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Analysis of multi-plane PIV measurements in a turbulent boundary layer: large scale structures, coupled and decoupled motions

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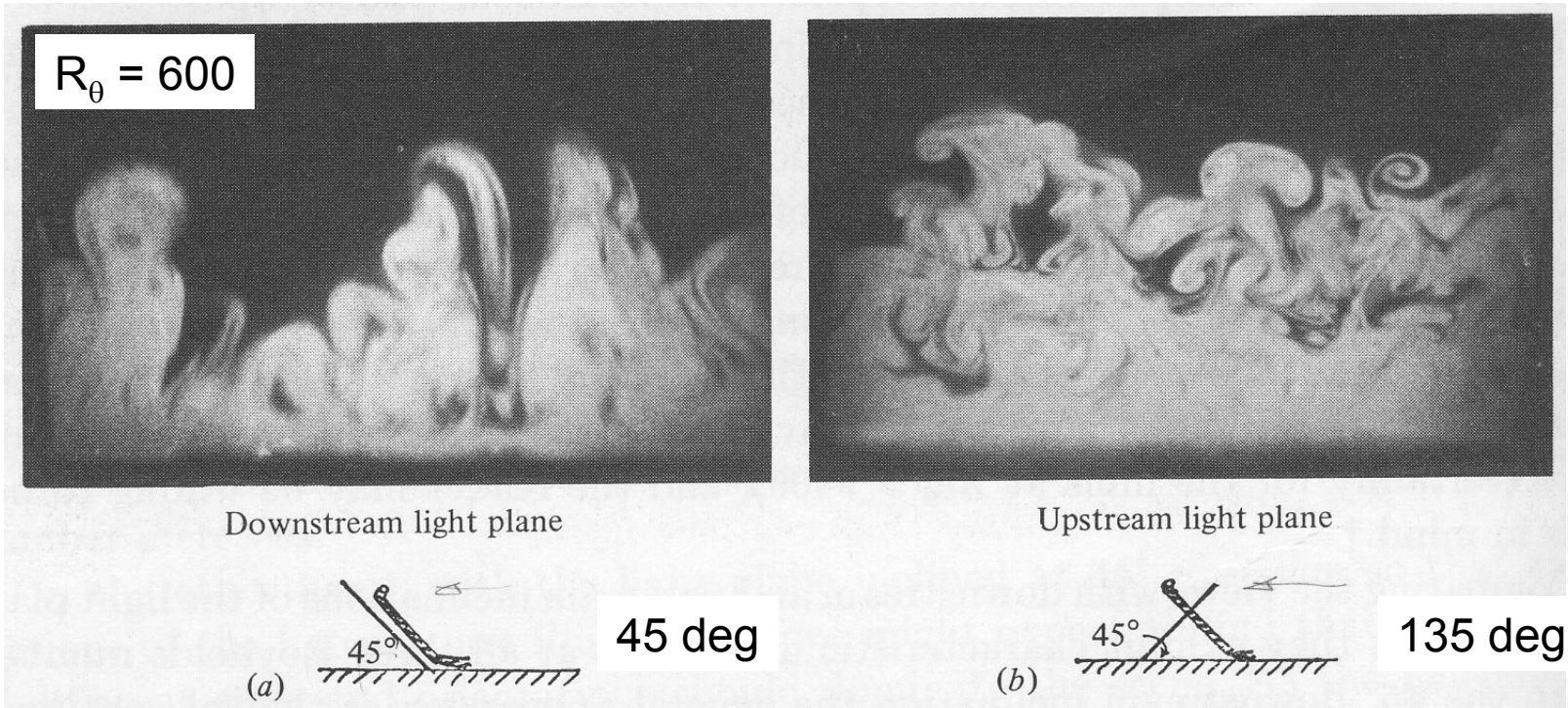
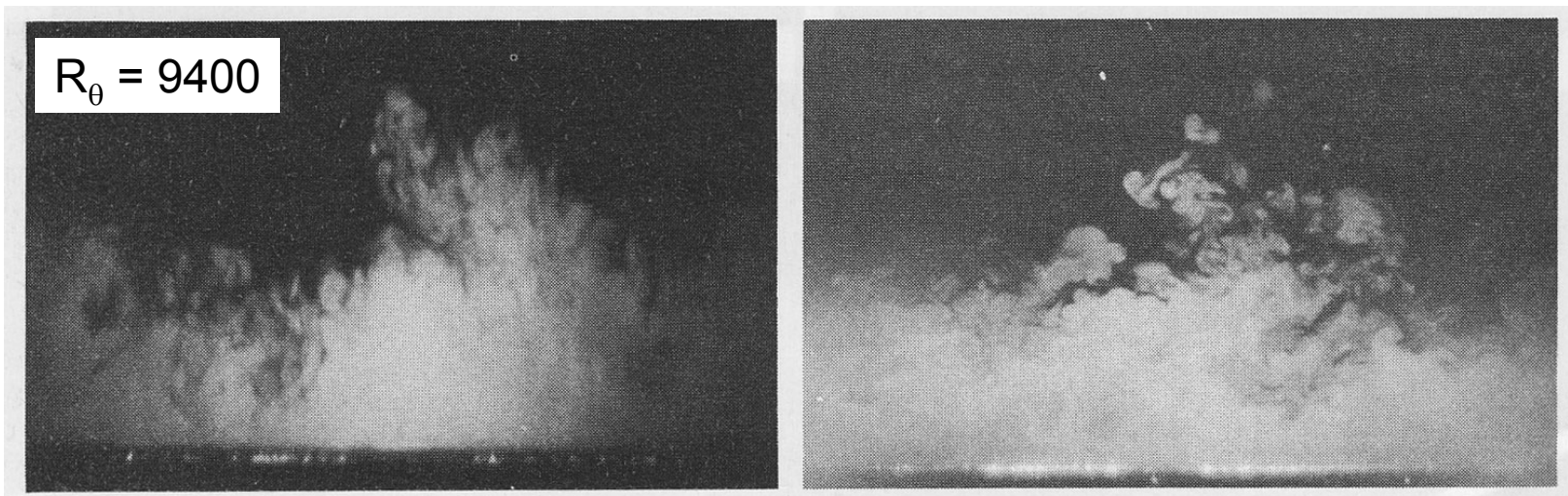
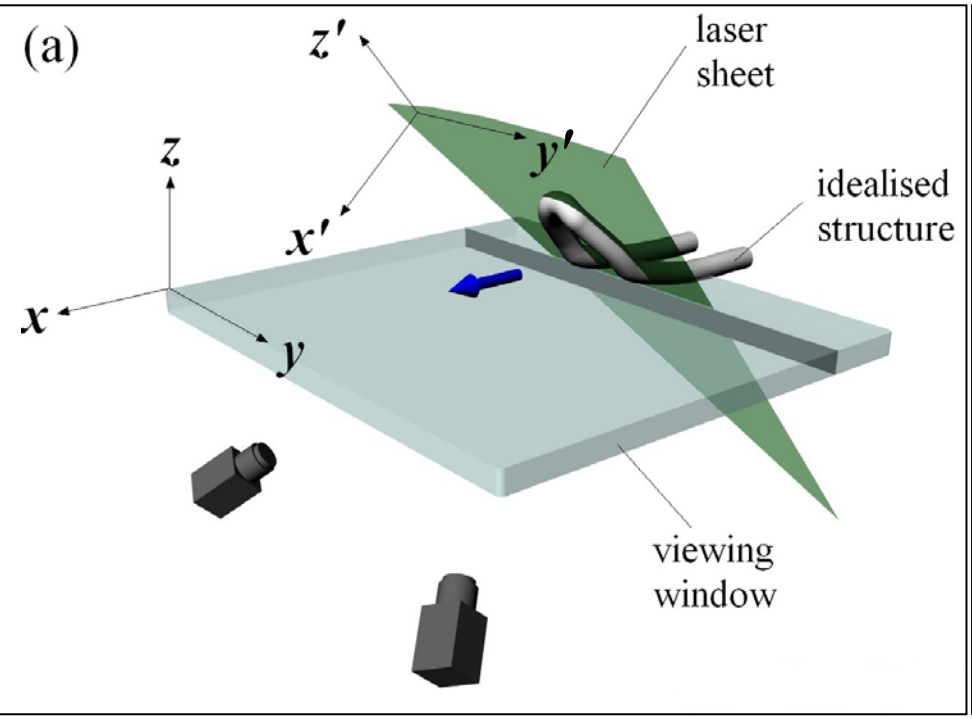
PRINCE ALFRED HOTEL

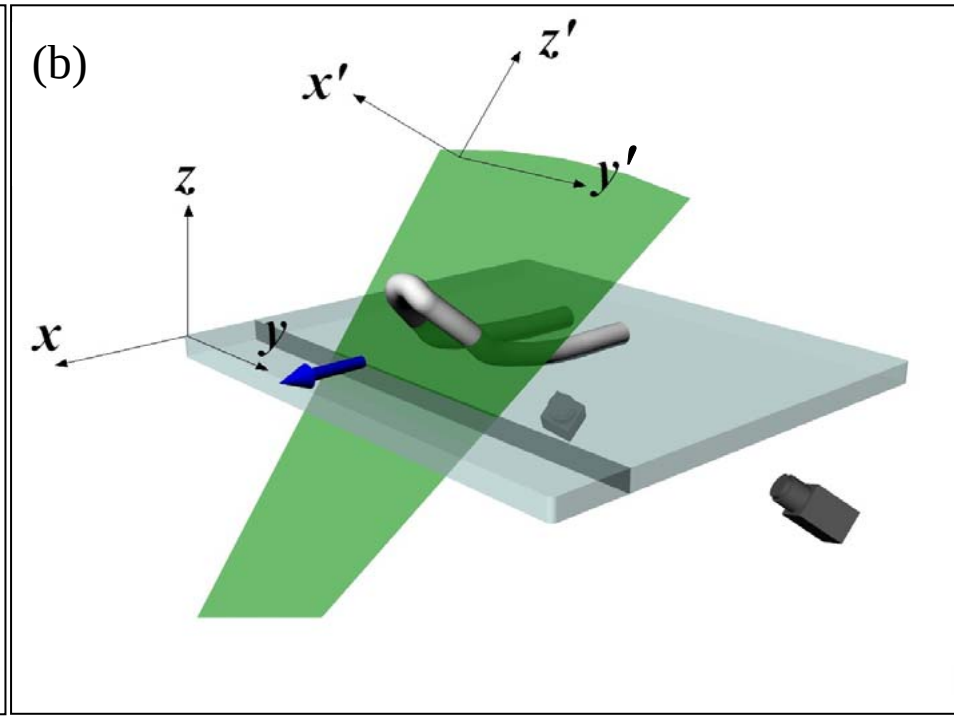
Head & Bandyopadhyay (1981)





Inclined-plane stereo PIV configuration

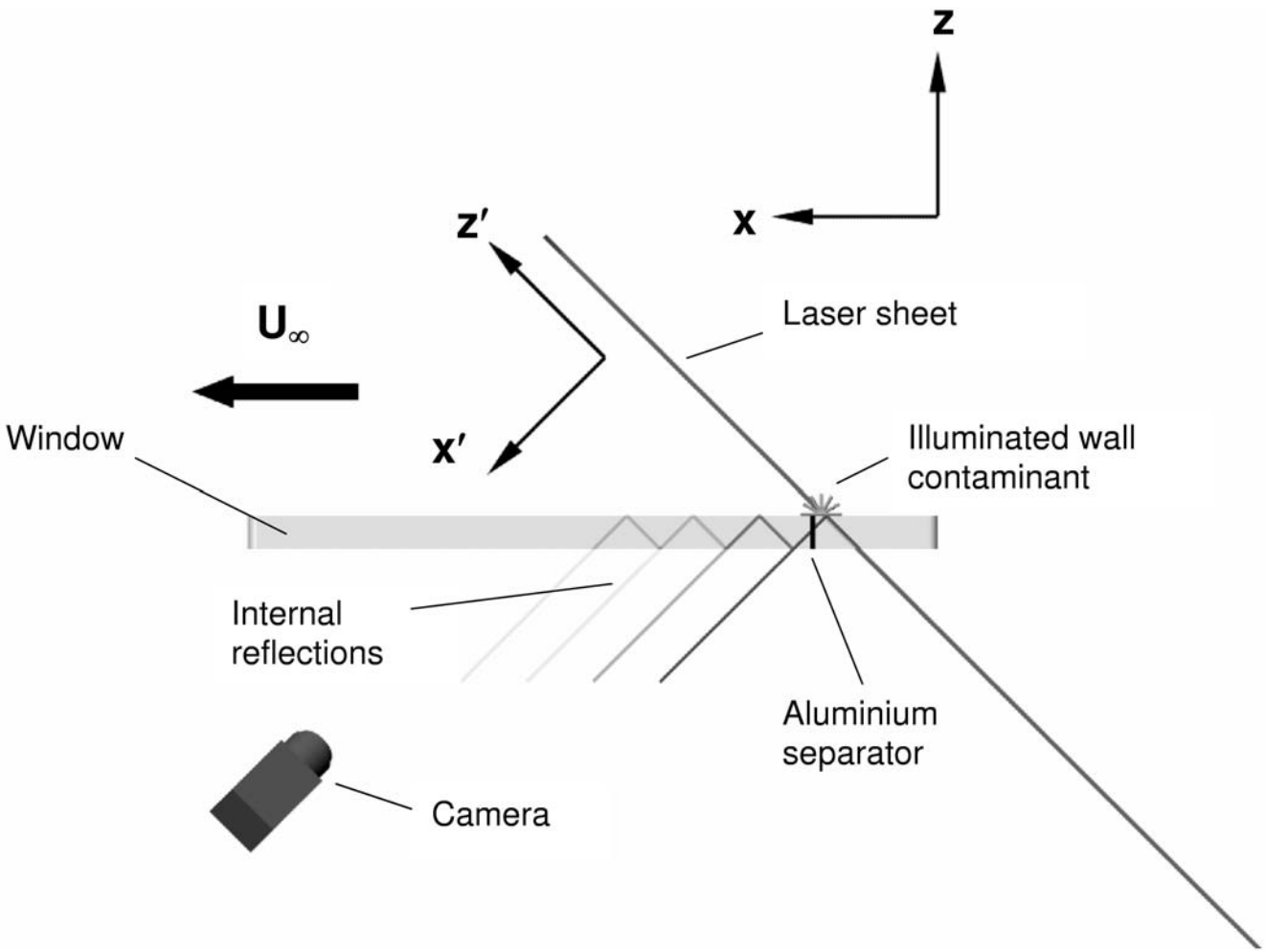




45° case

135° case

In plane measured components *u ′*, *v ′*, *w ′* are transformed into streamwise, spanwise and wall-normal velocities



$$\theta = \frac{\pi}{4} \quad , \qquad v = v'$$

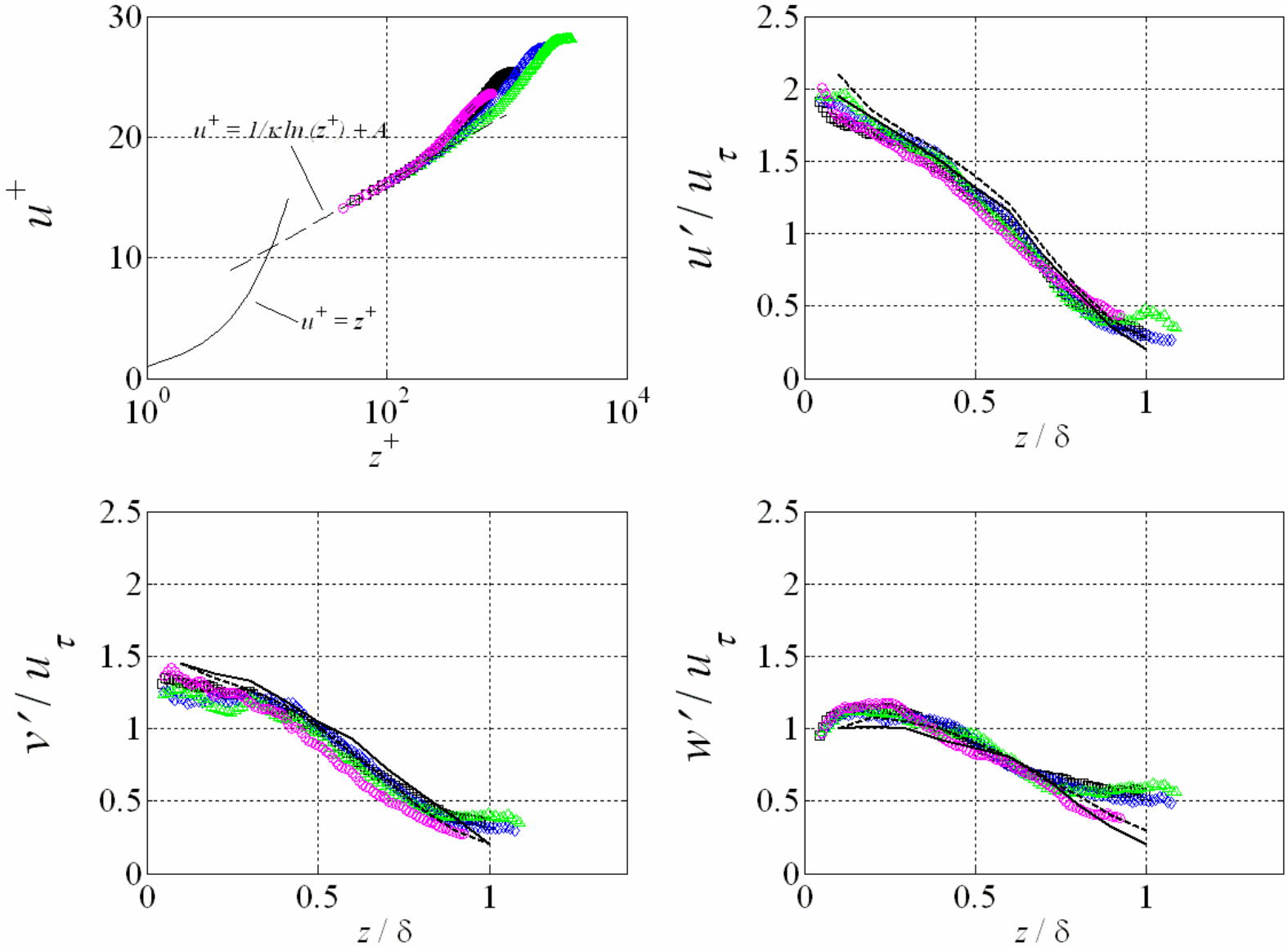
$$u = \frac{u' + w'}{\sqrt{2}}$$

$$w = \frac{w' - u'}{\sqrt{2}}$$

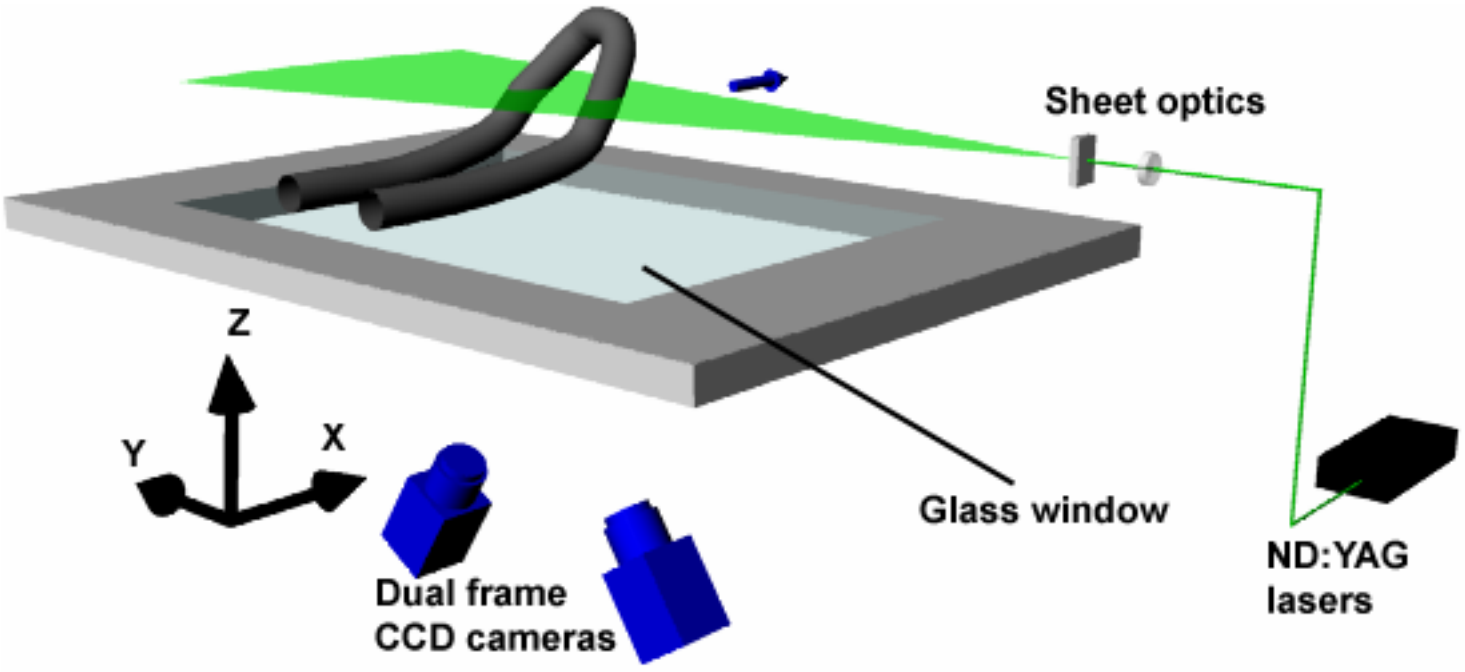
Both inclination angles repeated at four different Reynolds numbers

