# Statistics of the interaction of two isotropic turbulent fields

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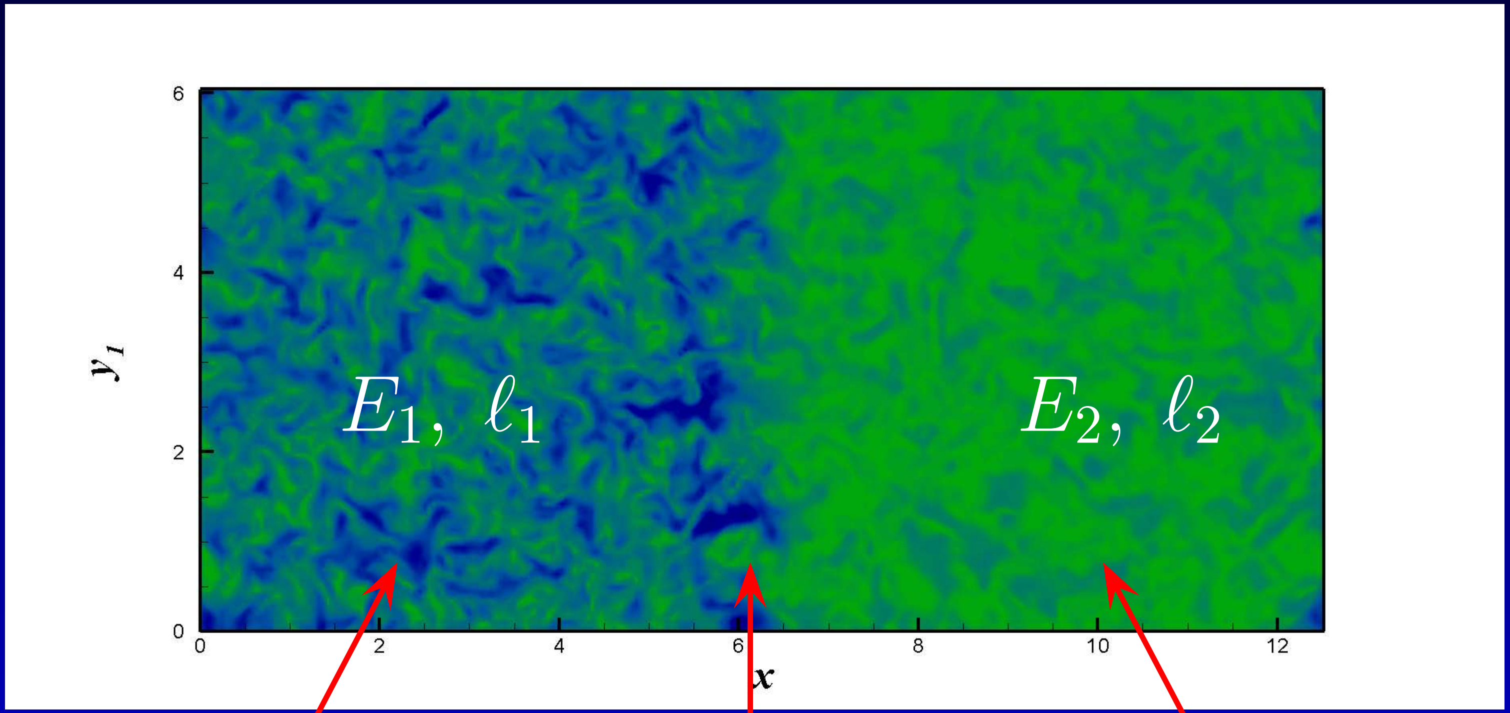
# Turbulent shearless mixing

Ref: *J. Fluid Mech.* **549**, 441-451, (2006).



