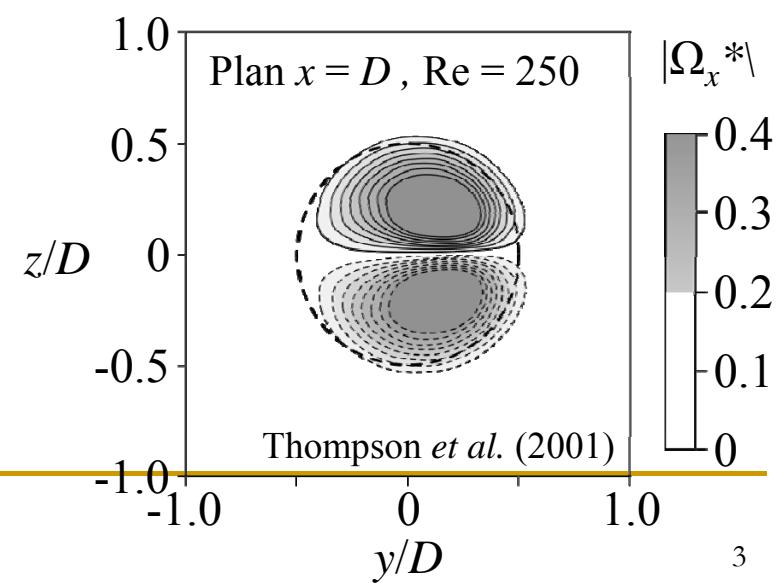
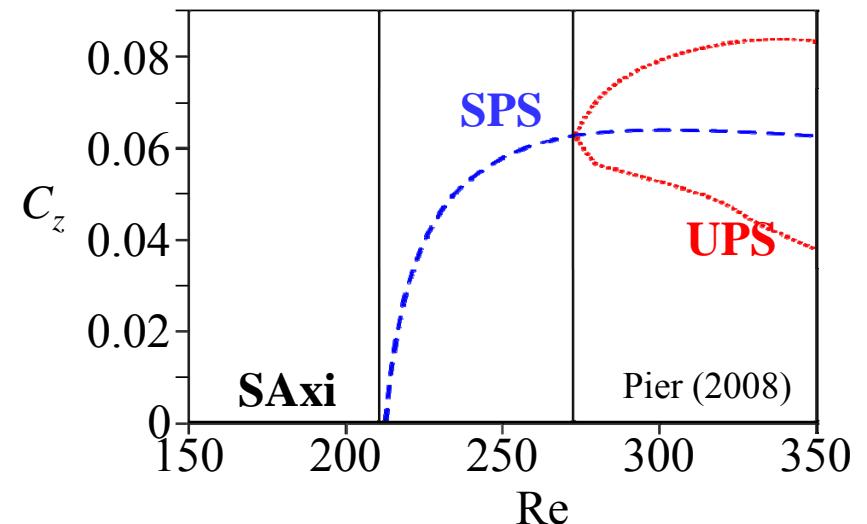
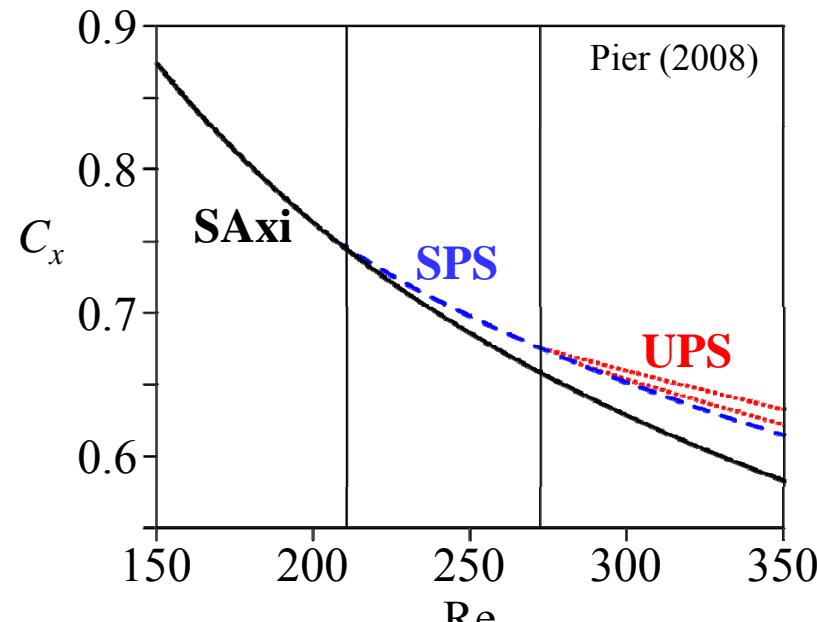
# Laminar Sphere $Re < 500$