45° case	135° case
$Re_\tau = 790$	○
■ $Re_\tau = 1140$	□
$Re_\tau = 2030$	◊
$Re_\tau = 3071$	Δ

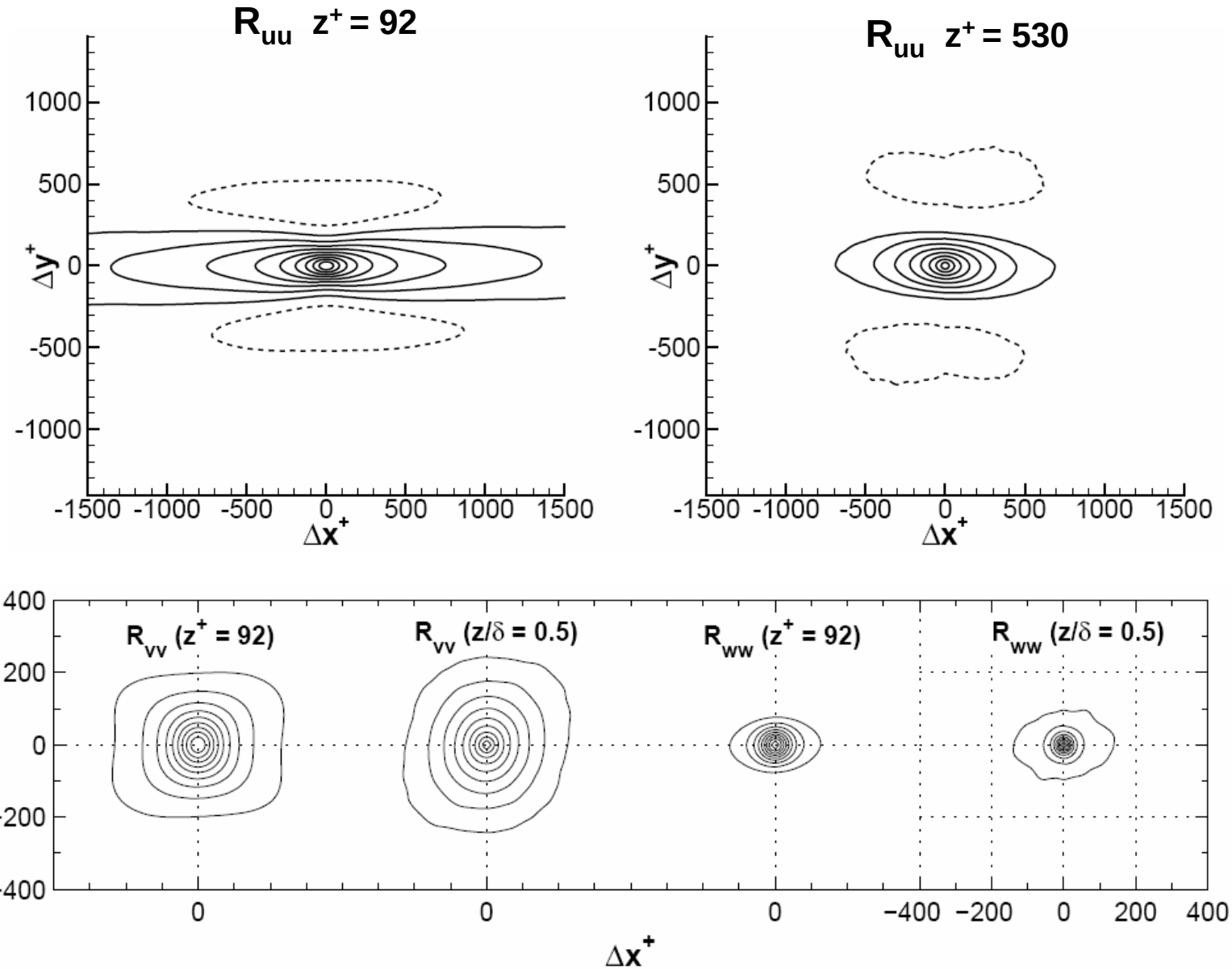
Comparison of mean flow parameters with data from (-) Klebanoff (1954) and (- -) Spalart (1988).



Wall-parallel plane set-up

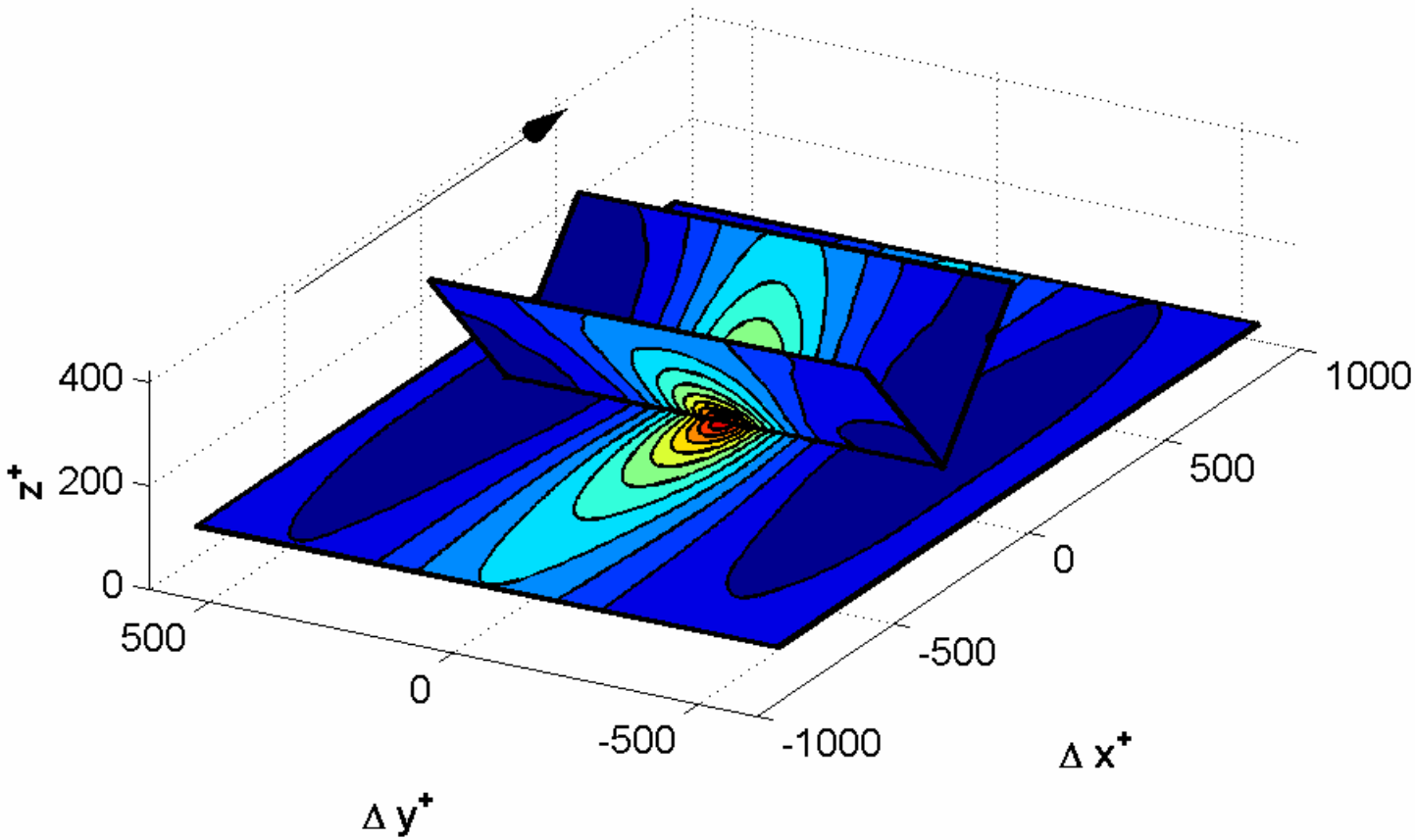


Wall-parallel plane



Two-point correlation maps – all three planes stacked together

$Re_\tau \approx 1100$



Two-point correlation maps – all three planes stacked together

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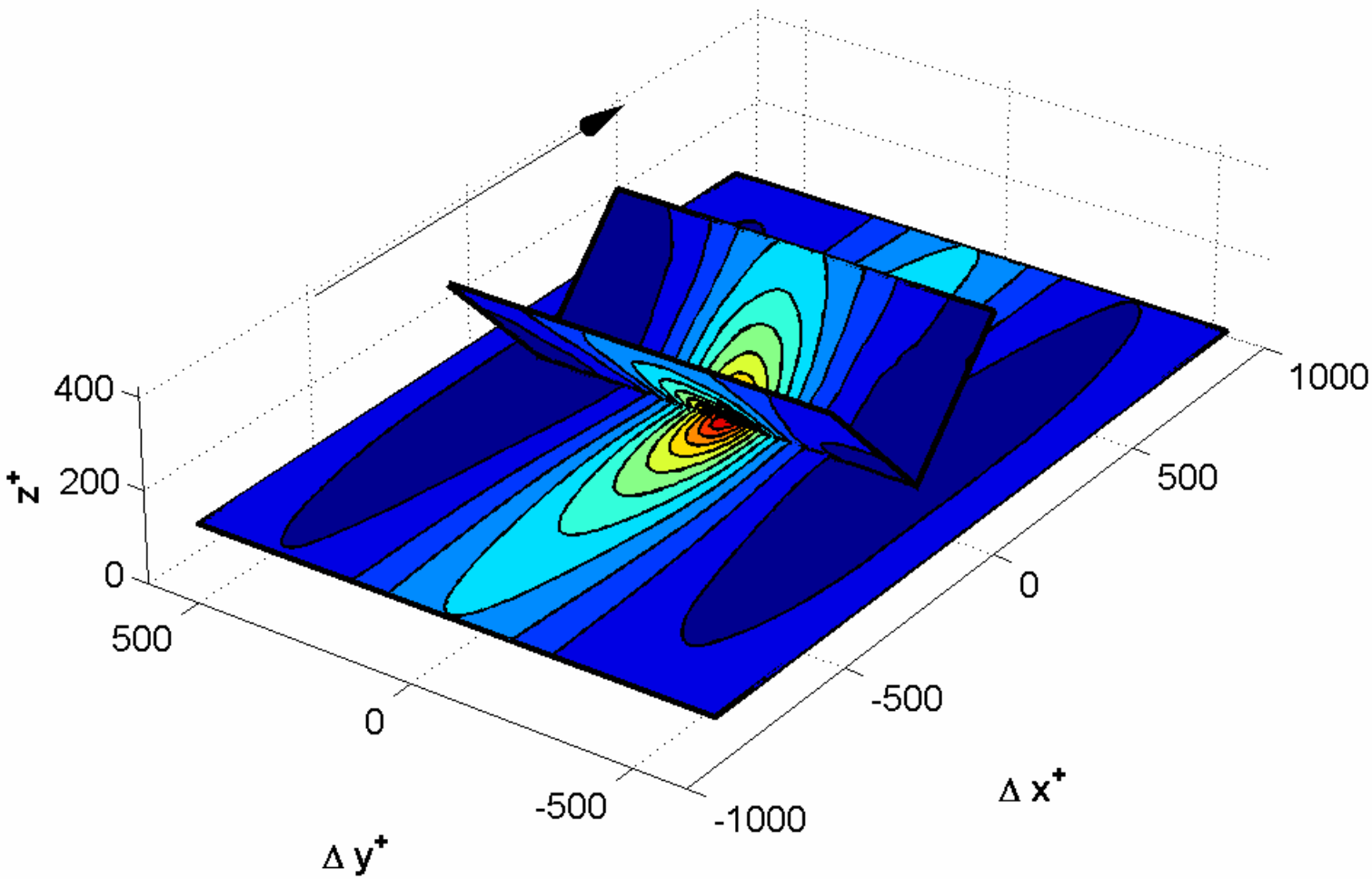

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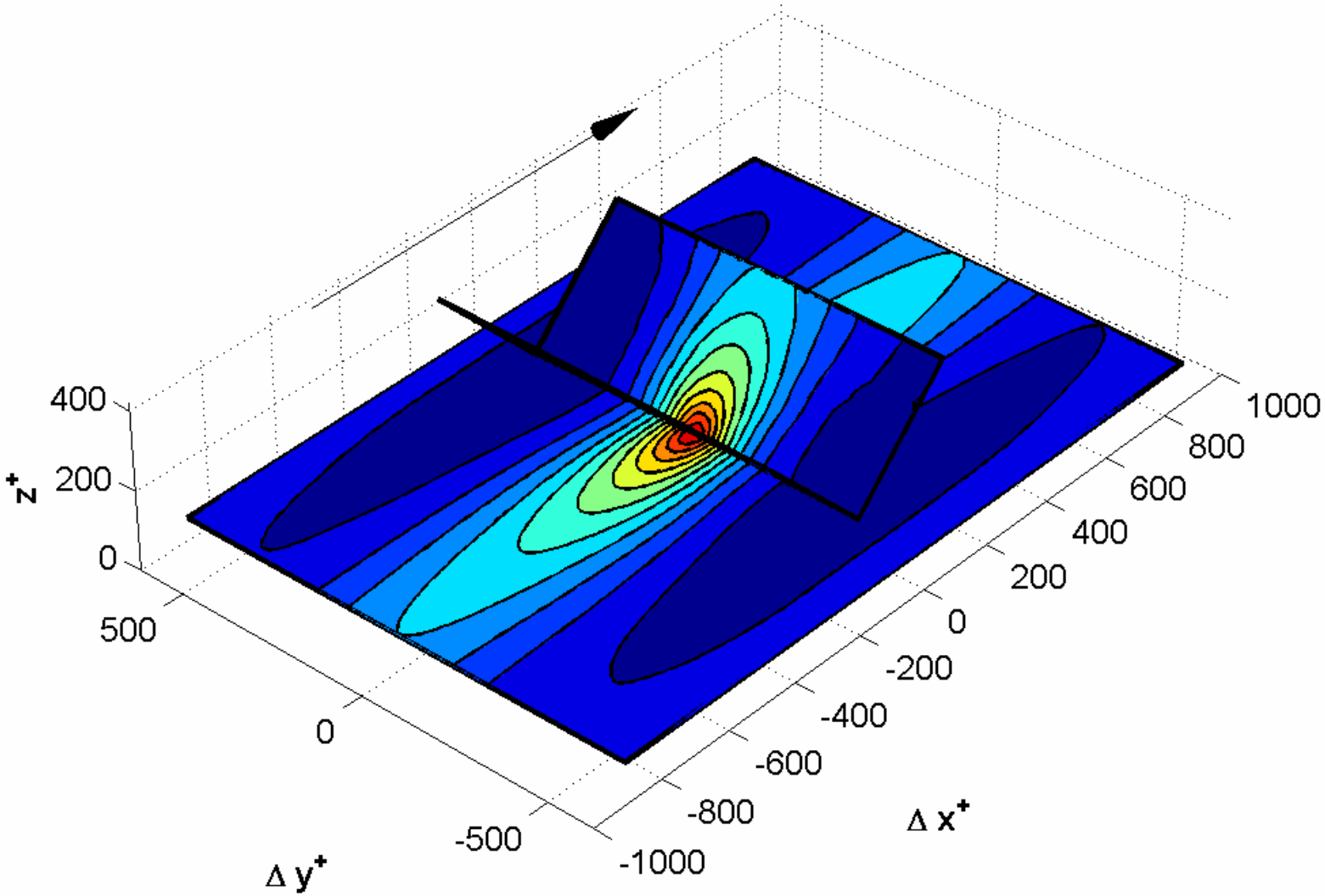