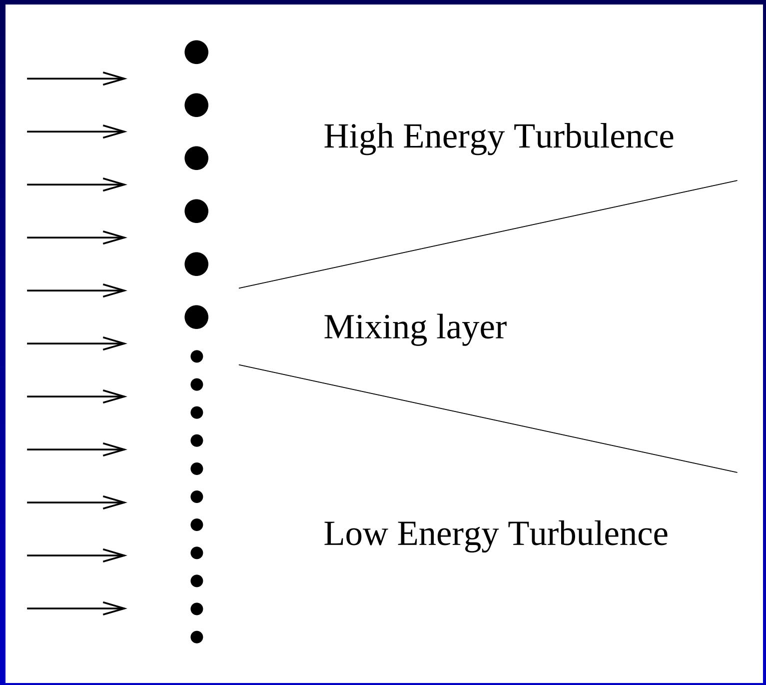

Run Movie 1-2

1-High energy turbulence

2-Low energy turbulence

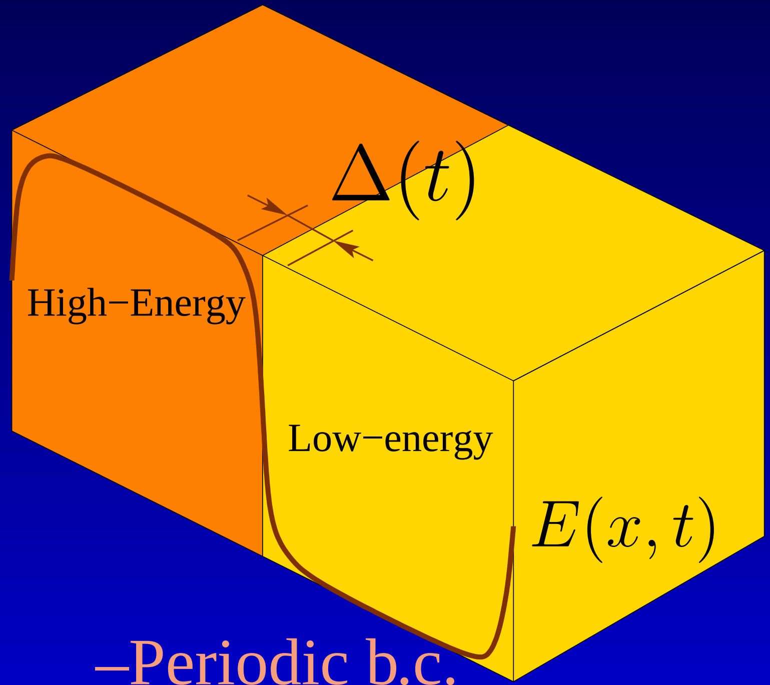
Mixing layer

# State of the art




- Grid turbulence experiments:
  - ▶ Gilbert *JFM* 1980
  - ▶ Veeravalli-Warhaft *JFM* 1989

# State of the art




–Periodic b.c.