## Bifurcation in a sphere wake

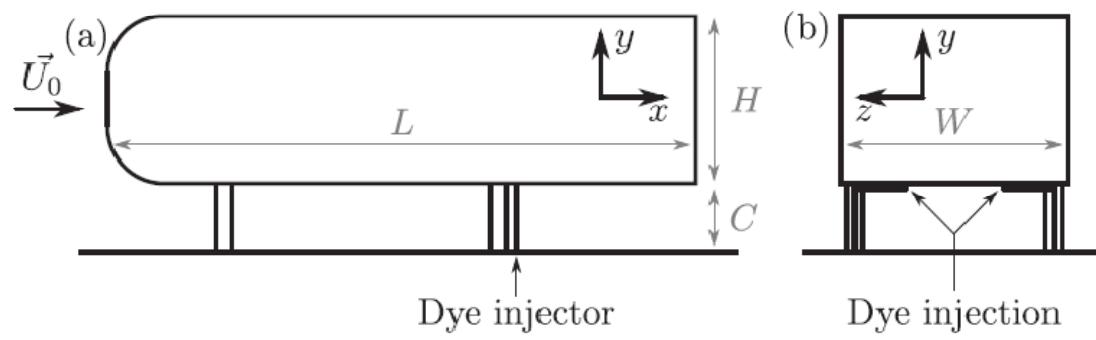


## Symmetries and aerodynamics force

- Symmetry breaking :
  - lift
  - additionnal drag

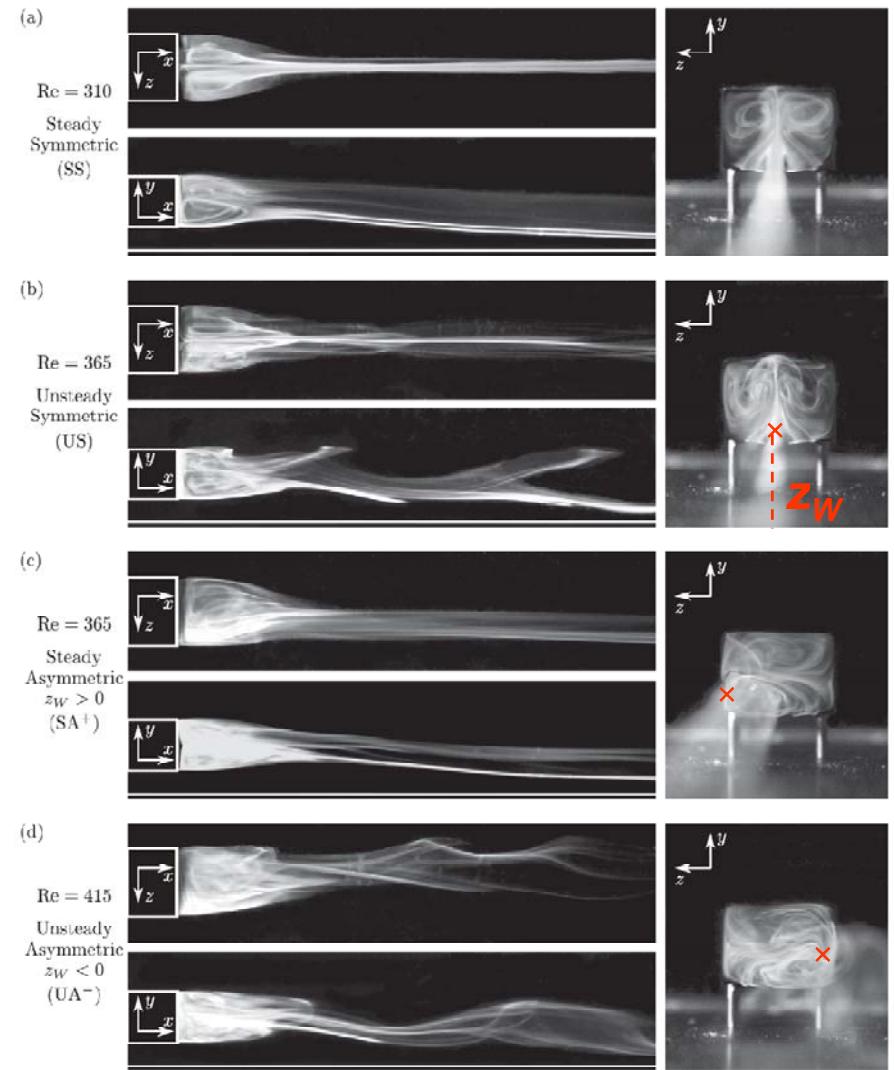
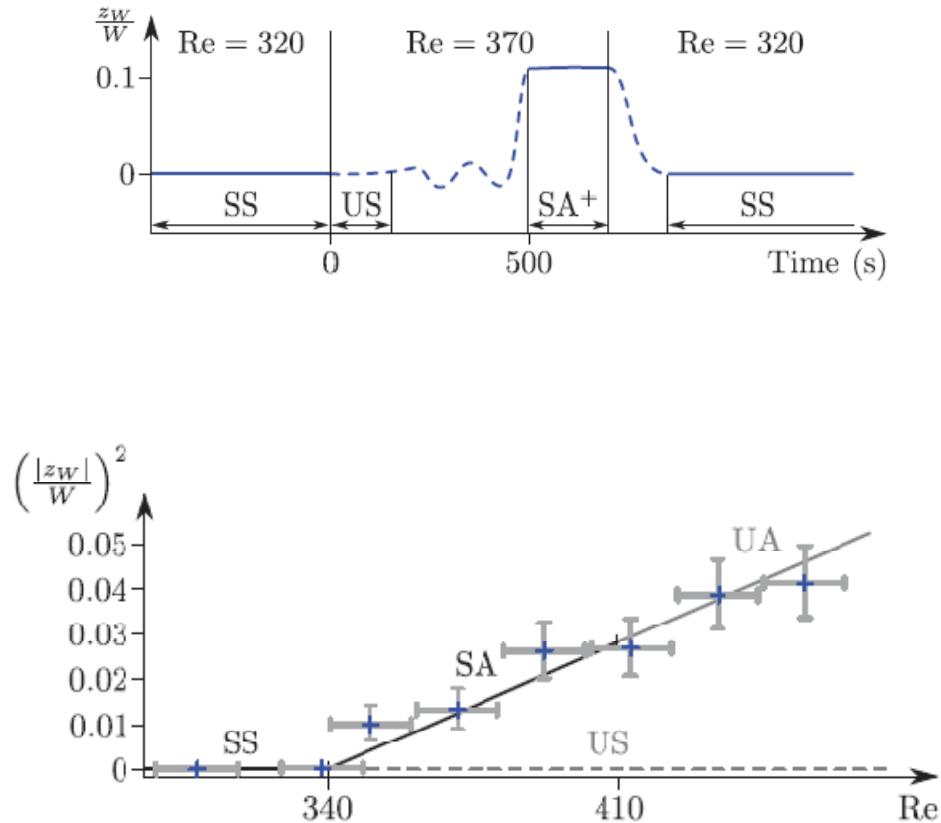


# Laminar Blunt Ahmed Body $\text{Re} < 500$



# Bifurcations in the laminar flow

*Grandemange et al.* PRE 2012



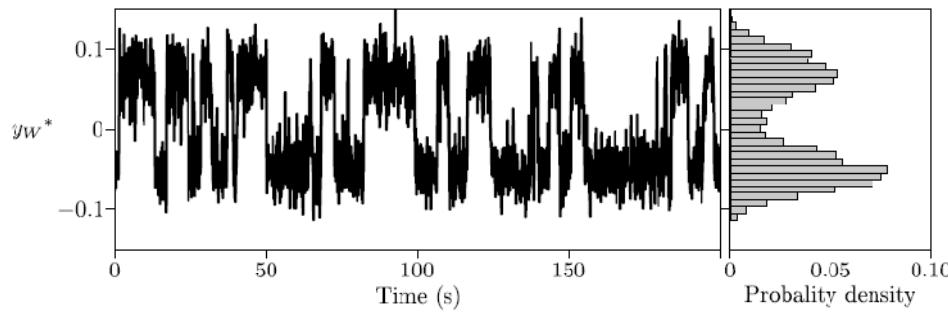
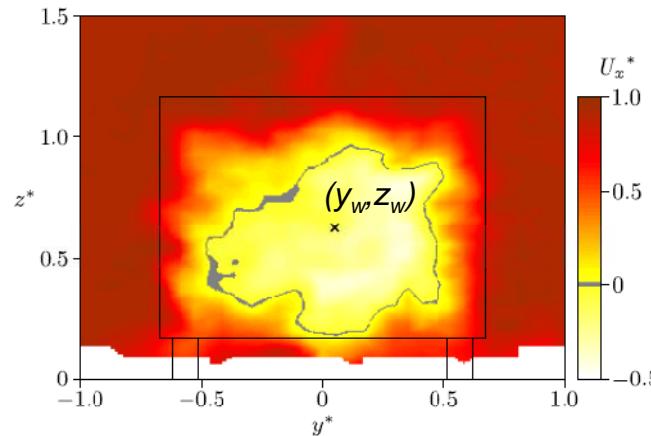
# Turbulent flow