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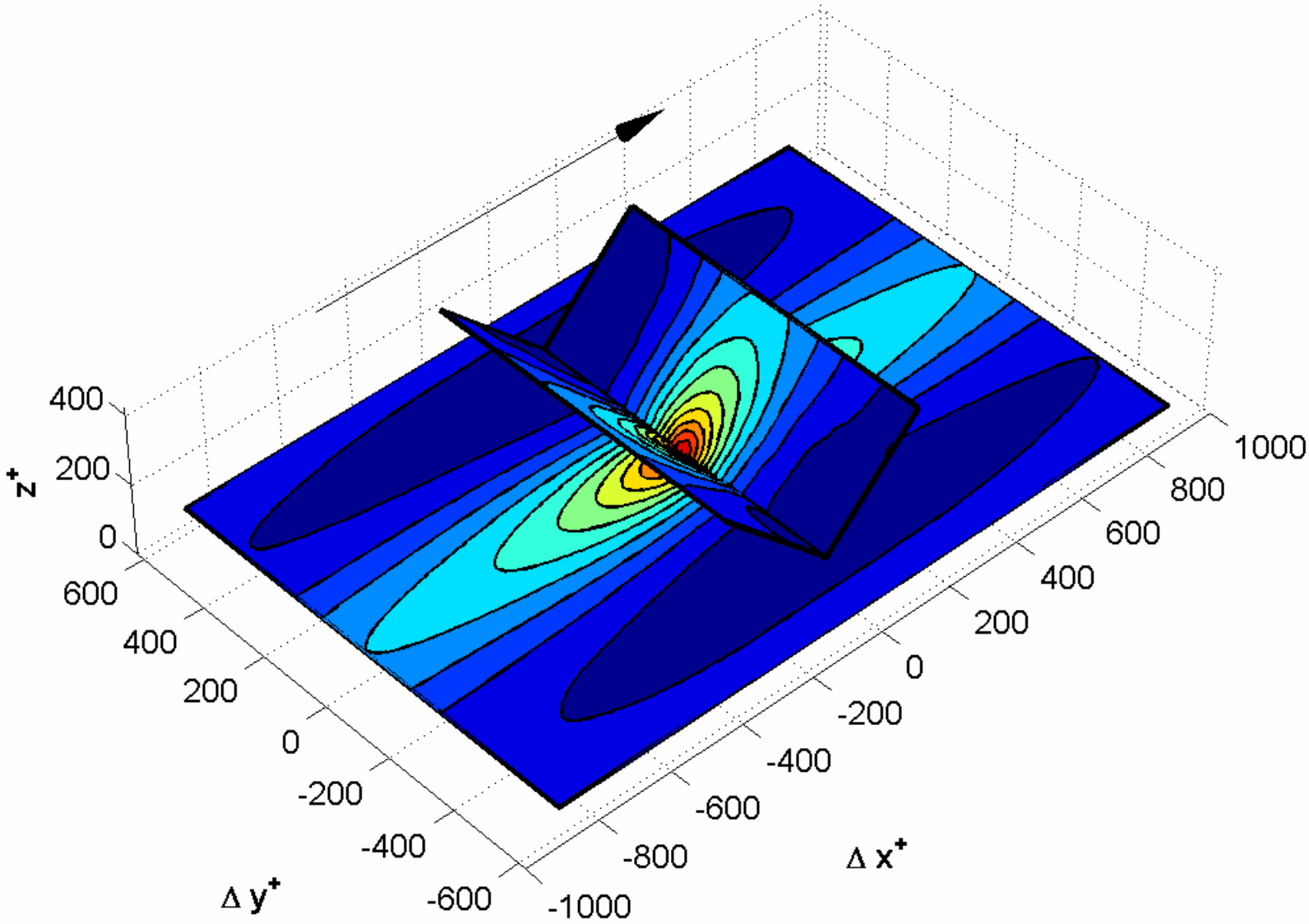

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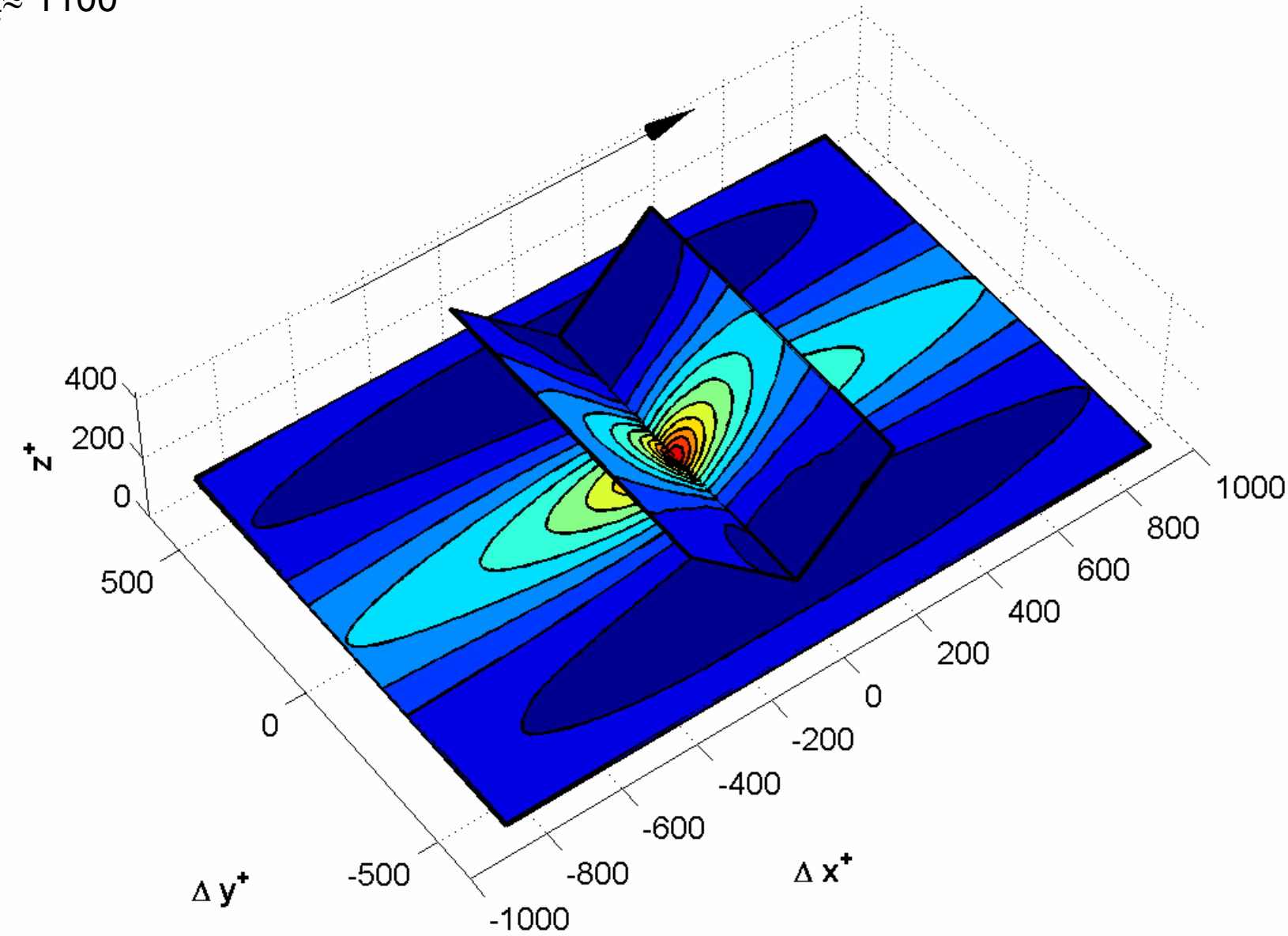

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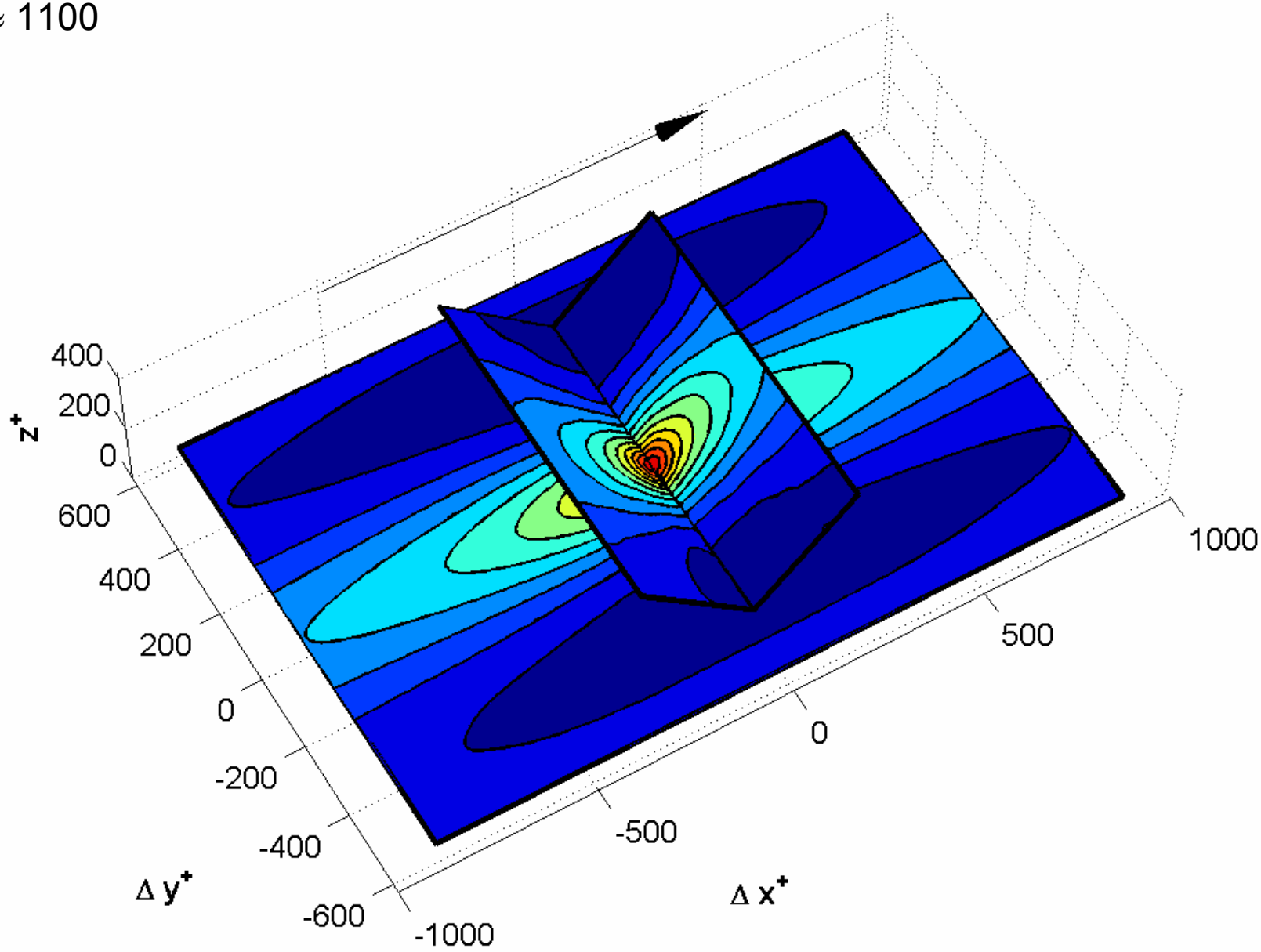

Two-point correlation maps – all three planes stacked together

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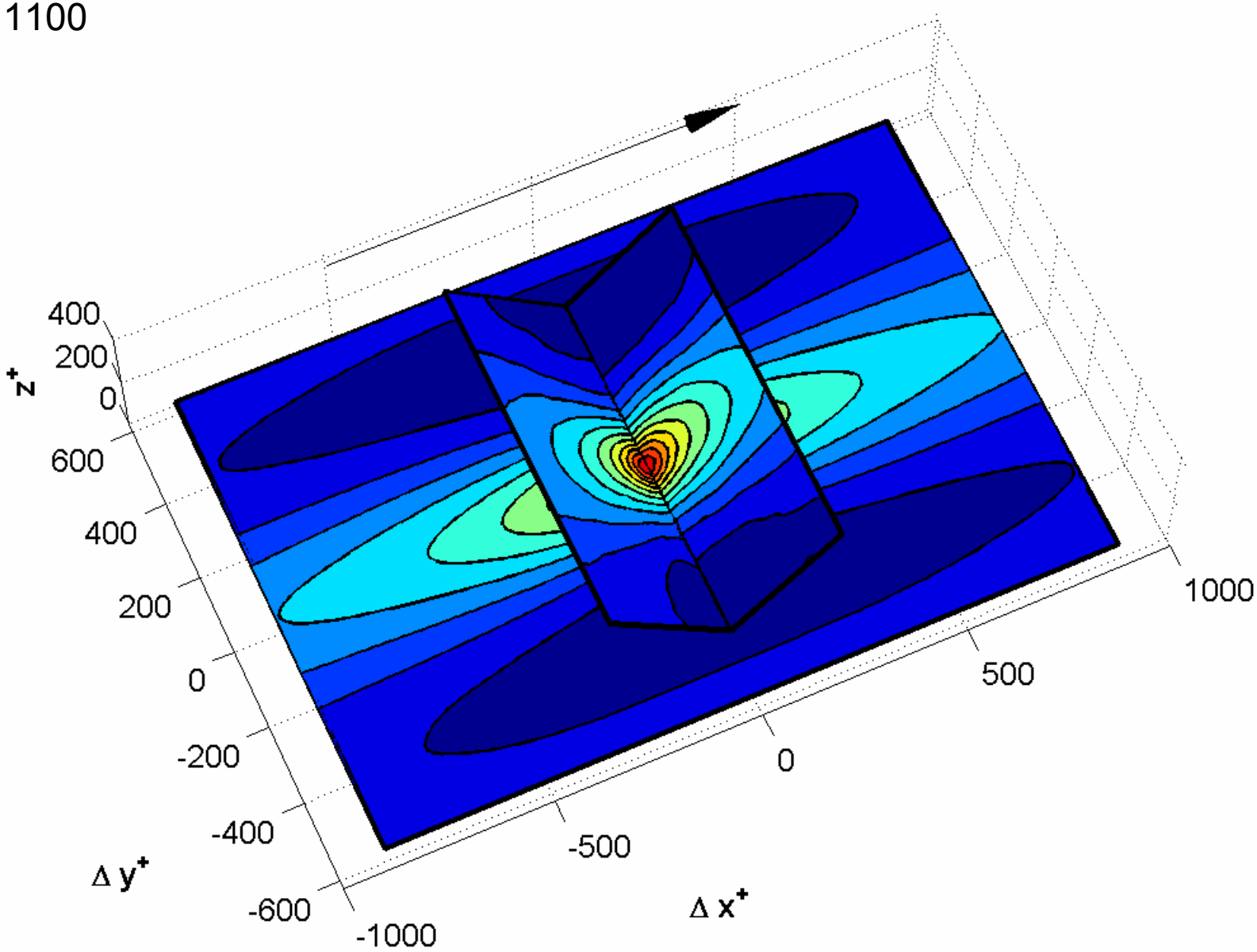
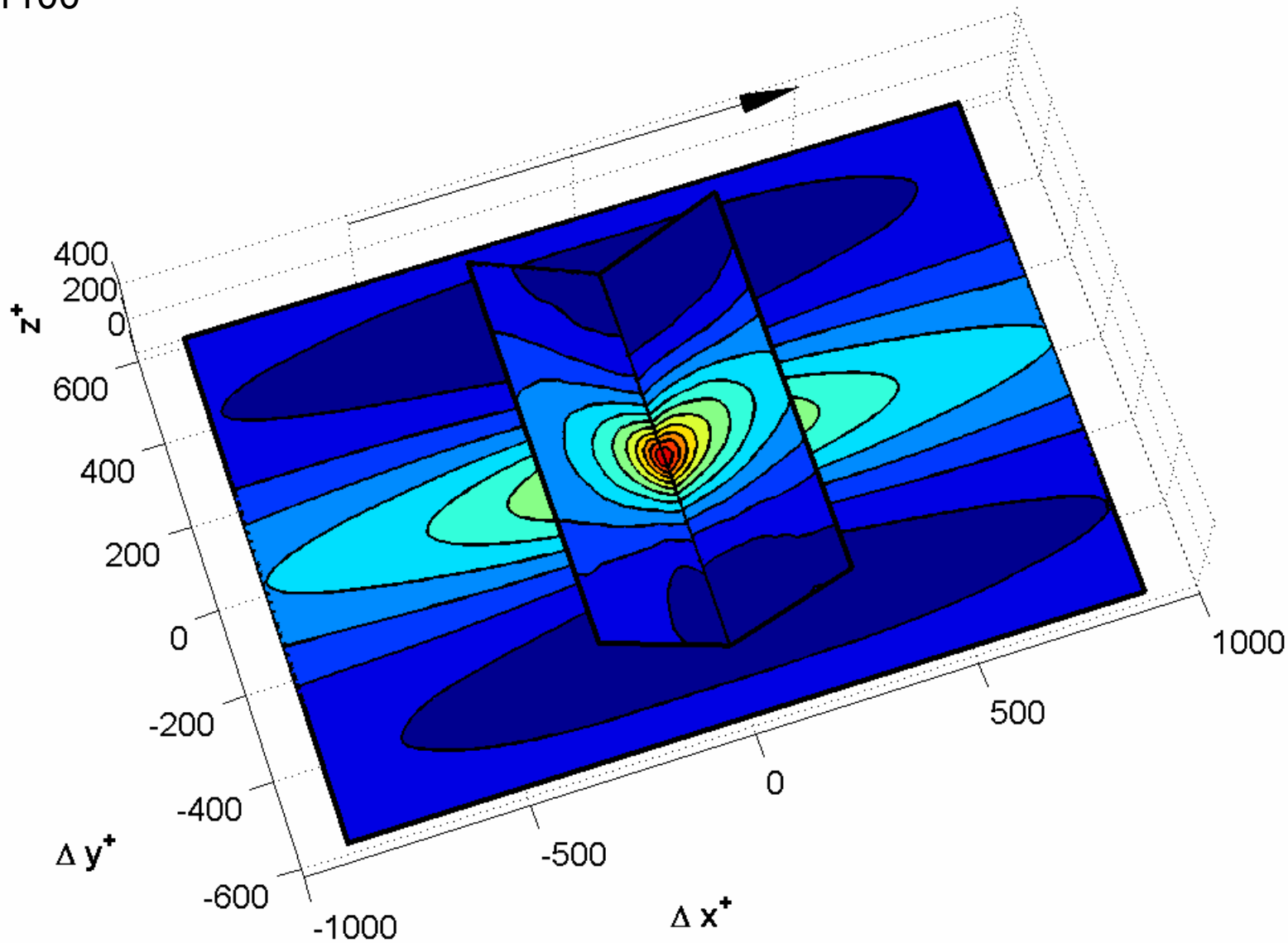


Two-point correlation maps – all three planes stacked together

$Re_\tau \approx 1100$



Two-point correlation maps – all three planes stacked together

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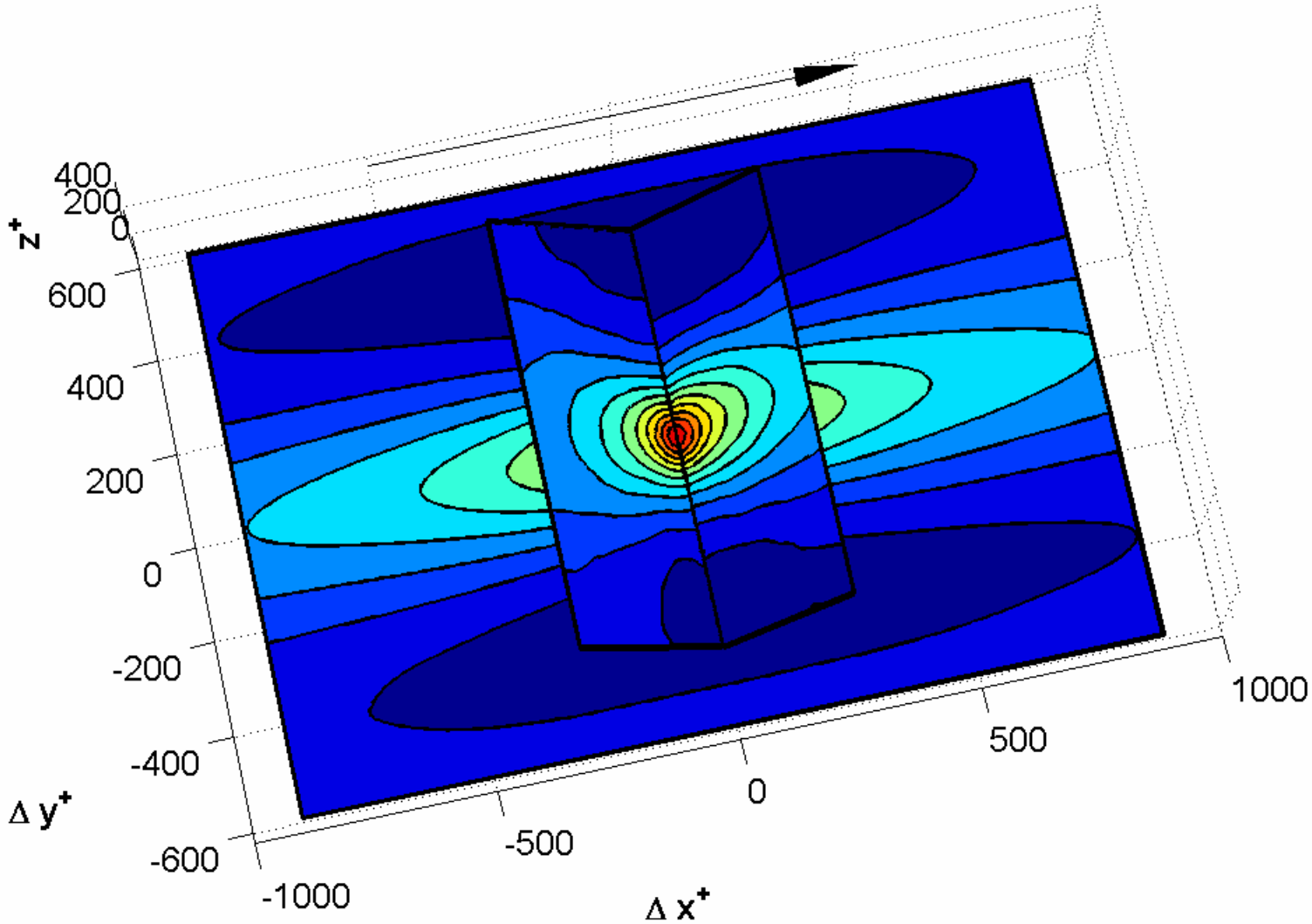