–Temporal decay

- Grid turbulence experiments:
  ▶ Gilbert *JFM* 1980
  ▶ Veeravalli-Warhaft *JFM* 1989
- Numerical experiments:
  ▶ Briggs *et al. JFM* 1996
  ▶ Knaepen *et al. JFM* 2004
  ▶ Tordella-Iovieno *JFM* 2006
  ▶ Iovieno-Tordella-Bailey *PRE* 2008)

# Main features

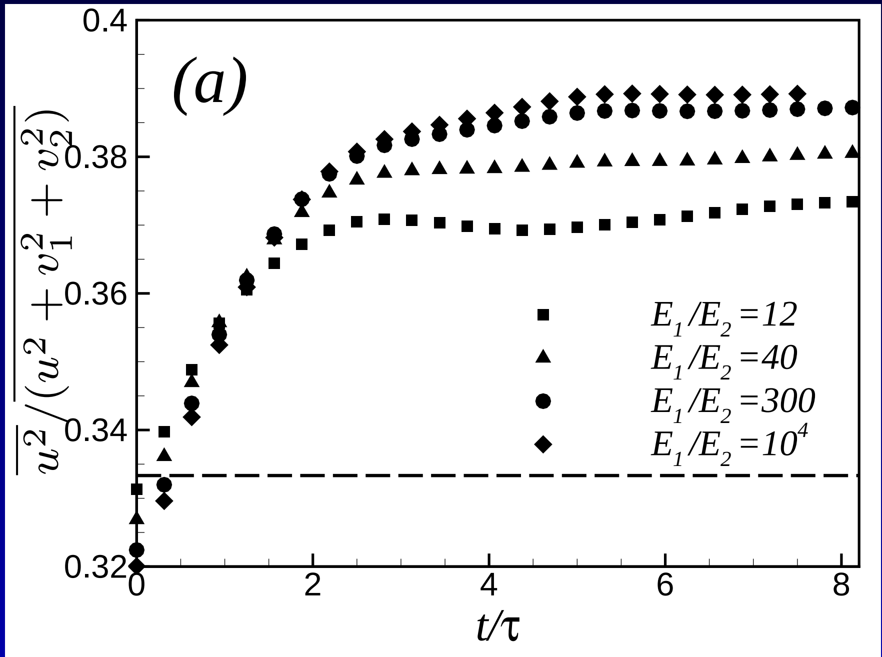
- High intermittency, function of:
  - gradient of turbulent kinetic energy
  - gradient of integral scale
- A gradient of kinetic energy is a sufficient condition for the onset of intermittency (*PRE* 2008)
- Intermittency is (*JFM* 2006)
  - *ENHANCED* if the energy gradient is concurrent with the integral scale gradient
  - *REDUCED* if the energy gradient is opposite to the integral scale gradient

# Aim and Method

- **Aim**: to study the intermittency features of the large as well of the small scales
- Three different Reynolds numbers: $Re_\lambda = 45$, 71 and 150.
- Energy ratio $\mathcal{E} = E_1/E_2$ from 6 to $10^4$ with uniform integral scale.
- Velocity and velocity derivative statistics
- **Method**: DNS
  - parallelepiped domain, $2\pi \times 2\pi \times 4\pi$
  - Fourier-Galerkin pseudospectral space discretization
  - RK-4 time integration