$\text{Re} \sim 100\,000$

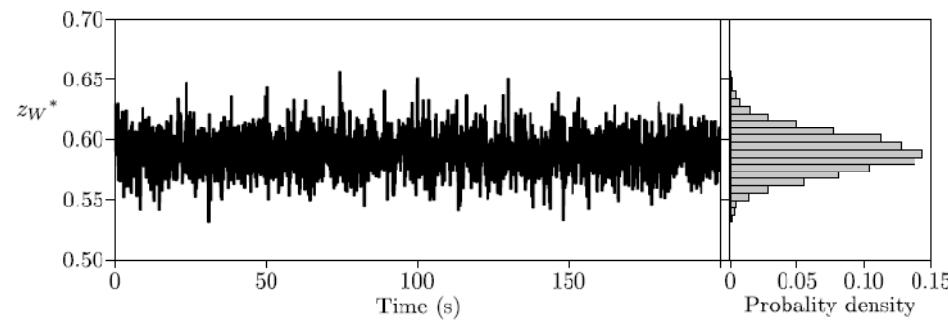
Instantaneous barycenter  
of momentum loss :

$$y_W^* = \frac{\int y^* \cdot (1 - u_x^*) ds}{\int (1 - u_x^*) ds},$$

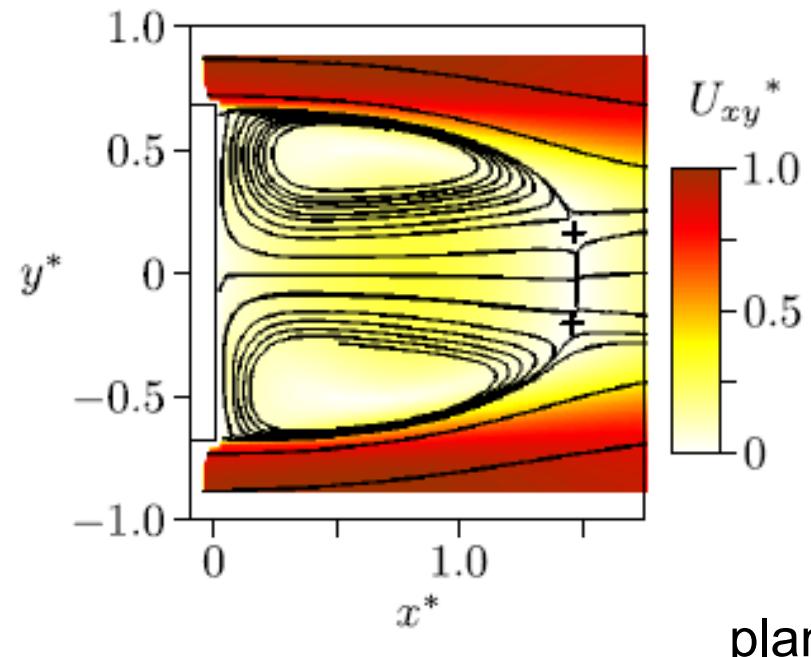
$$z_W^* = \frac{\int z^* \cdot (1 - u_x^*) ds}{\int (1 - u_x^*) ds};$$



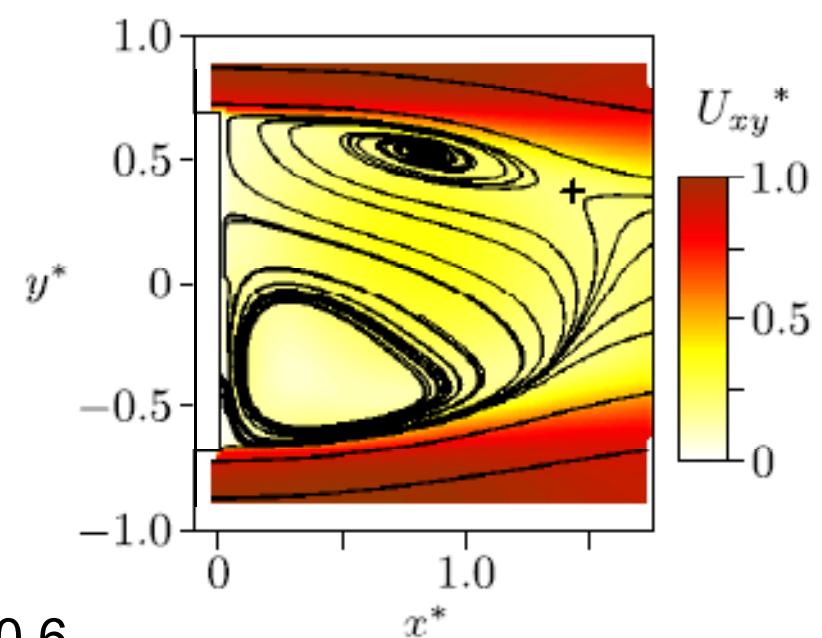
two  
mirror  
states



**Mean flow**



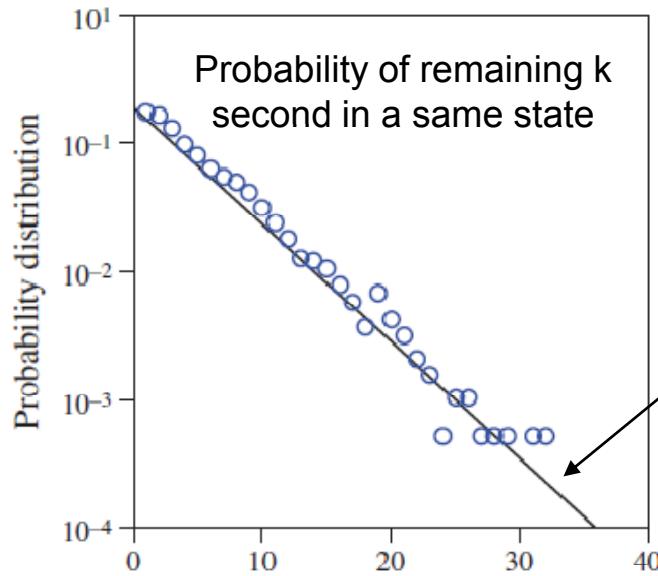
**Conditional averaging  
on the sign of  $y_w$**