Two-point correlation maps – all three planes stacked together

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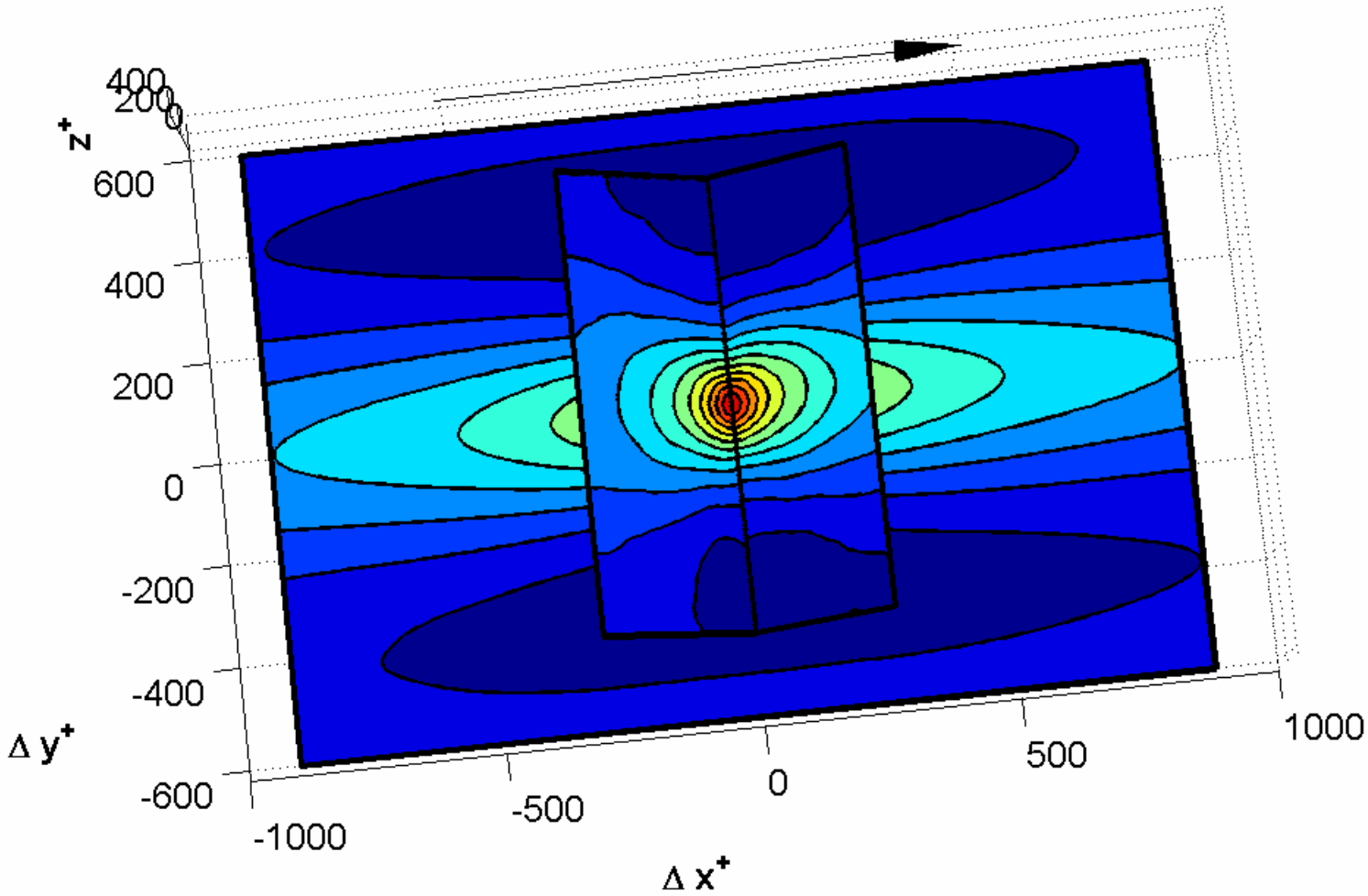

Two-point correlation maps – all three planes stacked together

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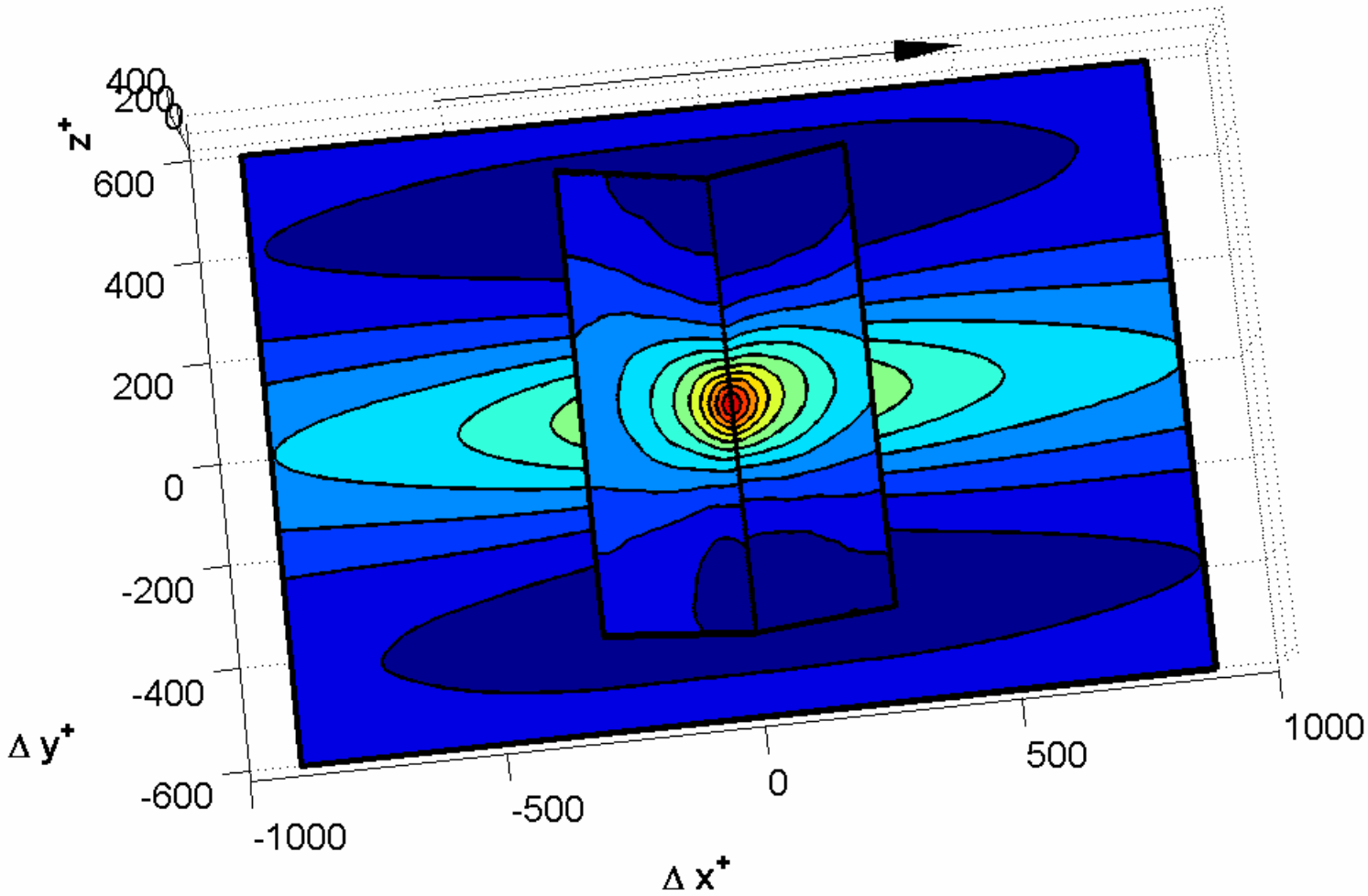

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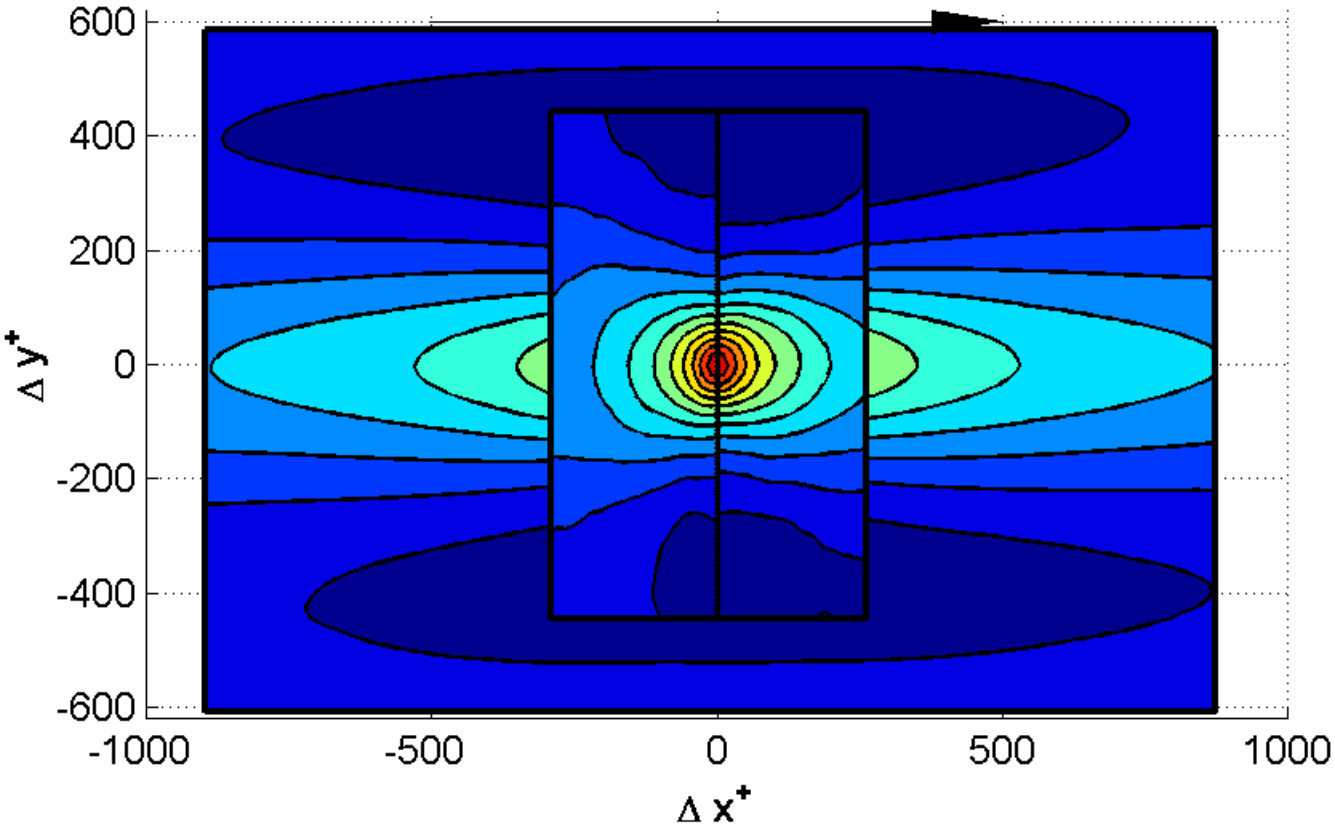

Two-point correlation maps – all three planes stacked together

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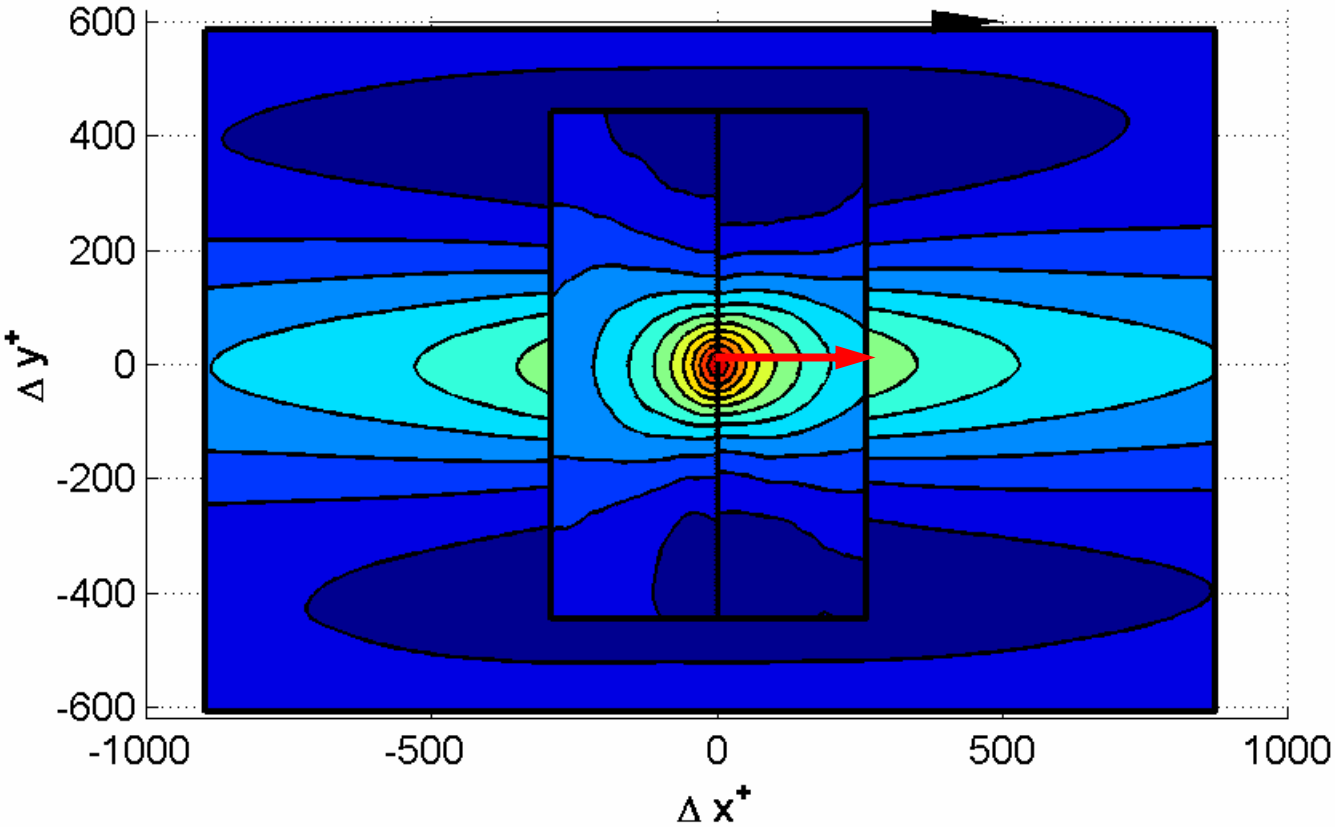
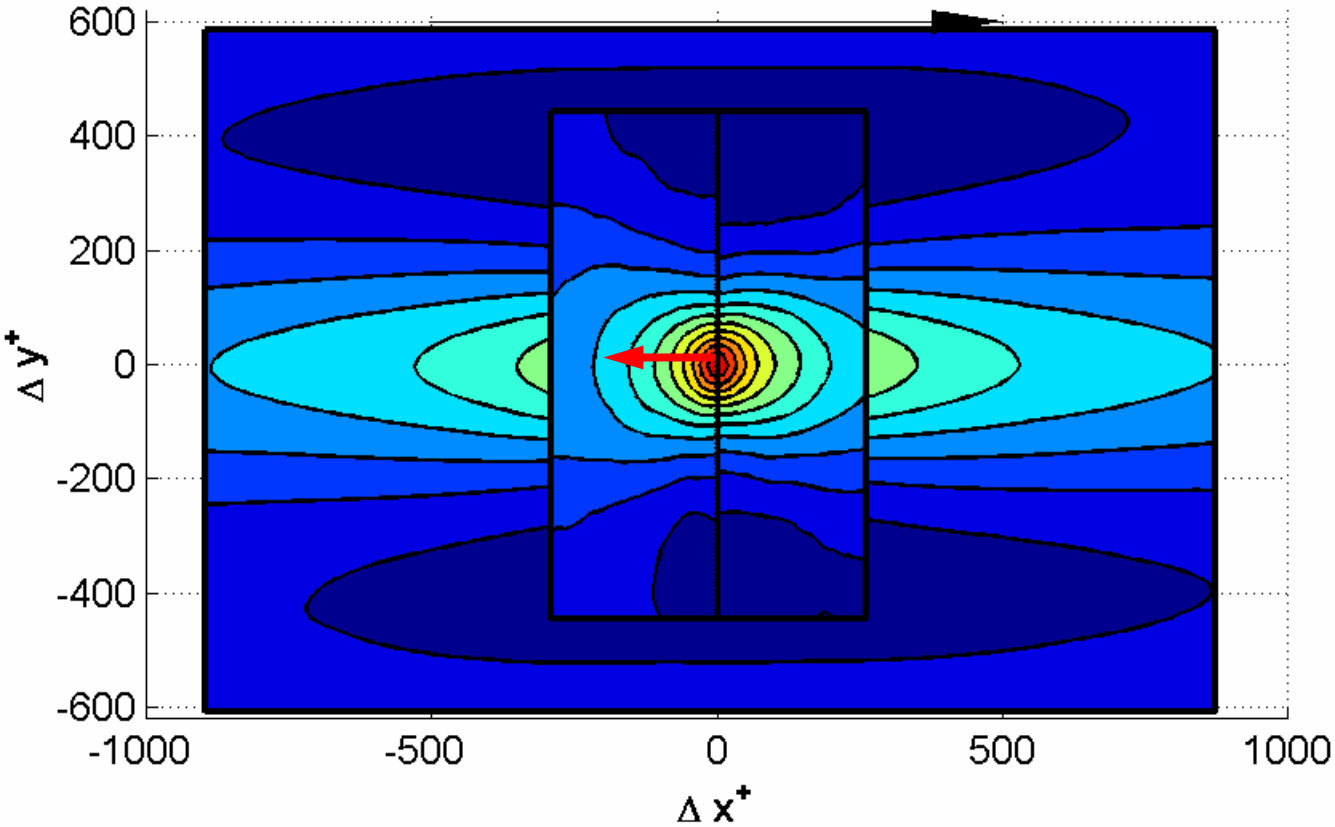