# Anisotropy of velocity statistics

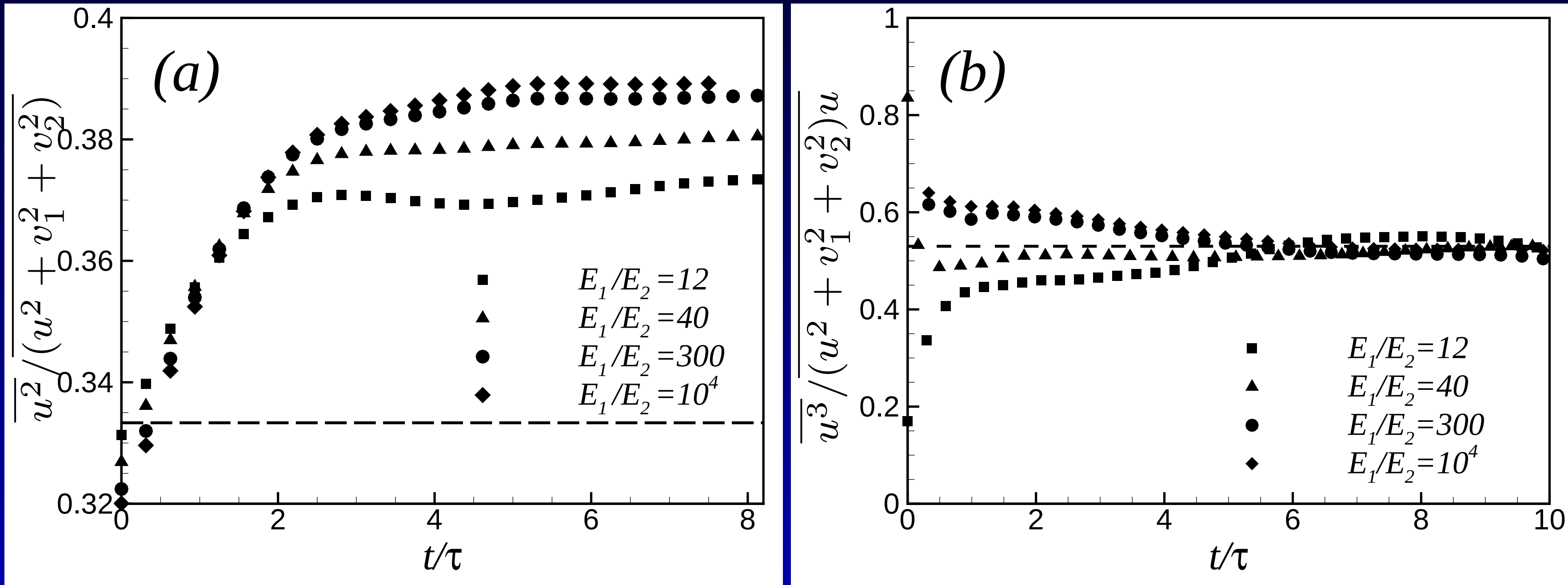
$Re_\lambda = 45$




Left: second order moment anisotropy

# Anisotropy of velocity statistics

$Re_\lambda = 45$

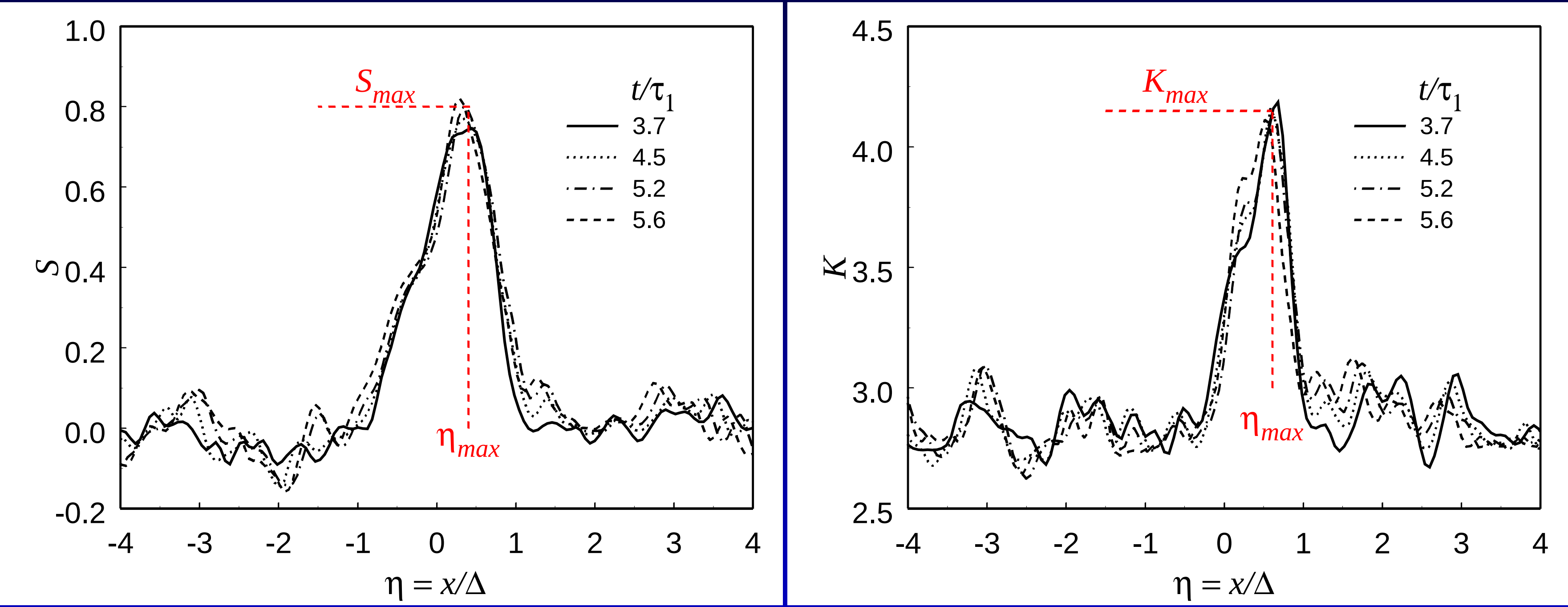



Left: second order moment anisotropy