plane  $z^*=0.6$

Mean flow = two mirror states

# Statistics of switches

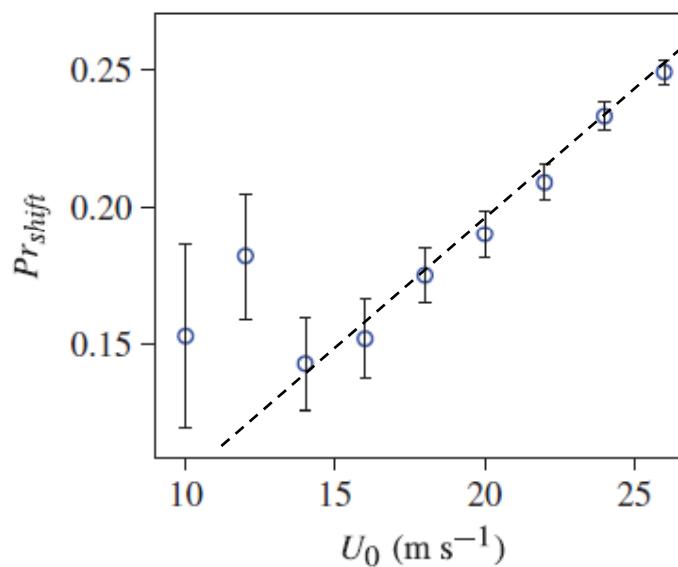


Theoretical  
Binomial law

$$Pr_{shift} \cdot (1 - Pr_{shift})^k .$$

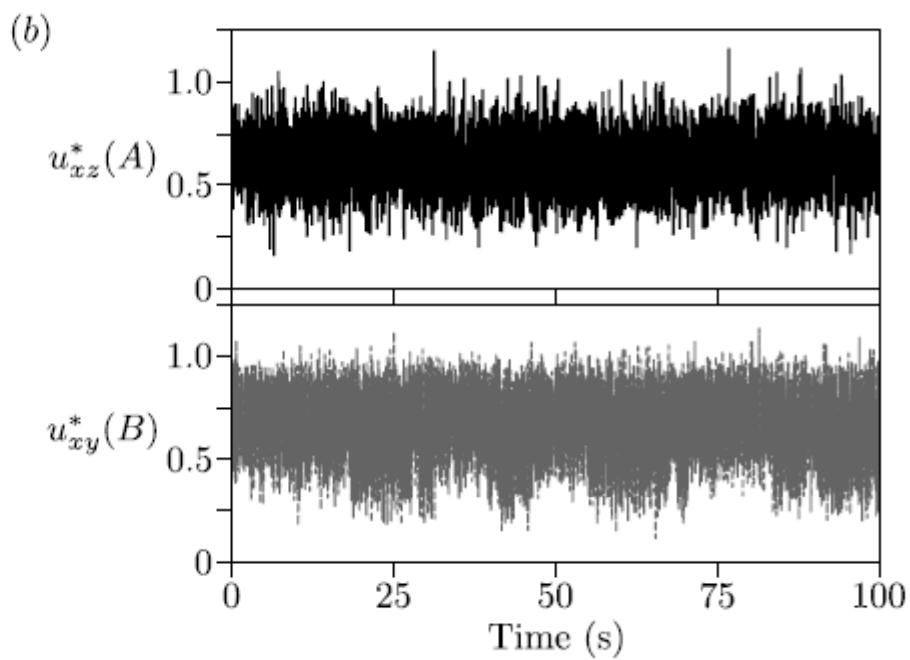
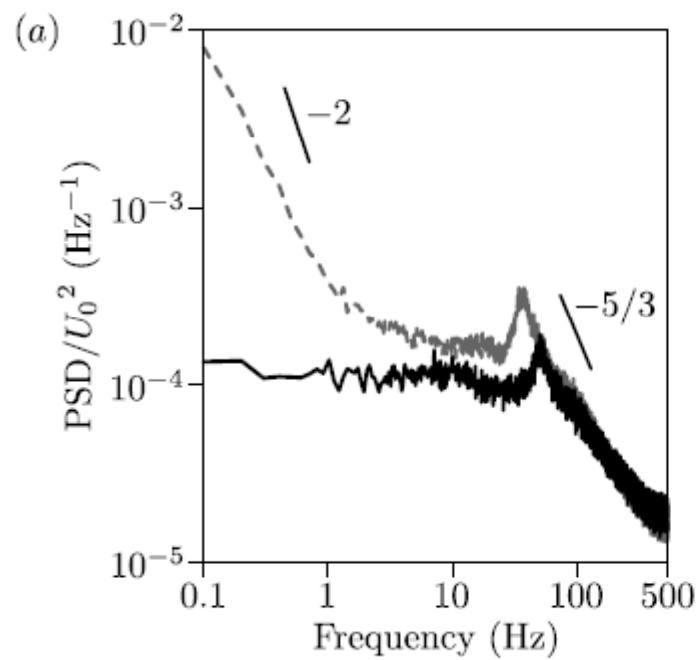
=