Note: positive correlations extend further in the z′ direction for the **45°** than for the 135° case

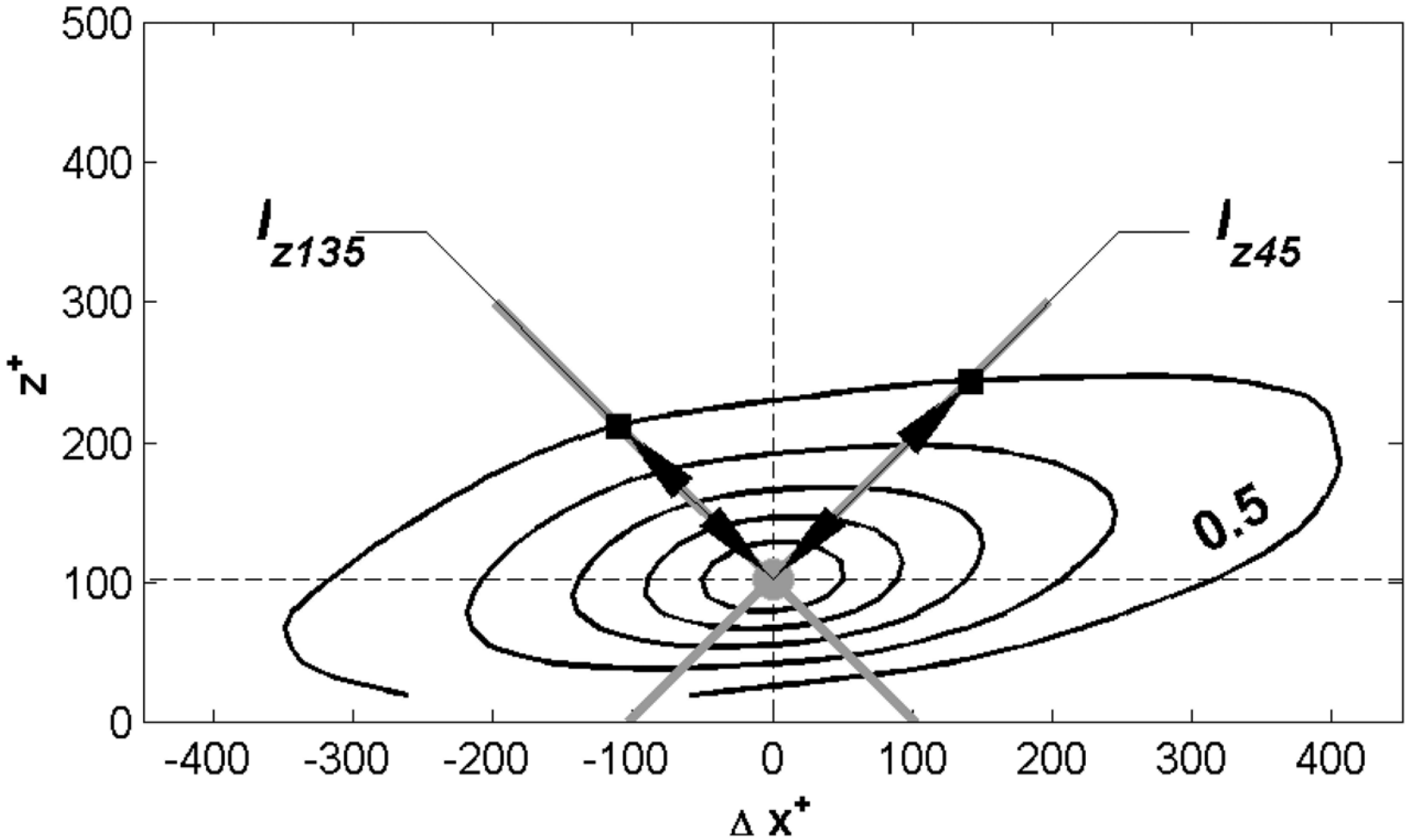
Two-point correlation maps – all three planes stacked together

$Re_\tau \approx 1100$

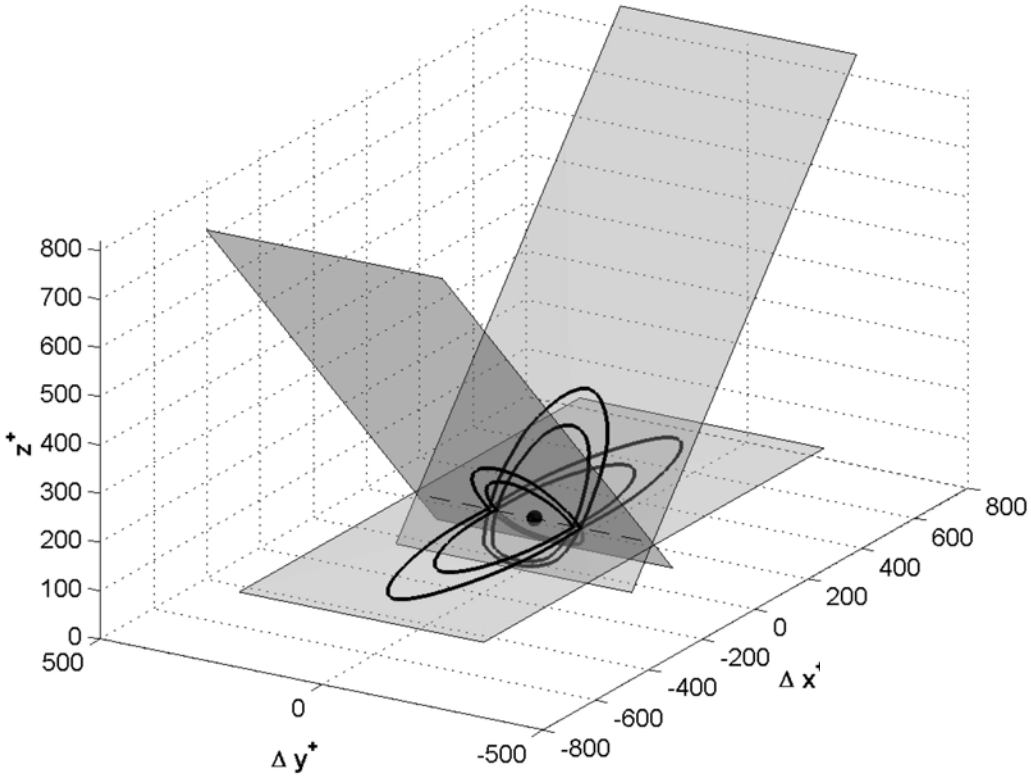


Note: positive correlations extend further in the z′ direction for the 45° than for the **135°** case

This is due to inclined nature of the large-scale events

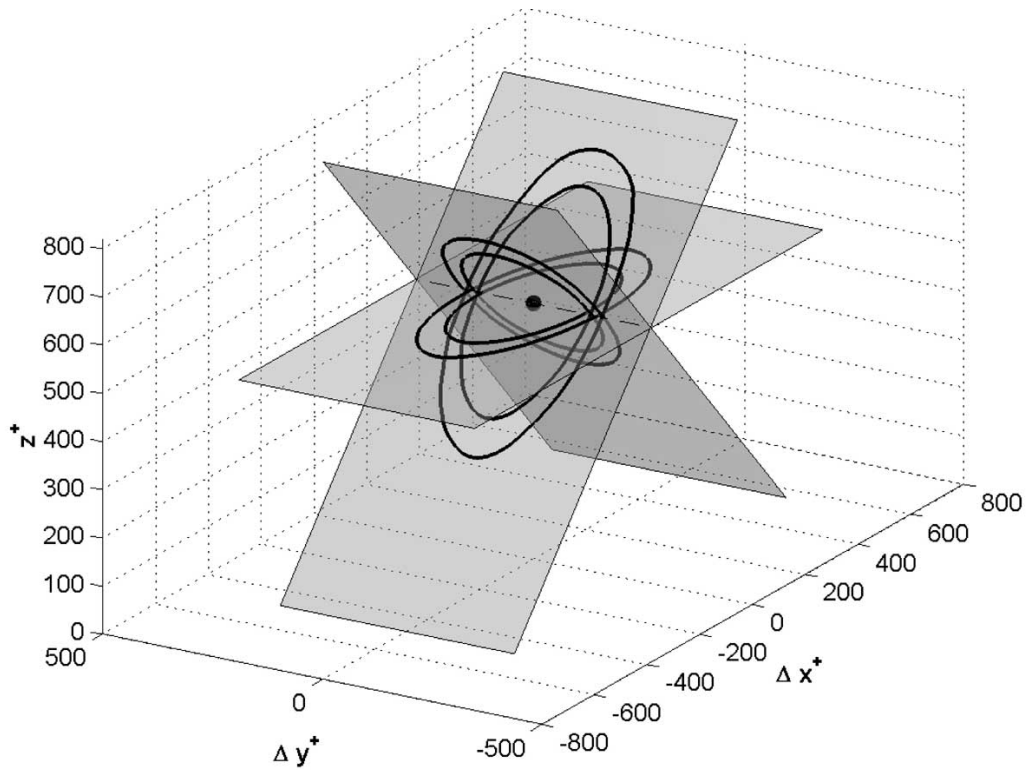


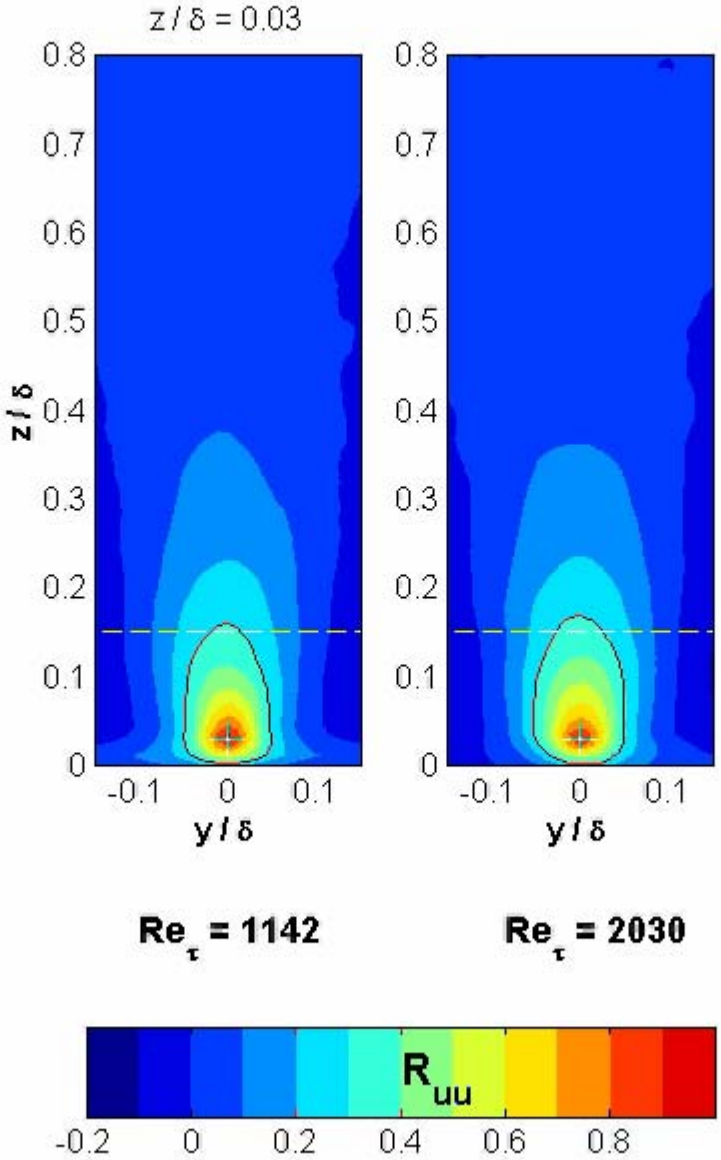
Christensen's two-point correlations from streamwise / wall-normal plane PIV measurements

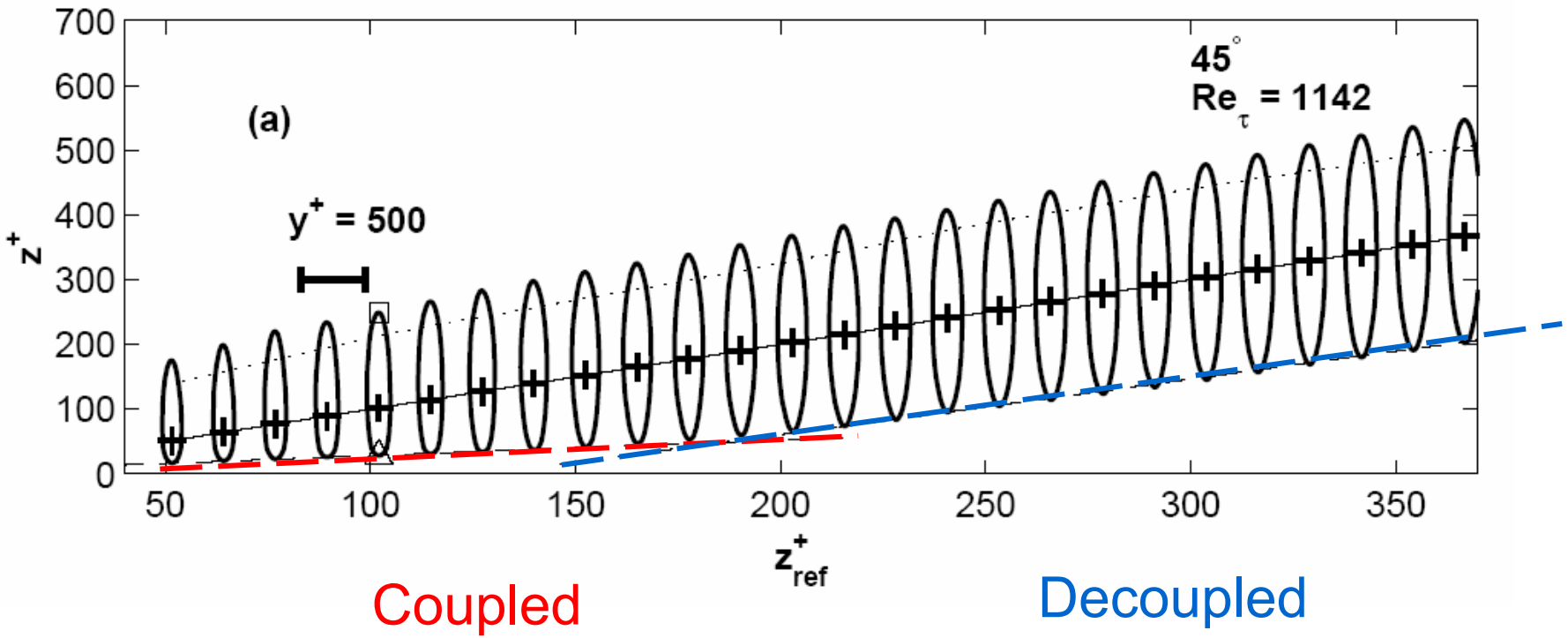


$z^+ = 92$

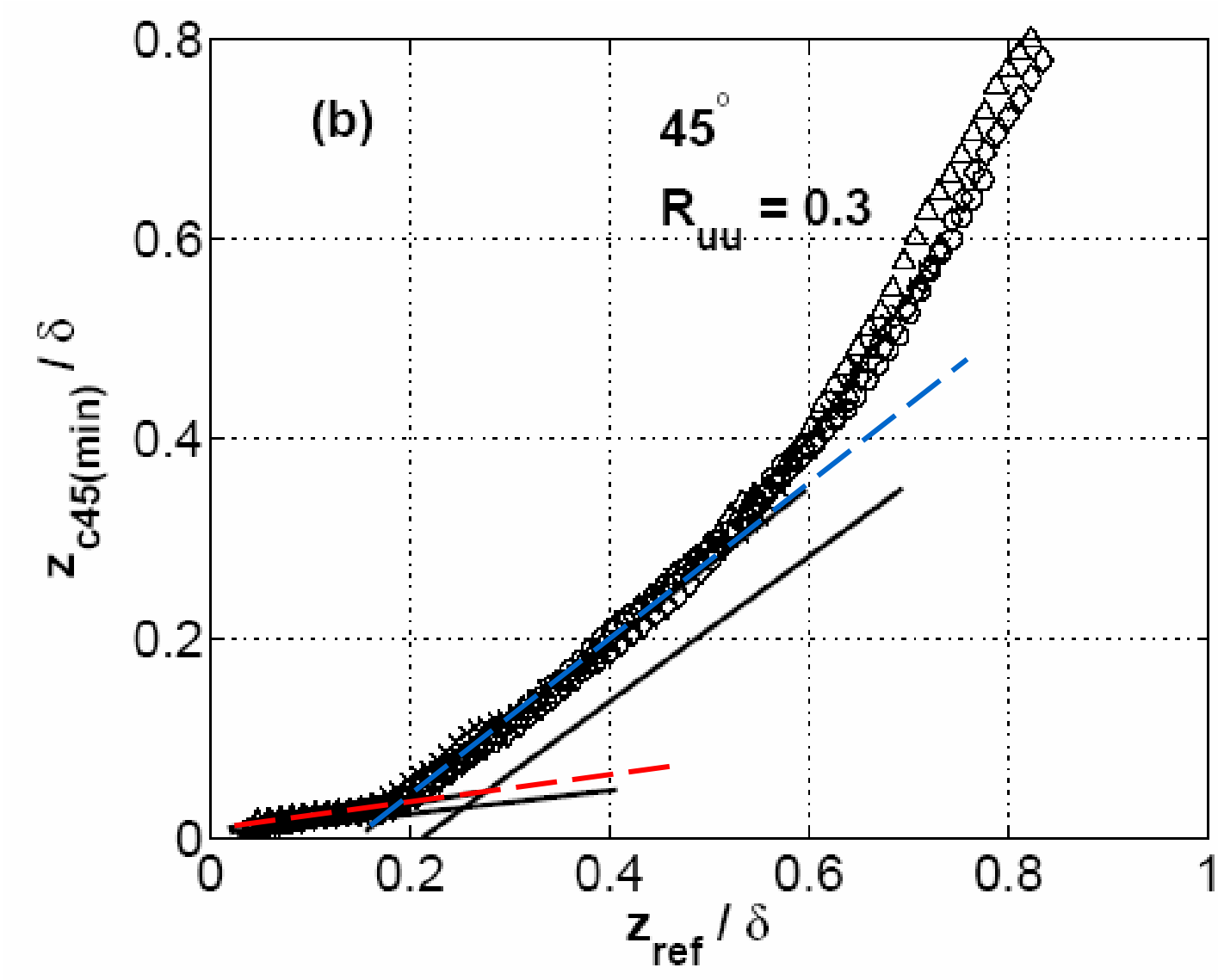
$z/\delta = 0.5$

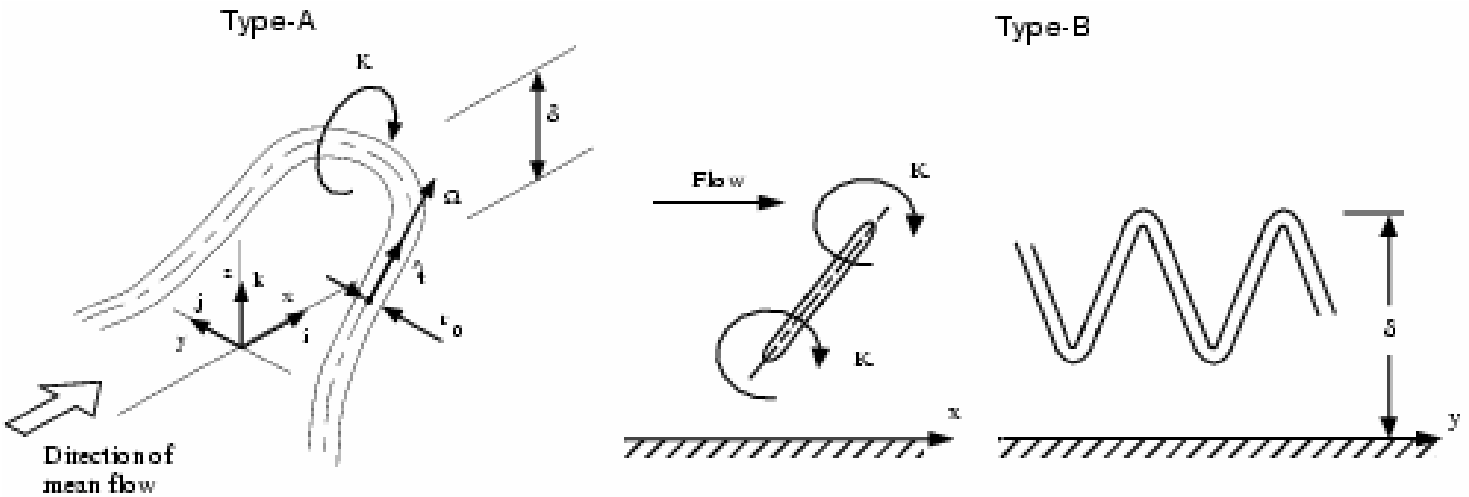



z / δ = 0.03
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
z / δ
-0.1
0
0.1
y / δ
Re_τ = 1142
Re_τ = 2030
R_uu
-0.2
0
0.2
0.4
0.6
0.8