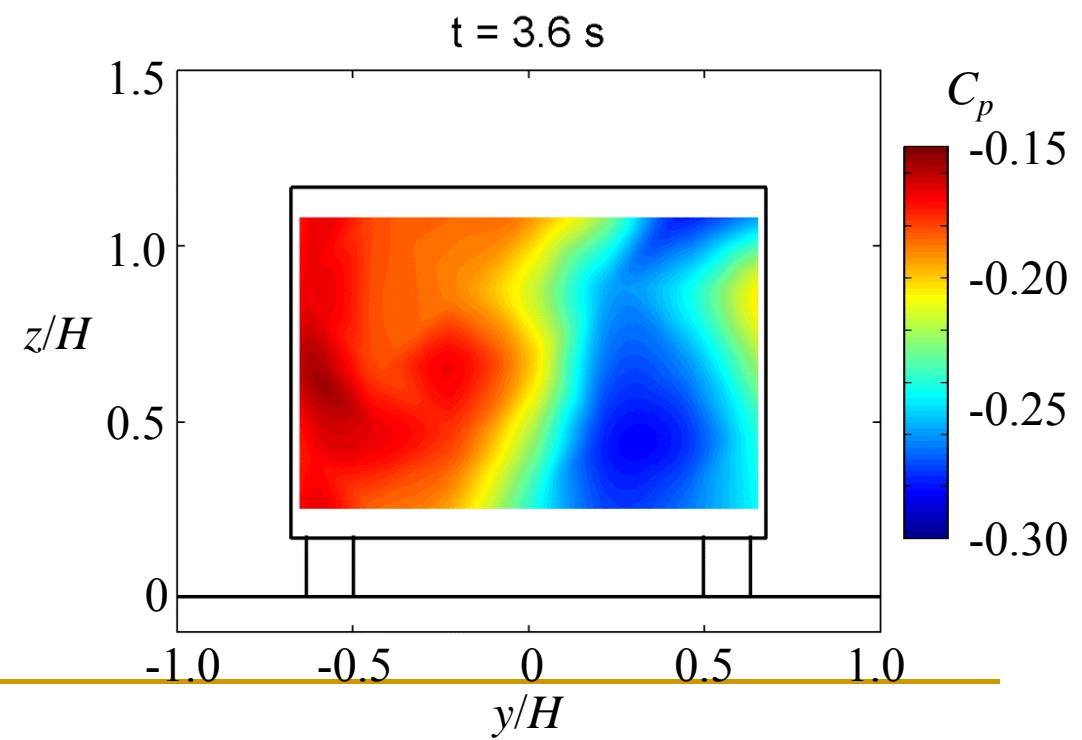
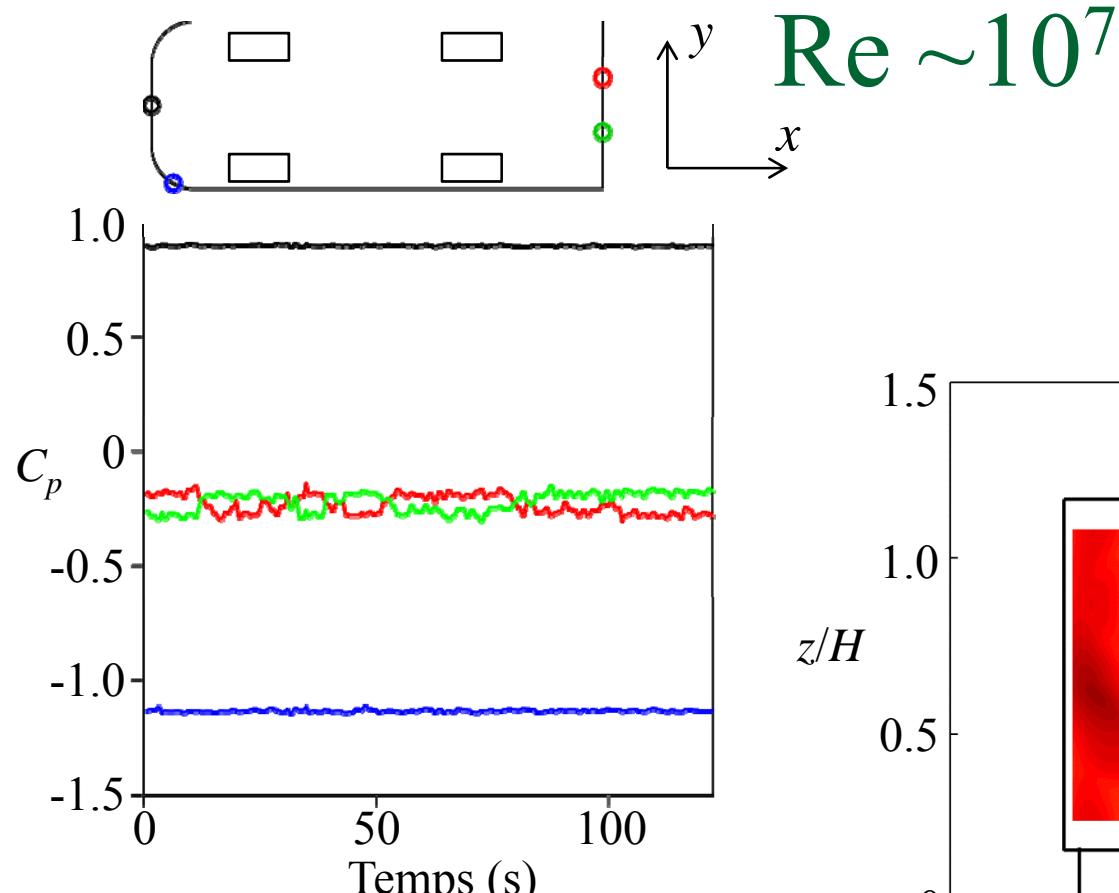
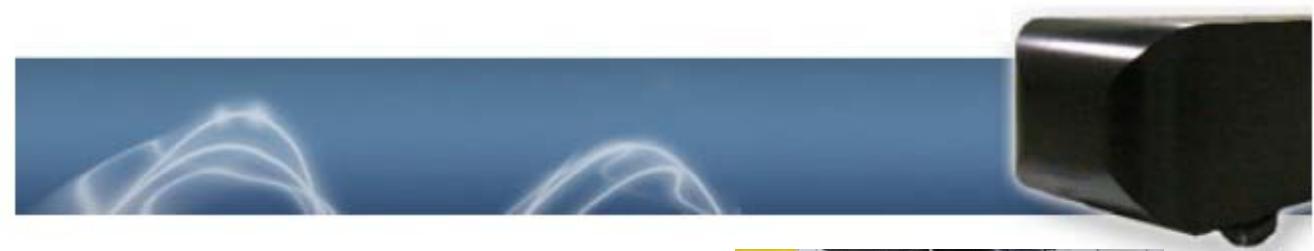
random process  
(i.e. no periodicity)



$\Rightarrow$  timescale  $\sim 1000 U_0/H$

# Signature fil chaud

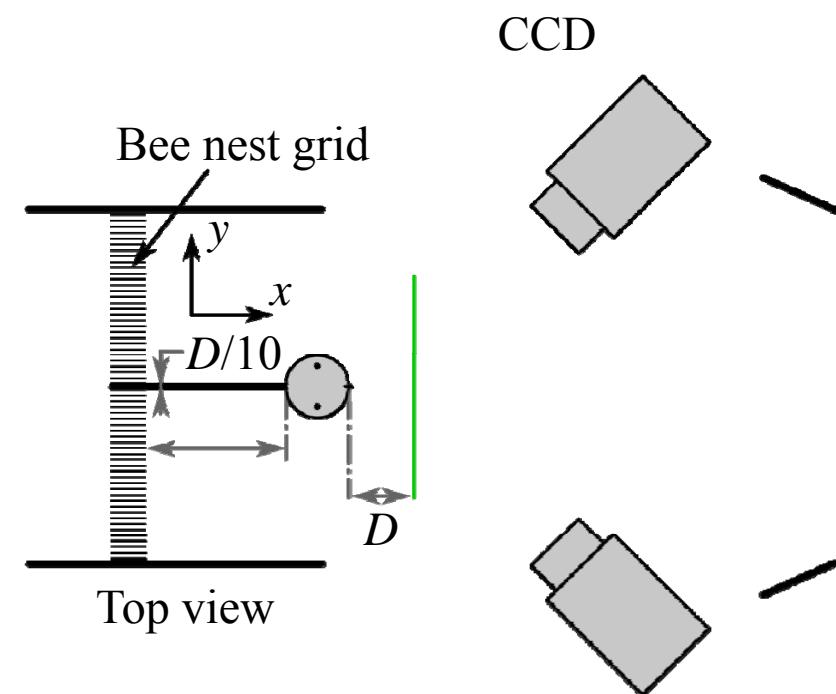
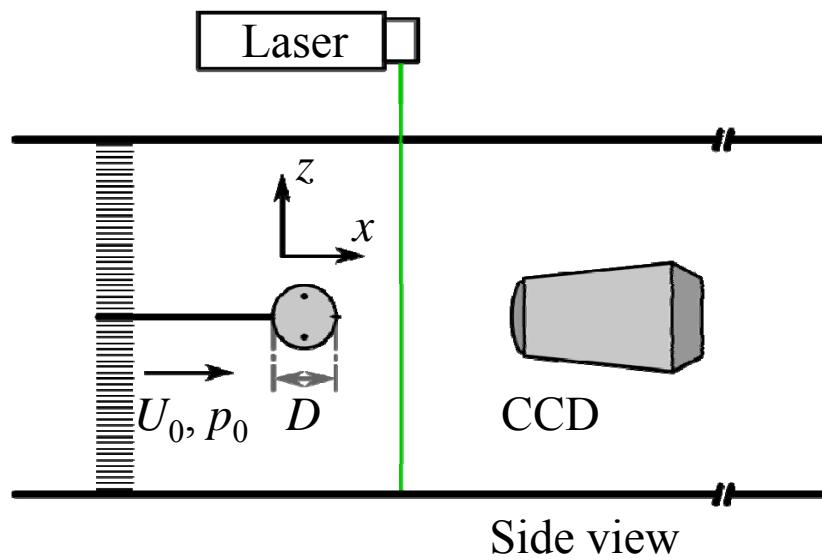




# Fully axisymmetric sphere wake

## Experiment

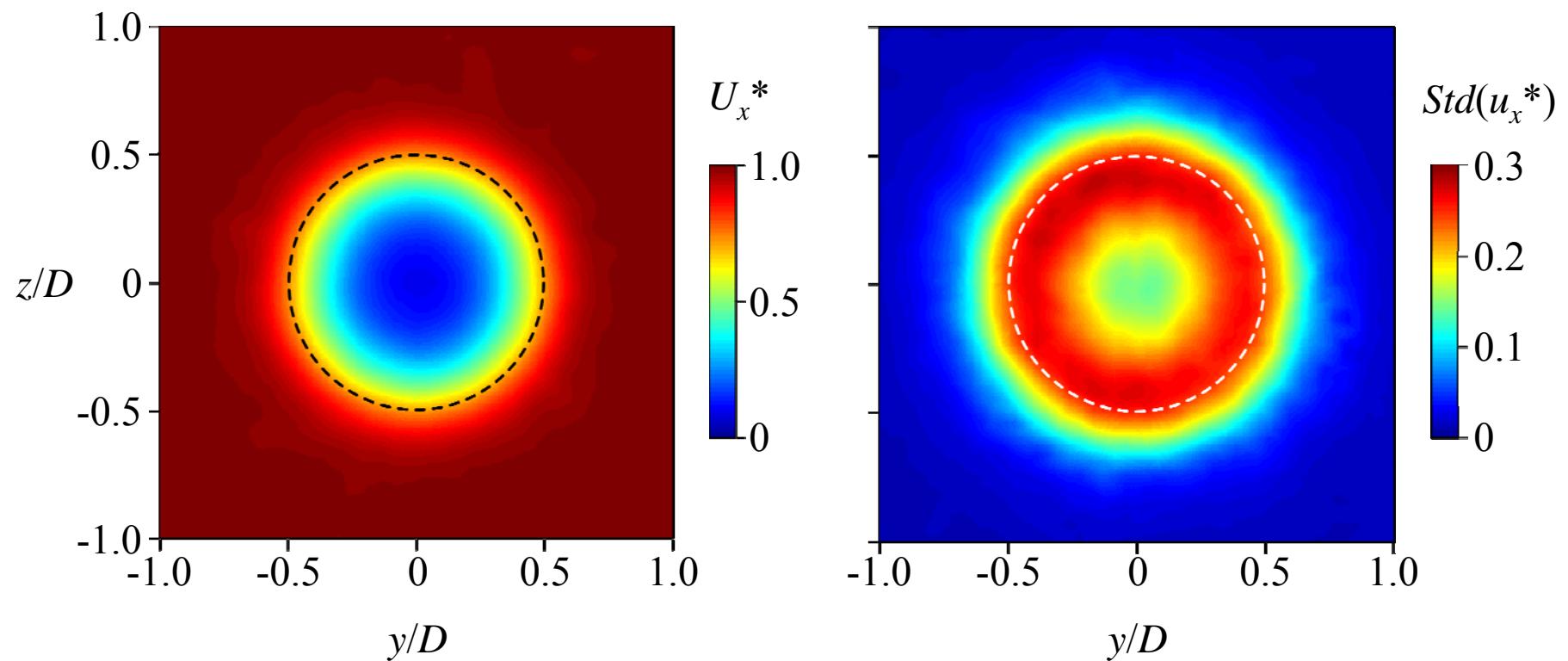
- Axixymmetry preserved



- $U_0 = 4.2 \text{ m s}^{-1}$
- $D = 70 \text{ mm}$   
→  $\text{Re} = 1.9 \cdot 10^4$  & subcritical wake