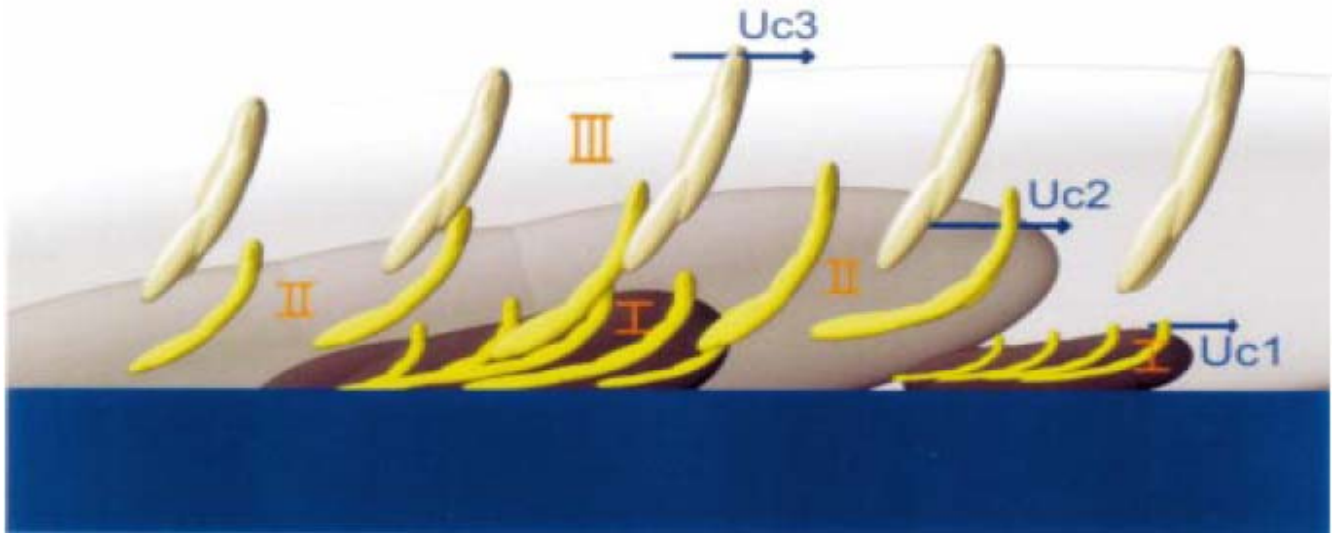

(a)
45°
Re_τ = 1142
y+ = 500
z+
z+ref
0
100
200
300
400
500
600
700
50
100
150
200
250
300
350
Coupled
Decoupled

Re_τ = 790, 1140, 2030, 3071





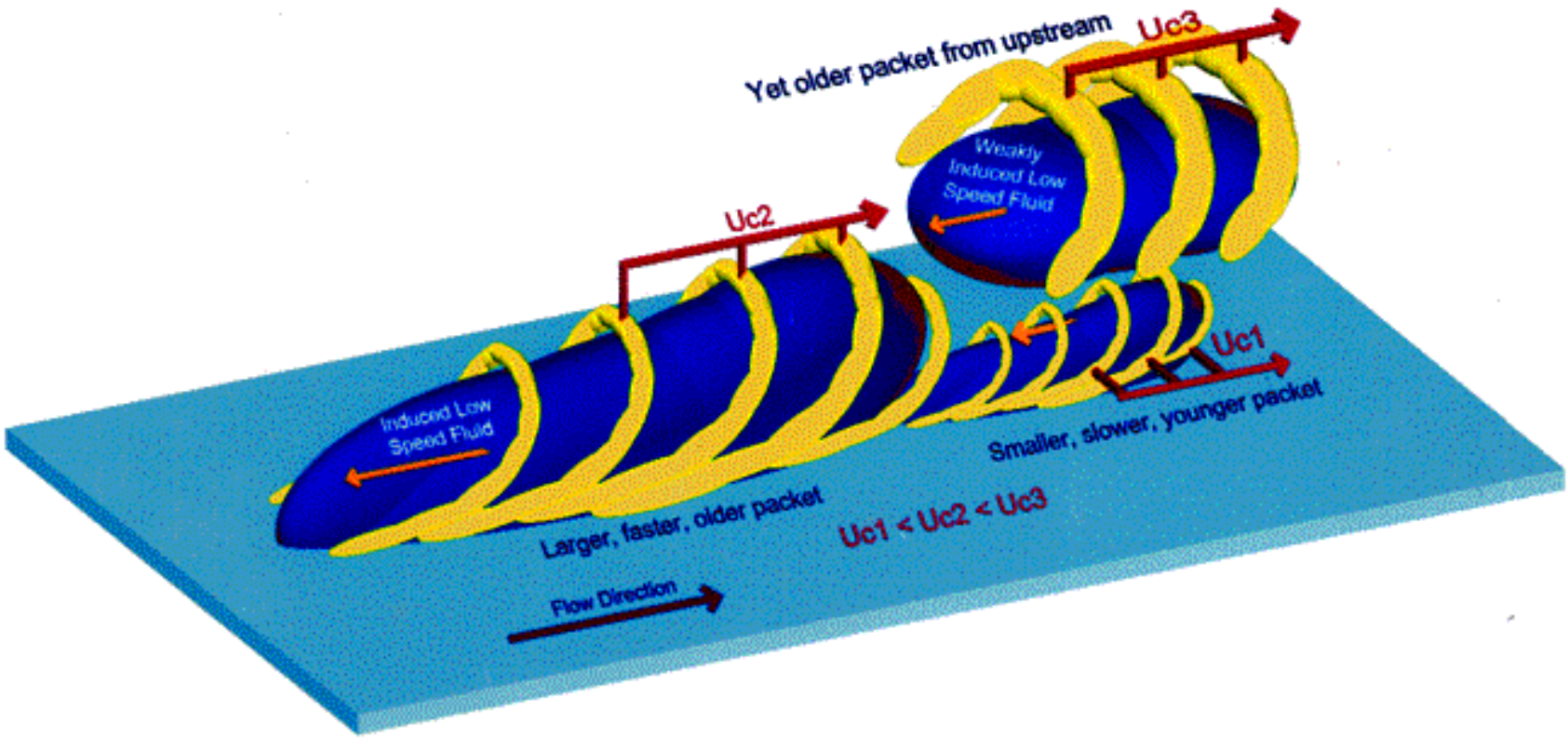
Marusic & Perry (1995)



Adrian, Meinhart & Tomkins (2000)

All of the above is consistent with the scenario of

packets of hairpin vortices

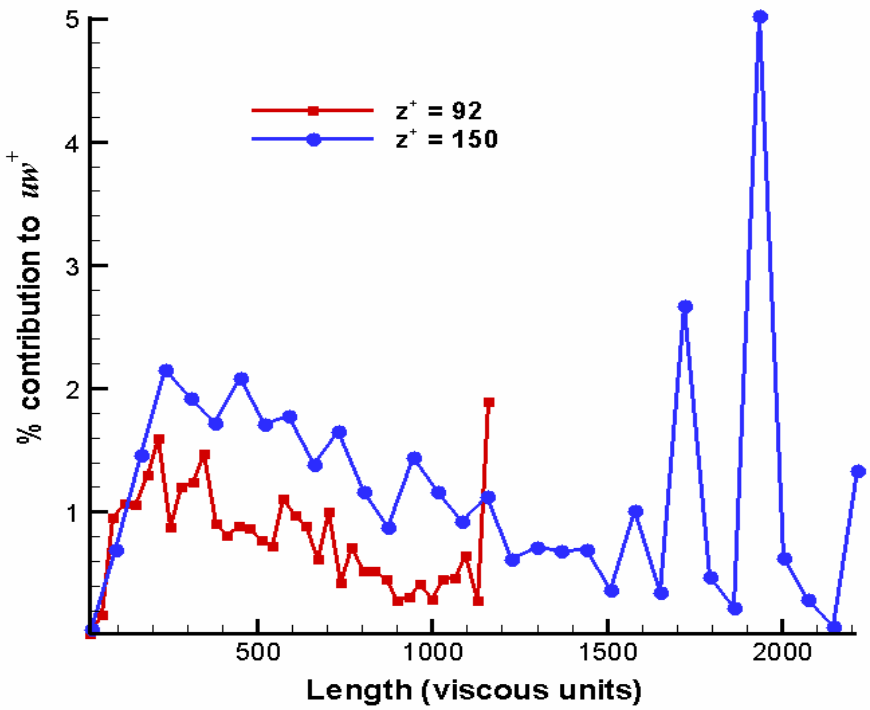


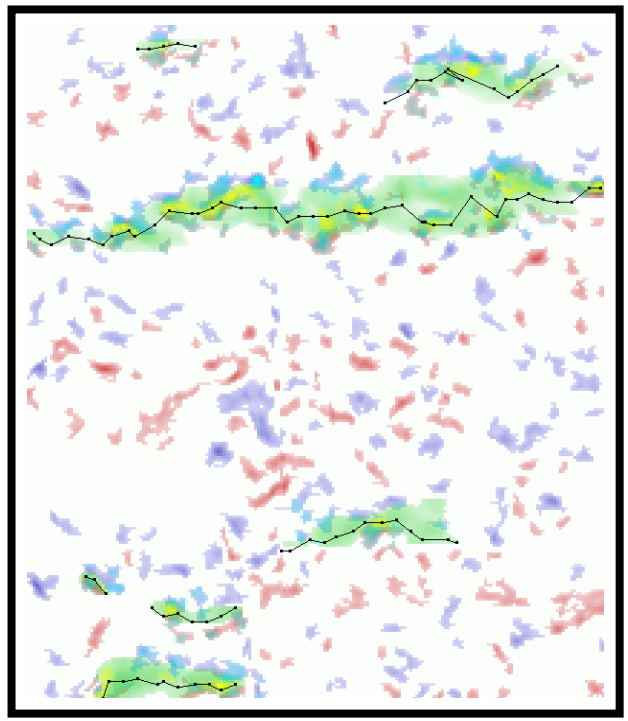
Adrian, Meinhart & Tomkins (2000)

Instantaneous wall-parallel plane data

Automated feature-extraction algorithm

Ganapathisubramani, Longmire and Marusic, JFM 2003

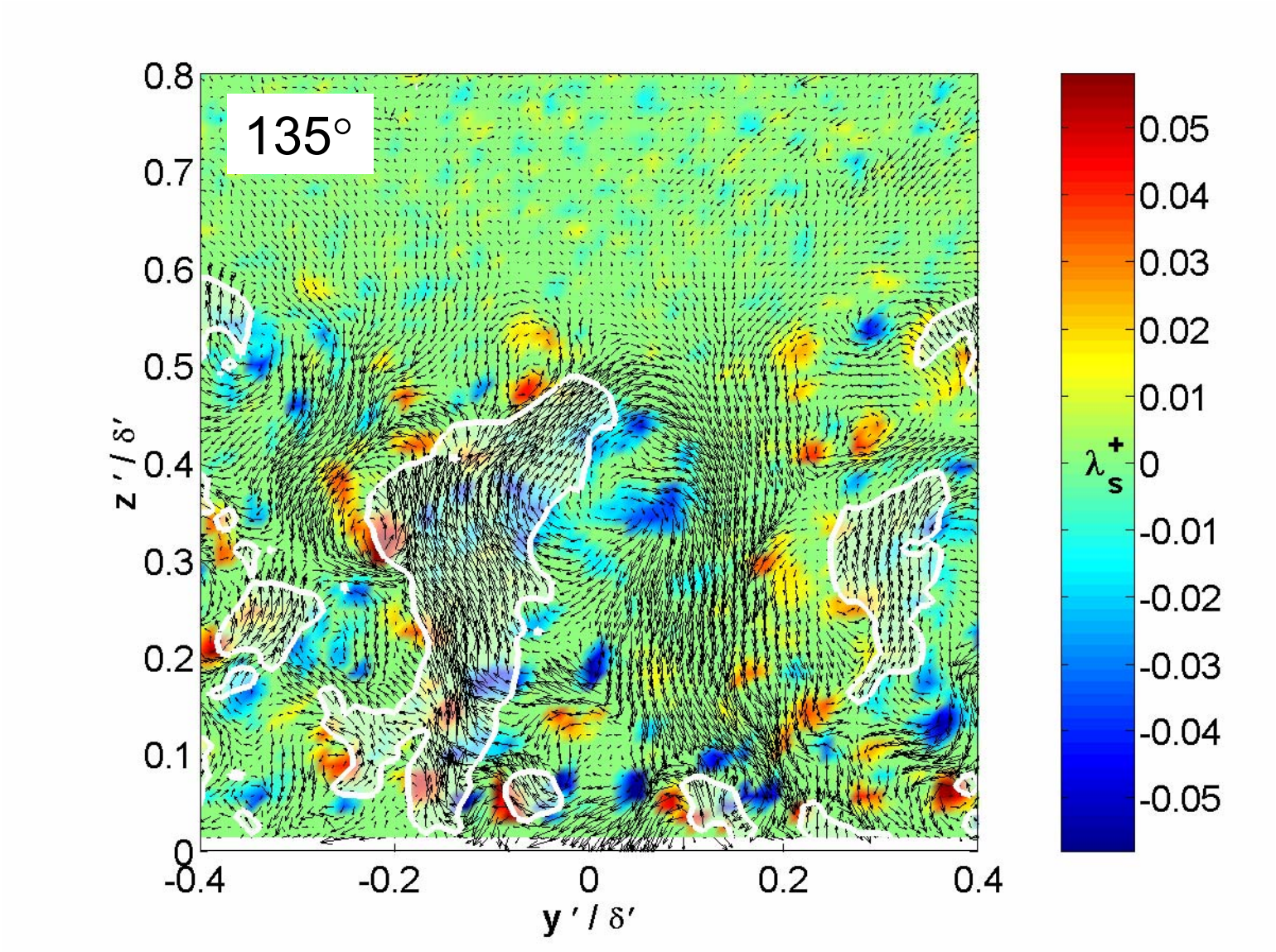




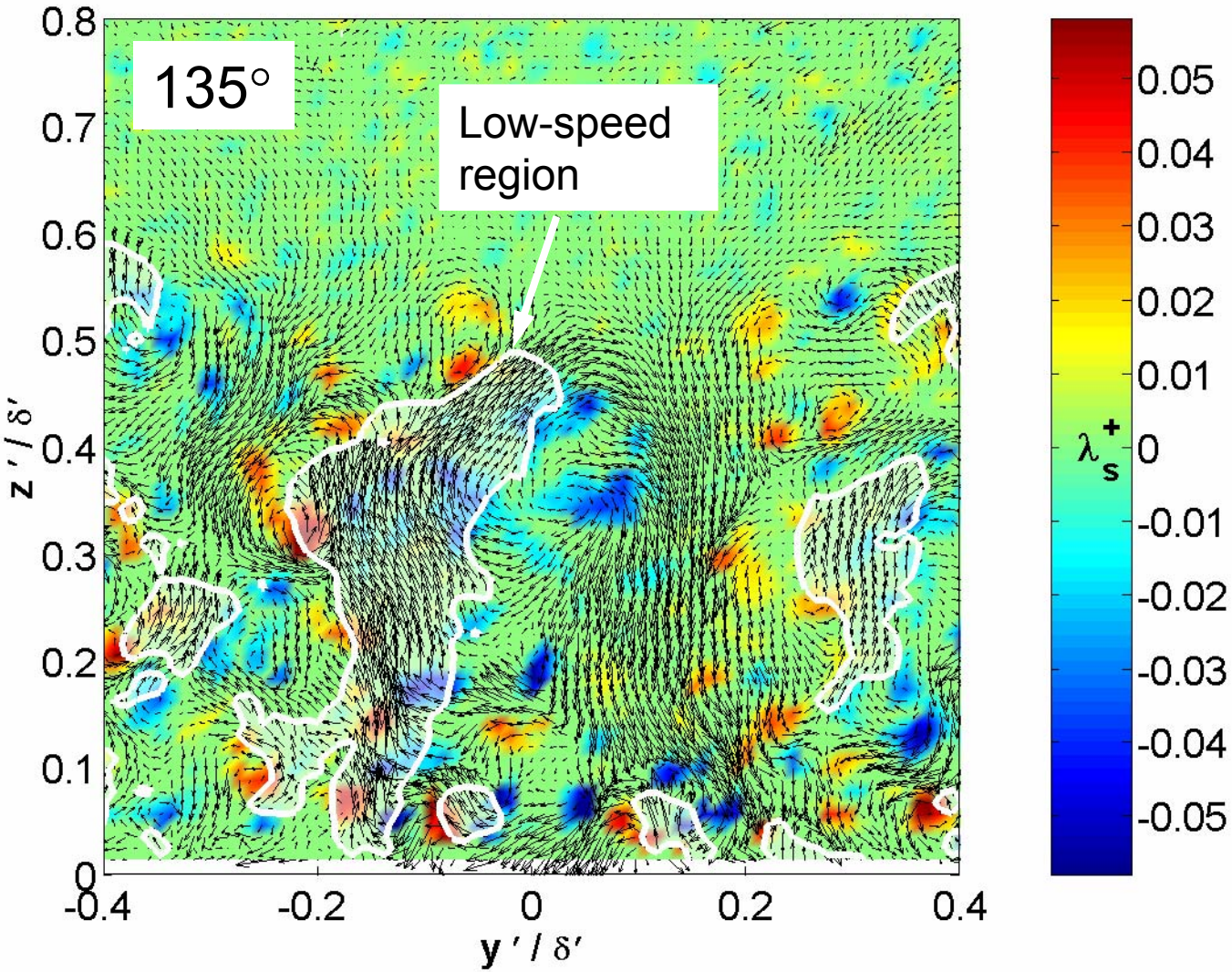
- $z^+ = 92$: packets contribute 27% of <-*uw*>, occupy 4% of area
- $z^+ = 150$: packets contribute 24% of <-*uw*>, occupy 4.5% of area