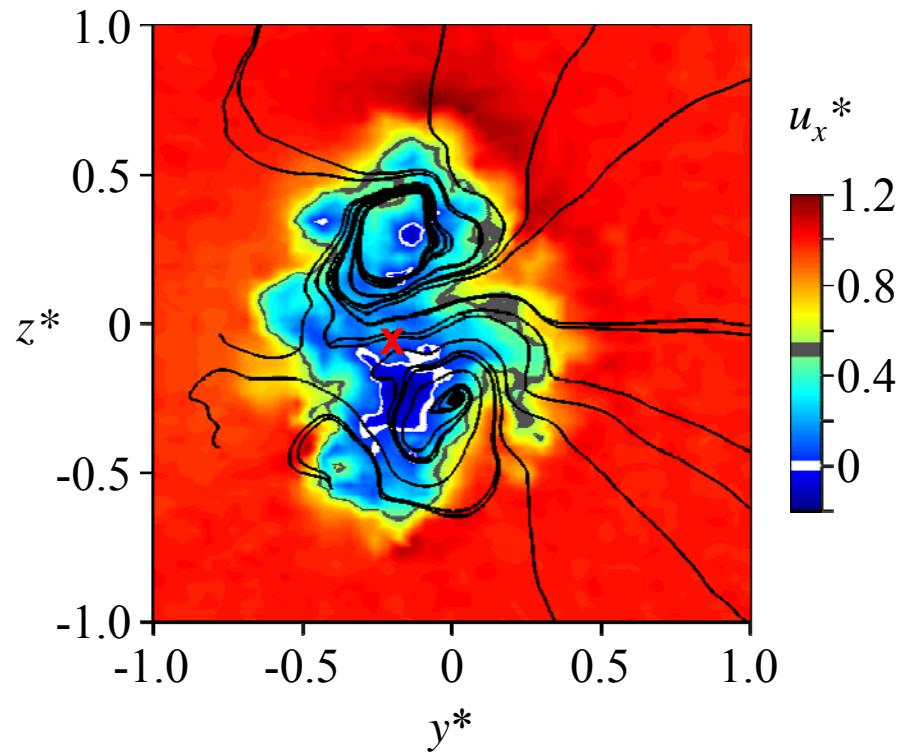
- Velocity measurements stereo-PIV plane  $x = D$ , 2000 fields

## Result :Axisymmetric mean flow



## Statistical axisymmetry

- On each instantaneous field, barycenter of deficit of  $u_x^*$  :



$$y_w^* = \frac{\int y^* \cdot (1-u_x^*) \, ds}{\int (1-u_x^*) \, ds}$$

$$z_w^* = \frac{\int z^* \cdot (1-u_x^*) \, ds}{\int (1-u_x^*) \, ds}$$

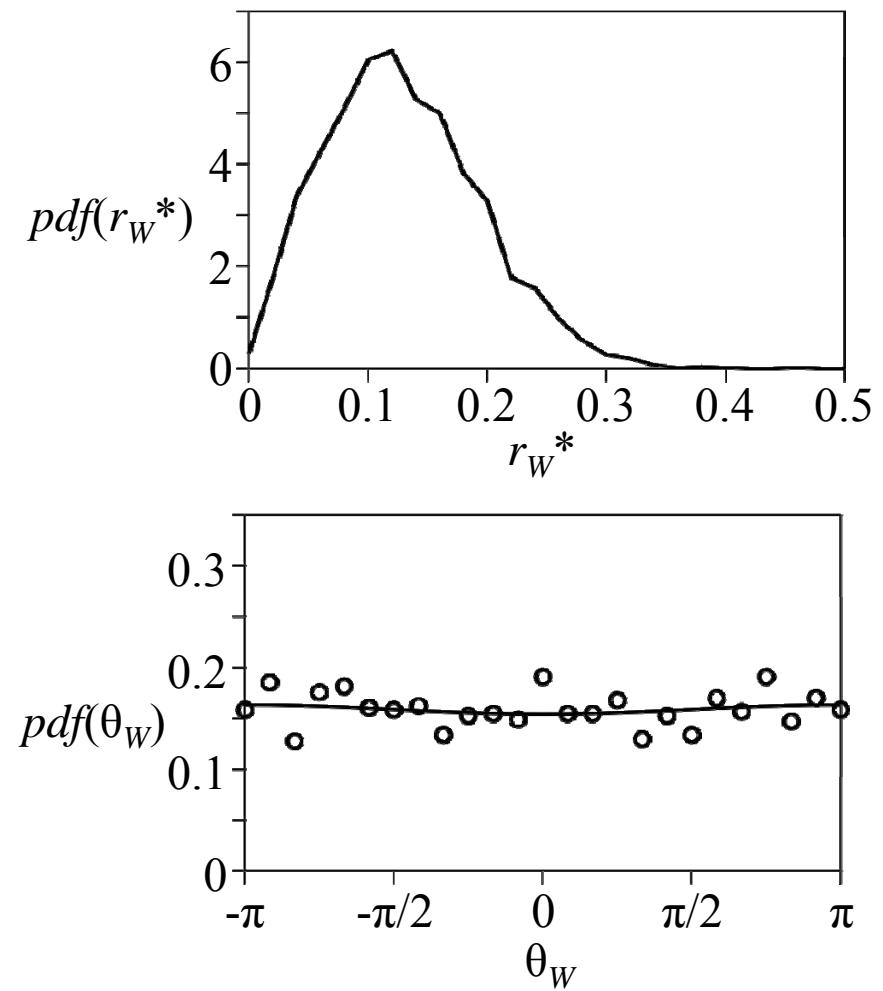
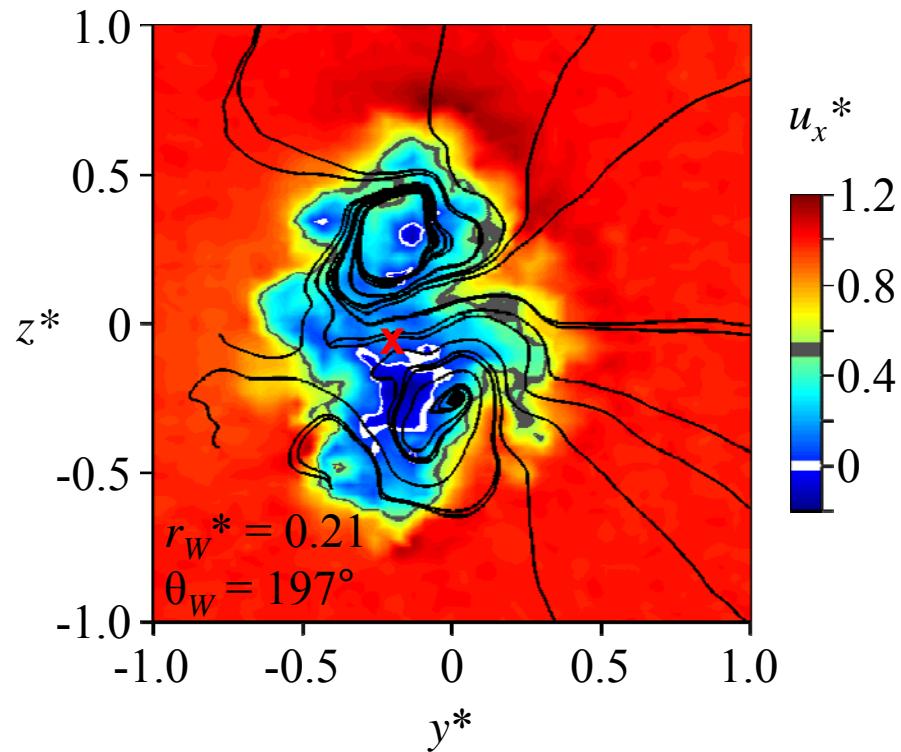
→  $r_w$  et  $\theta_w$  in polar coordinates

$$r_w^* = 0.21$$

$$\theta_w = 197^\circ$$

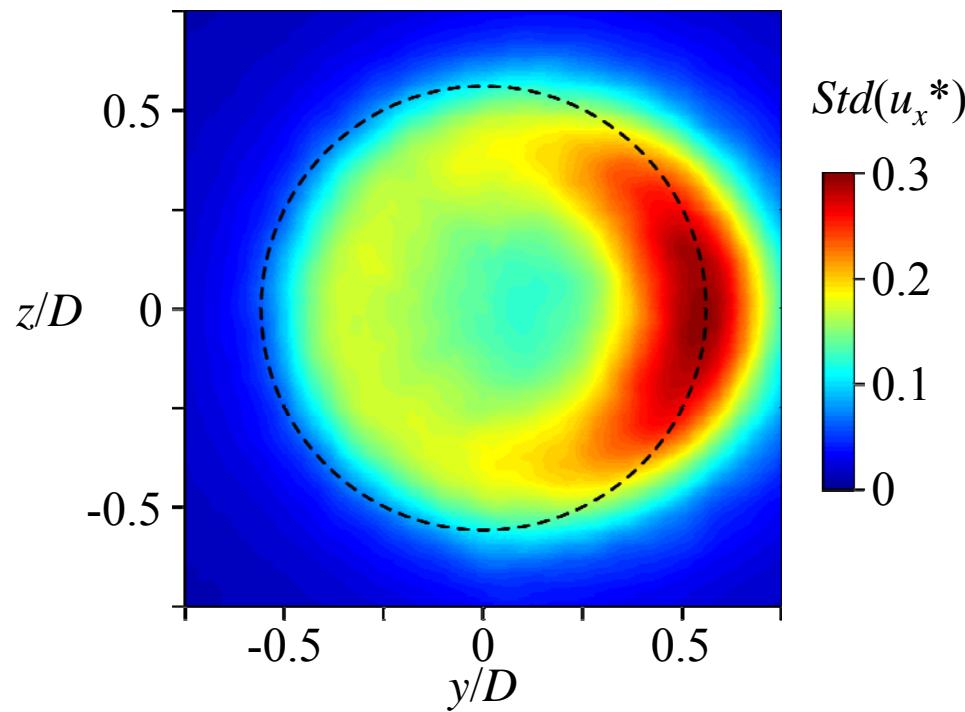
## Statistical axisymmetry

- Statistics over the 2000 fields

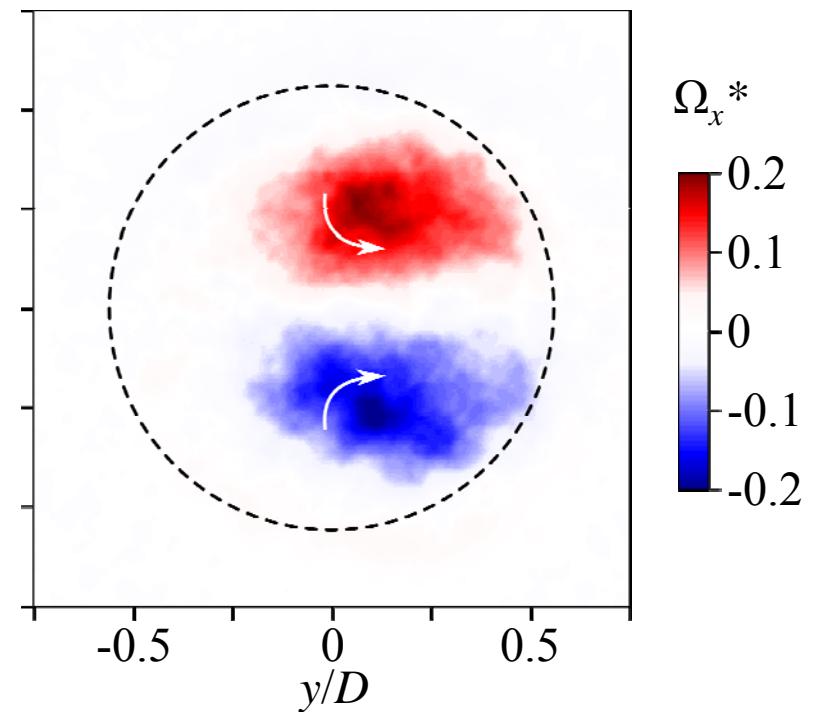


## The non-axisymmetry of instantaneous field is reminiscent of the SPS régime

- Conditionnal averaging on  $\theta_W = 0$ :



Consistent with loops shedding at  
 $\theta_W = 0$



Pair of counter rotating vortices  
 → Lift & induced drag

# Conclusion

- Steady mode associated to the symmetry breaking of 3D bodies at low  $Re$  is still present for turbulent flows
- Long time dynamics with random behavior of its azimuthal phase (multistability)
- This mode contributes significantly to the drag (3D+Lateral force=induced drag)
- It is sensitive to any local perturbation