NB: positive and negative *uw* included in %

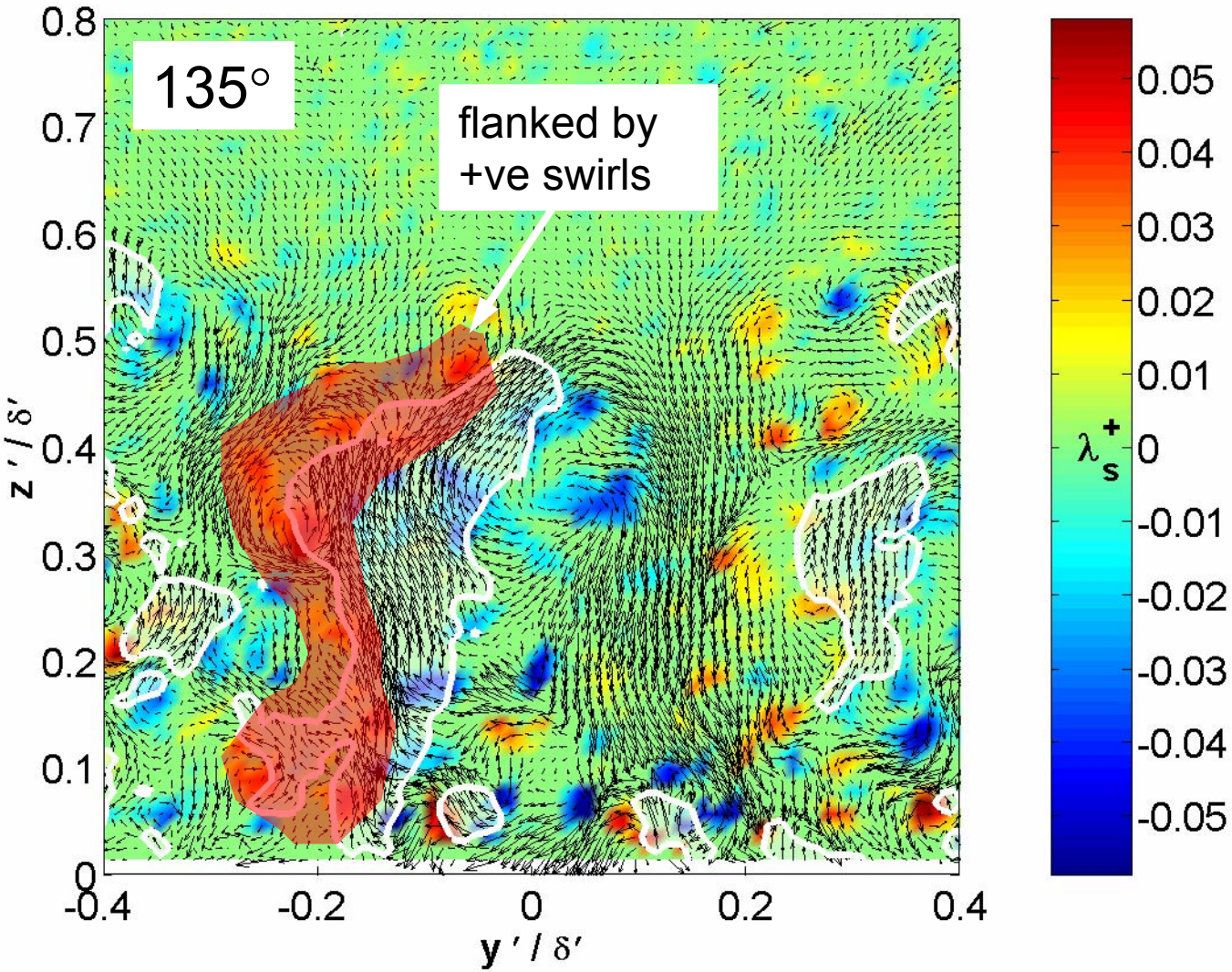
Instantaneous swirl result - 135° plane



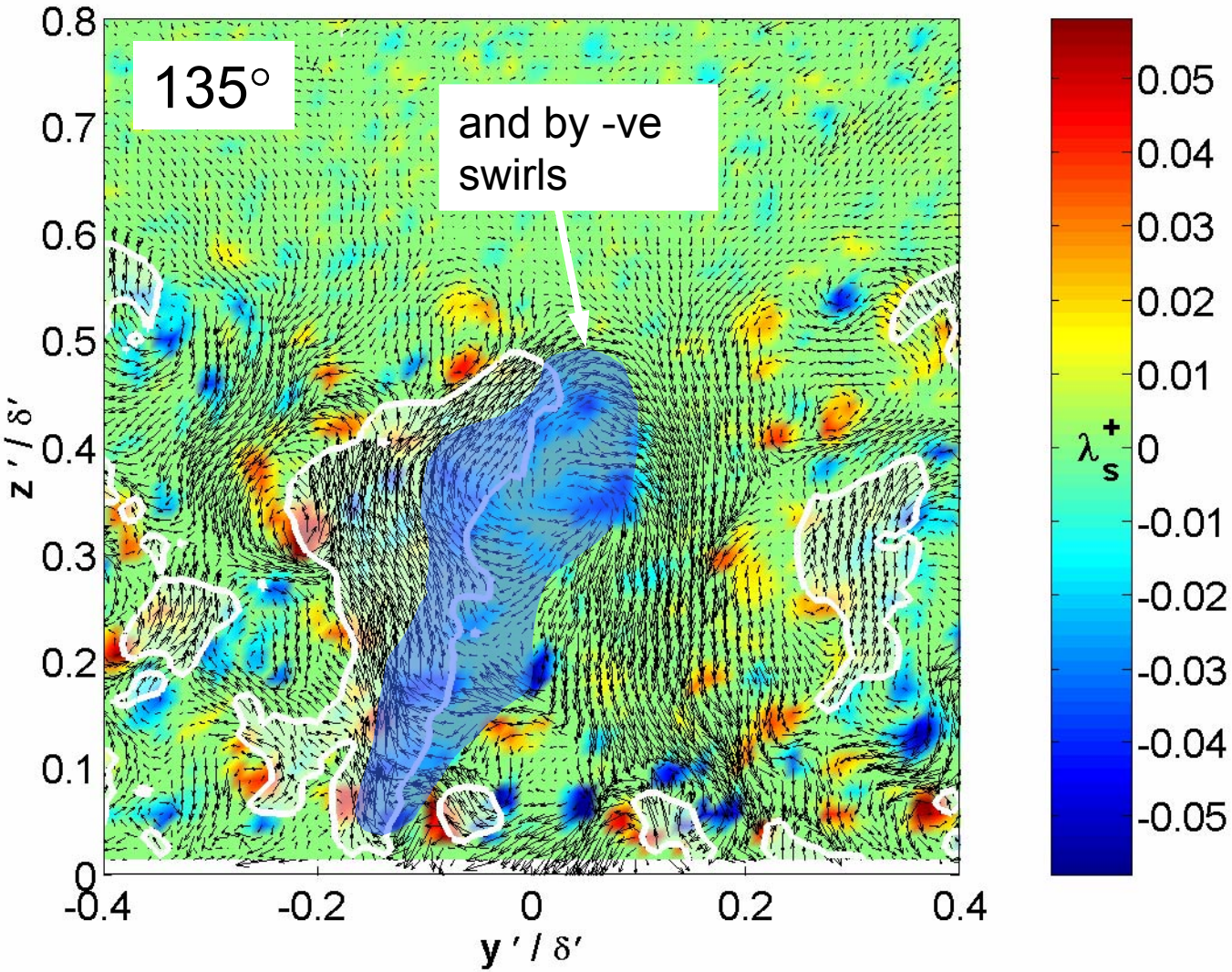
Instantaneous swirl result - 135° plane



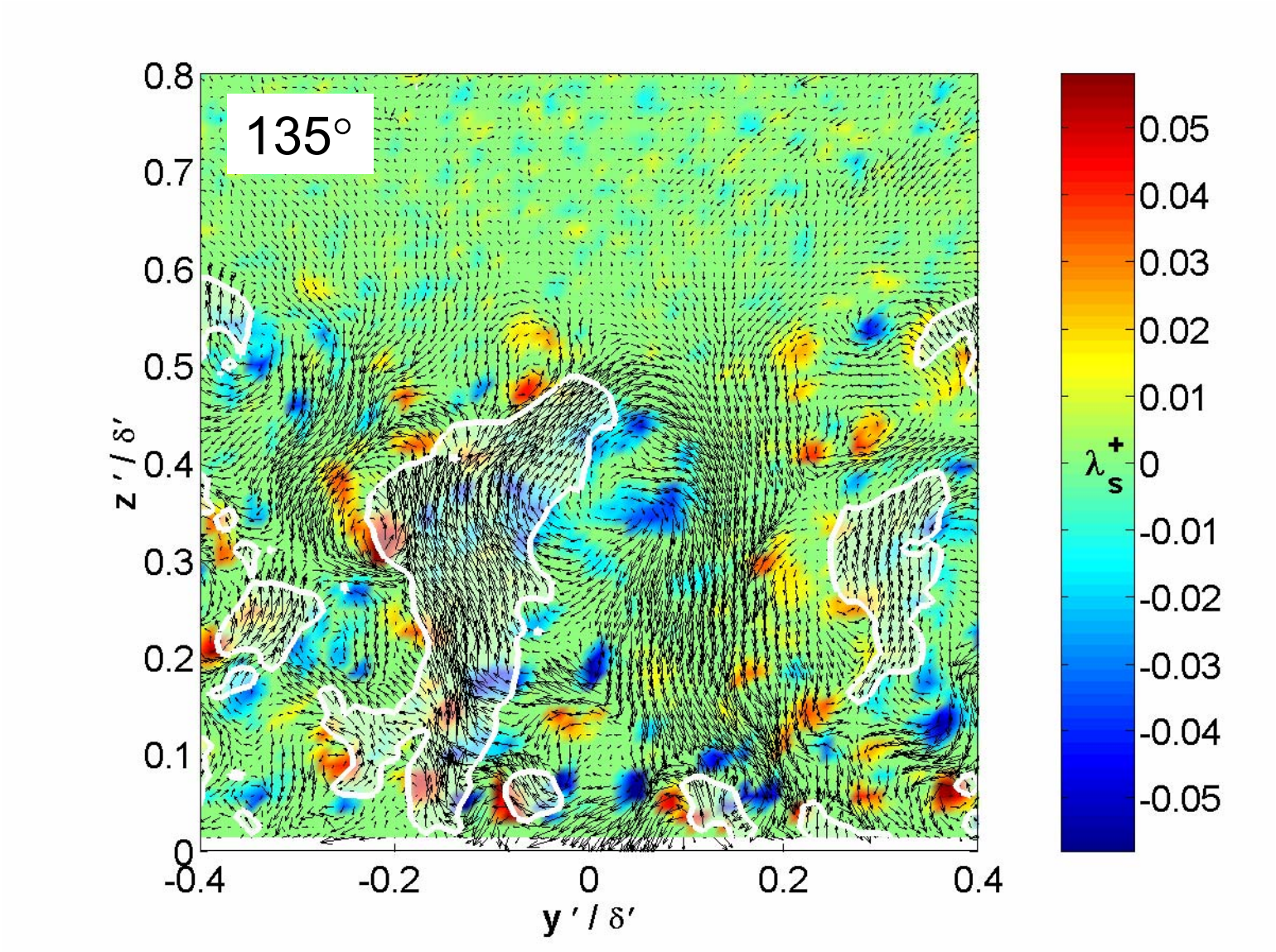
Instantaneous swirl result - 135° plane



Instantaneous swirl result - 135° plane

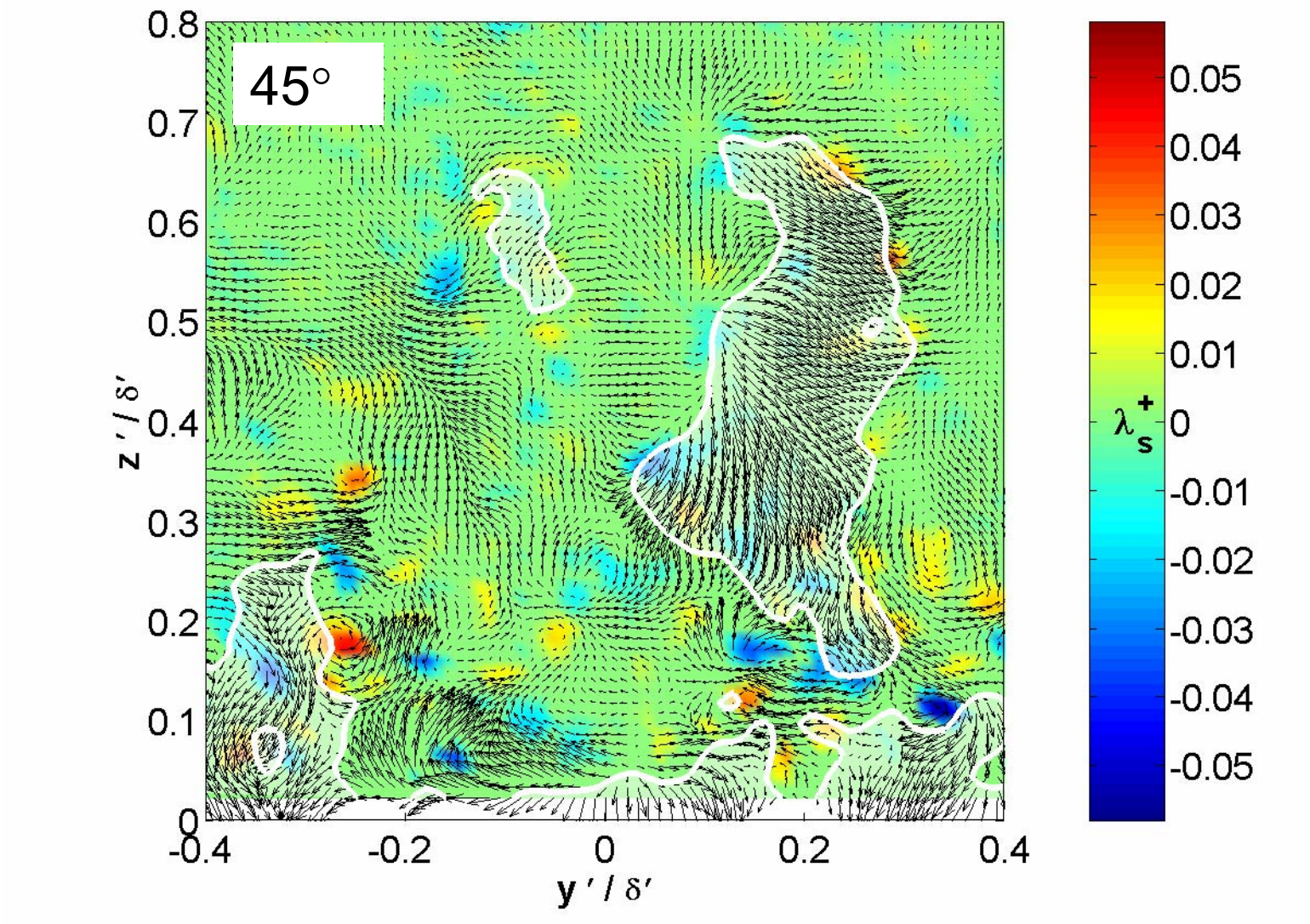


Instantaneous swirl result - 135° plane

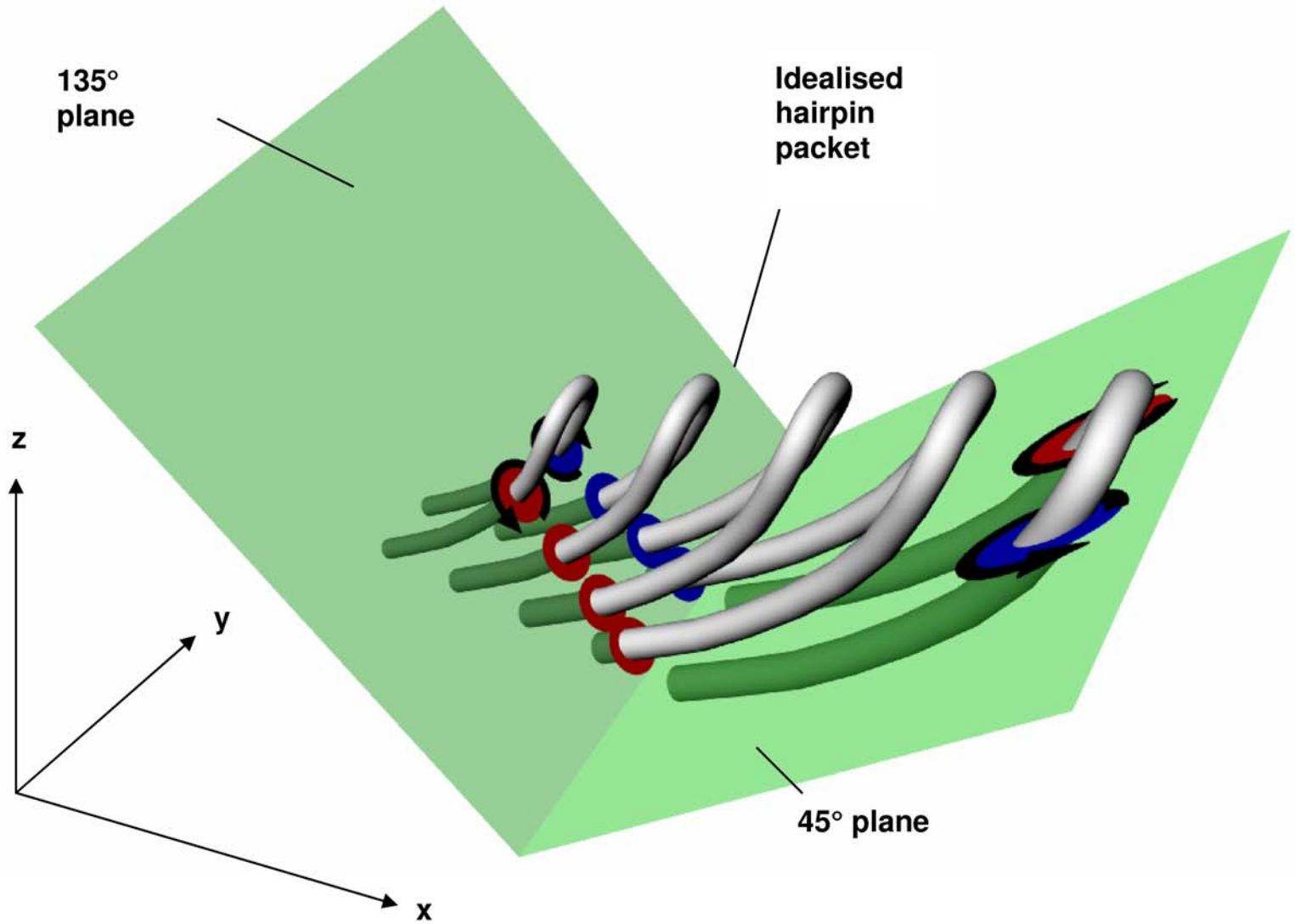


Instantaneous swirl result - 45° plane

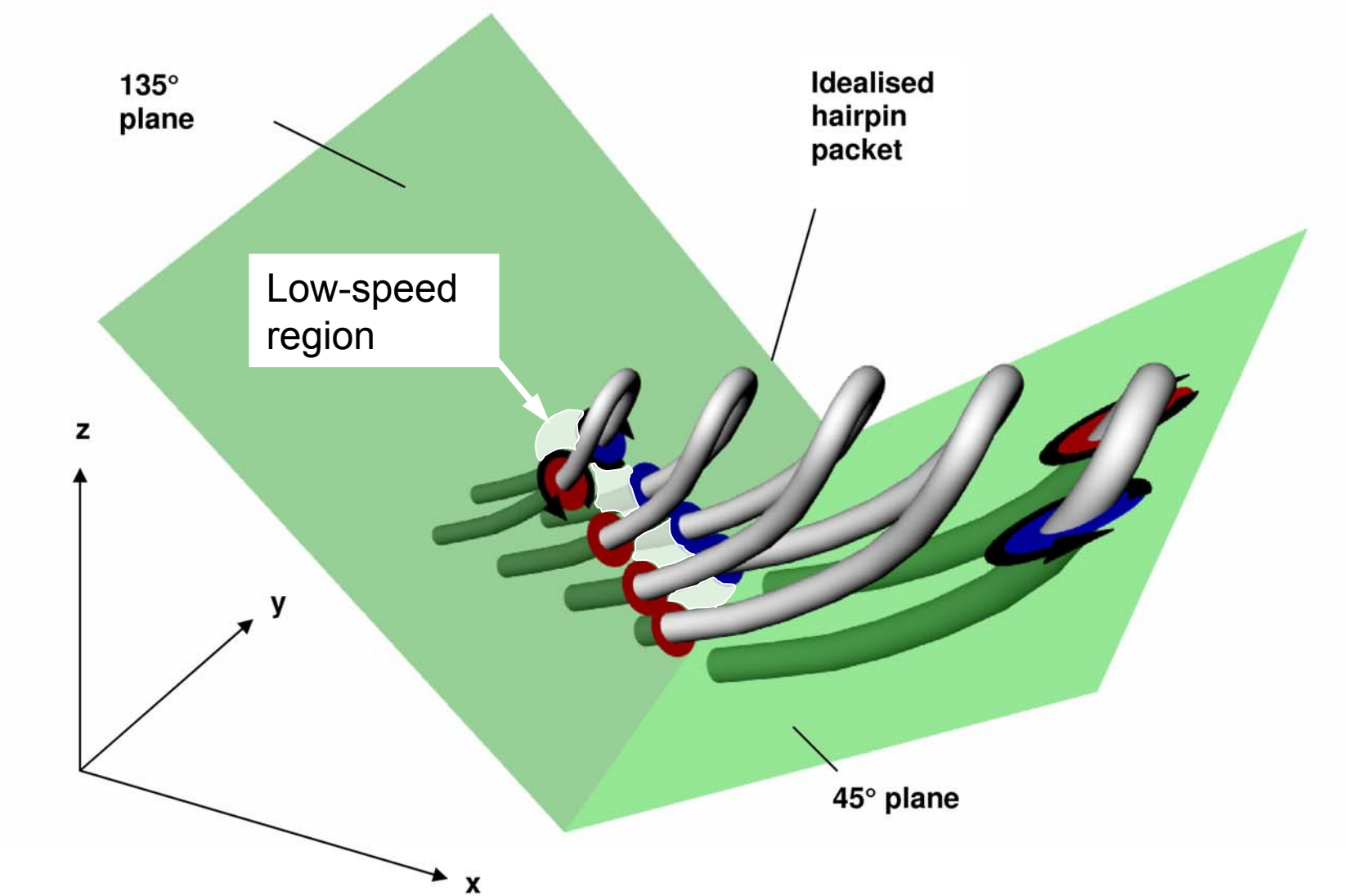
Note: decreased occurrence of swirl over the 135° plane



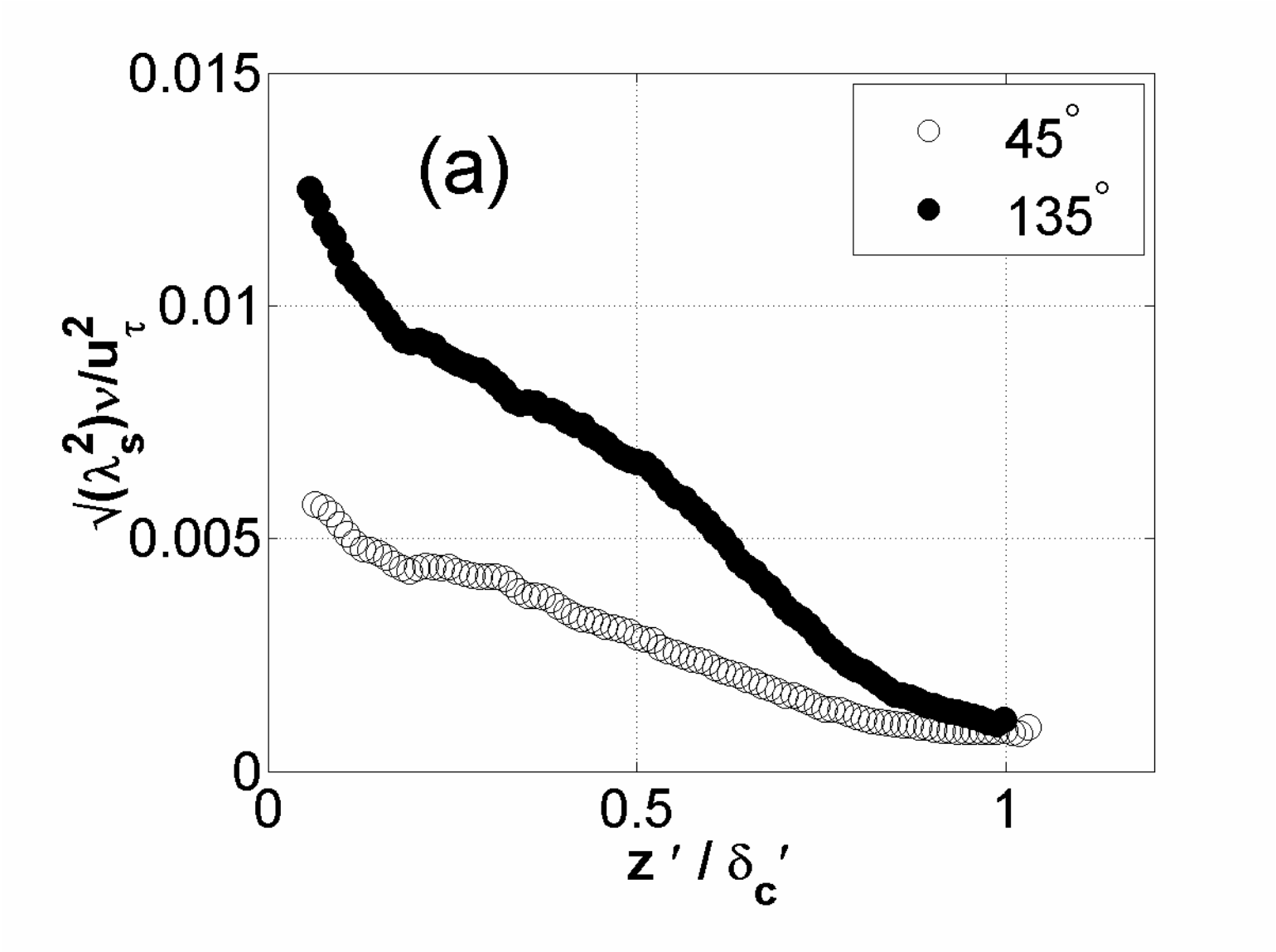
The hairpin packet model to explain the increased occurrence of swirl in the 135° plane over the 45° case.



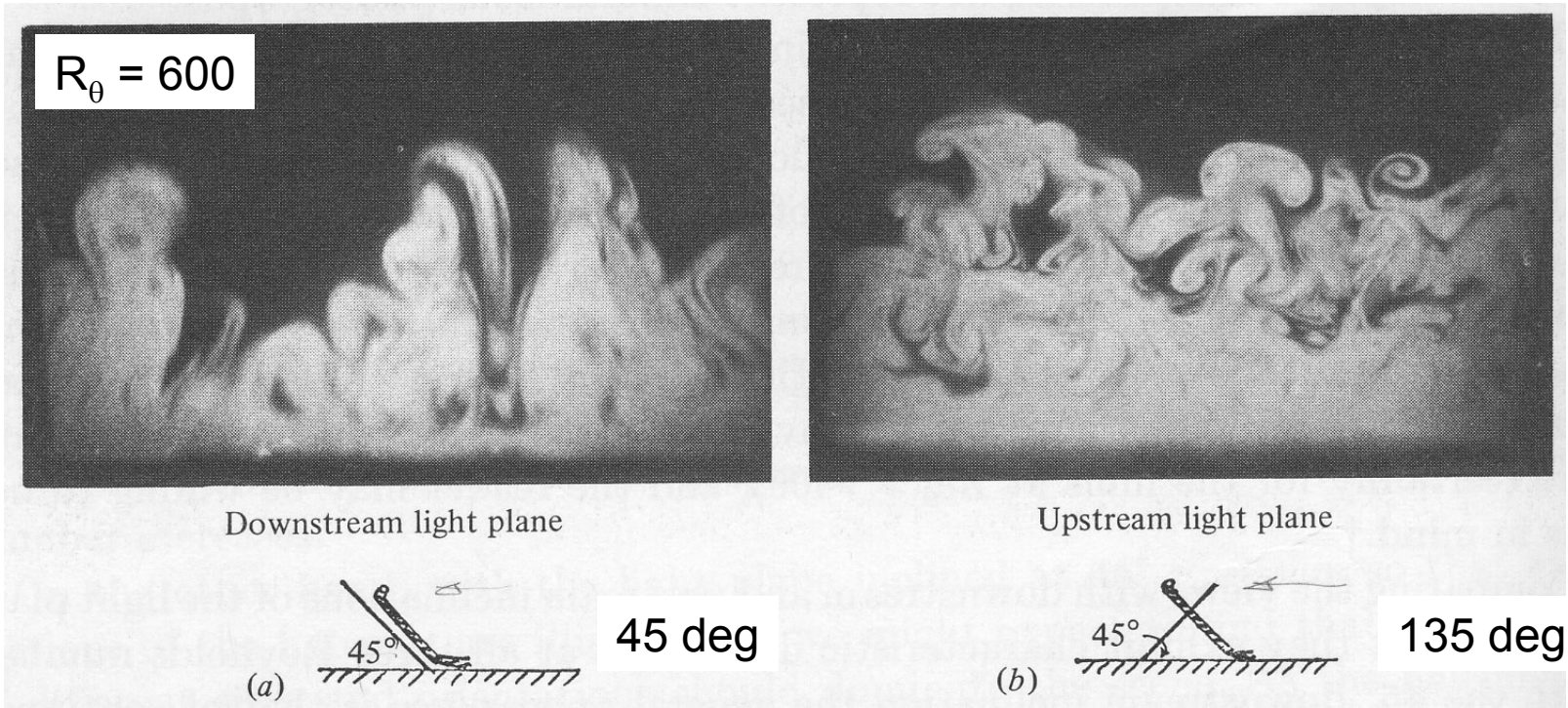
The hairpin packet model to explain the increased occurrence of swirl in the 135° plane over the 45° case.

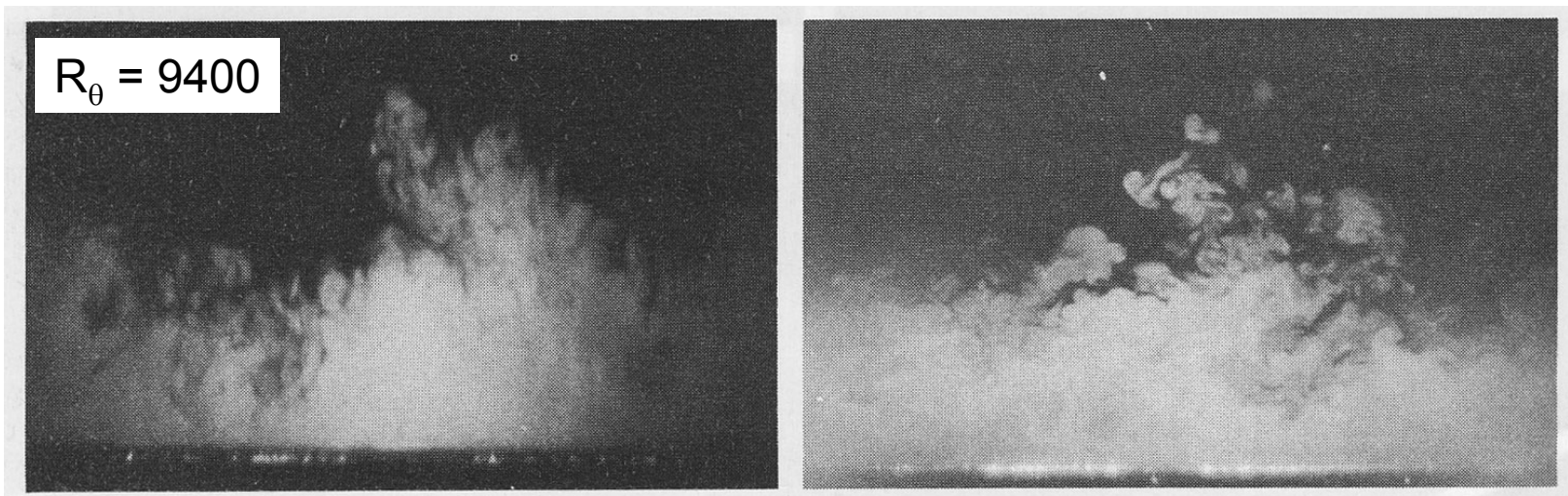


Comparison of RMS swirl in the 45° and 135° planes.



Head & Bandyopadhyay (1981)





Conclusions

- Inclined 45 deg. and 135 deg. PIV shows clear evidence of inclined eddies.

- Two point correlation functions from multi-plane stereo PIV measurements indicate existence of long narrow coherent structures, with characteristics consistent with packets of hairpin eddies in log. region of boundary layer.

- Near-wall region, including log region, is characterized by wall-*coupled* or attached structures, while outer wake region is characterized by *decoupled* structures. Consistent with notion of wall-wake eddy models.

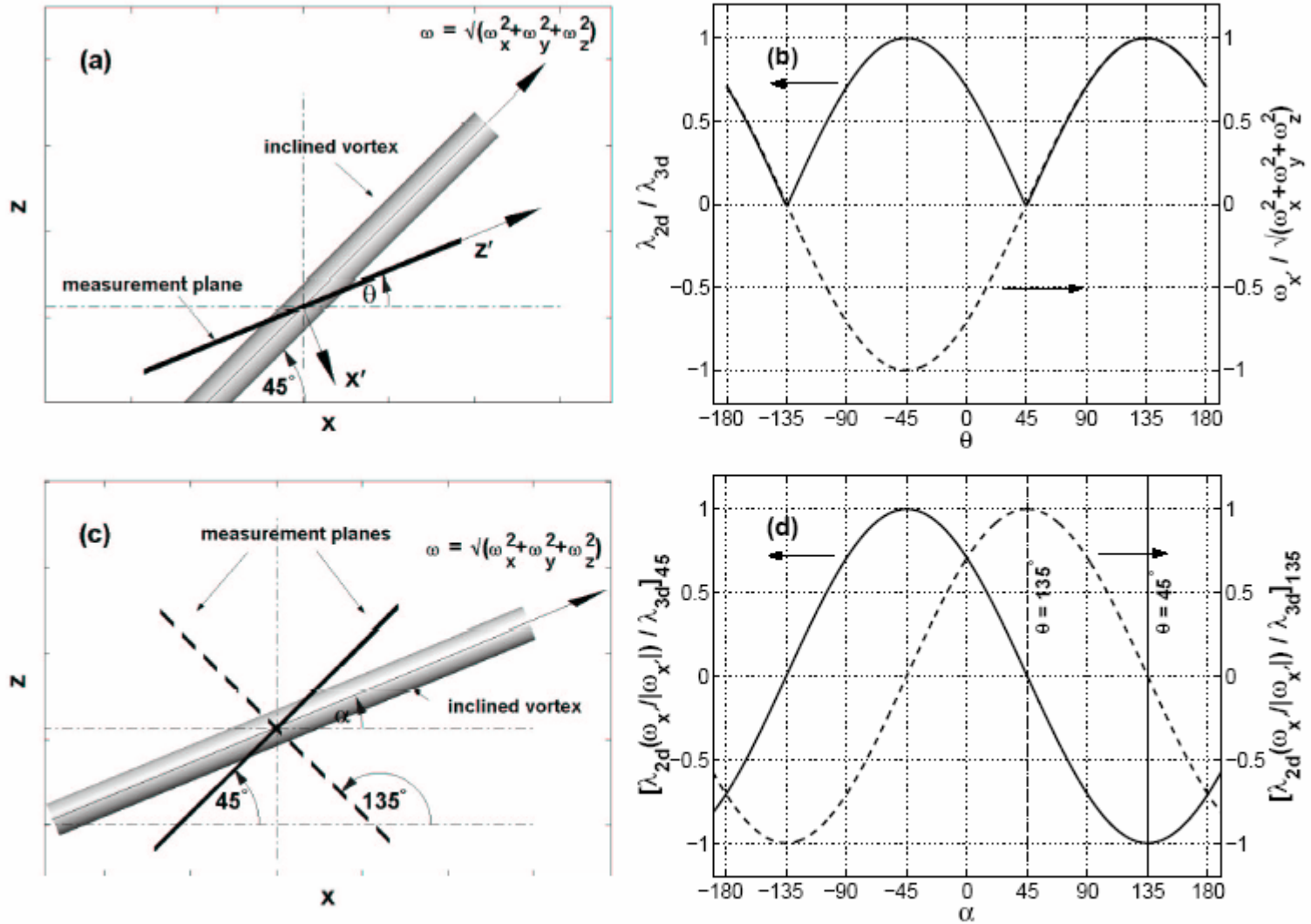


FIGURE 8. (a) $\alpha = 45°$ inclined vortex system bisected by the measurement plane at various angle θ; (b) variation with θ of (solid) $\lambda_{2d}/\lambda_{3d}$ and (dashed) $\omega_{x'}/\sqrt{(\omega_x^2+\omega_y^2+\omega_z^2)}$; (c) $\theta = 45°$ & $135°$ measurement planes with vortex at various inclination angles α; (d) variation of signed λ_{2d} with α as registered in the $\theta = 45°$ & $135°$ measurement planes.