Right: triple moment anisotropy

# Large scale intermittency

$Re_\lambda = 45, \mathcal{E} = 6.7$

$S = \overline{u^3}/\overline{u^2}^{3/2}$ $K = \overline{u^4}/\overline{u^2}^2$



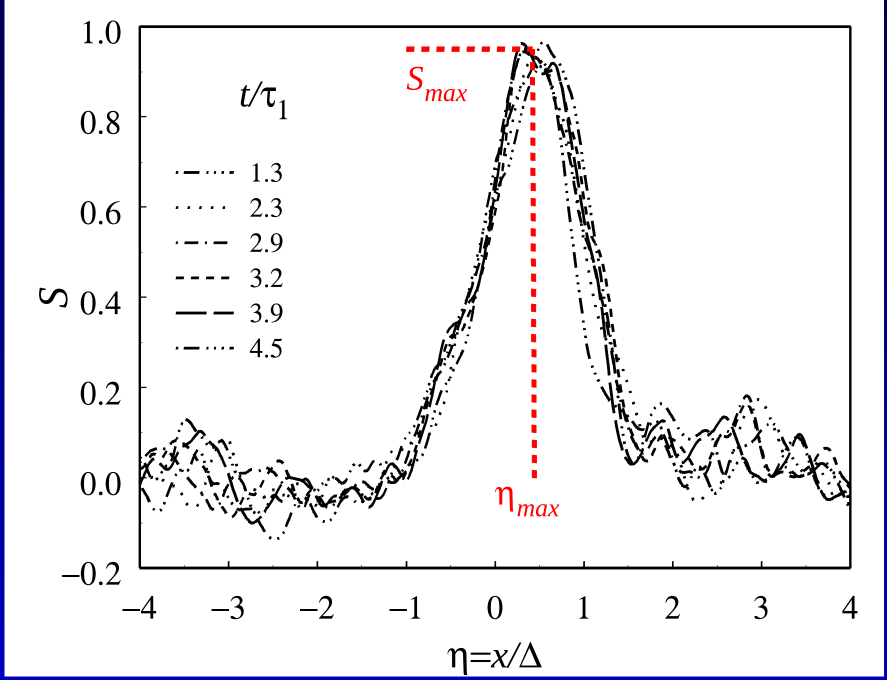

$S_{max}$, $K_{max}$ = maximum of Skewness and Kurtosis in the mixing layer

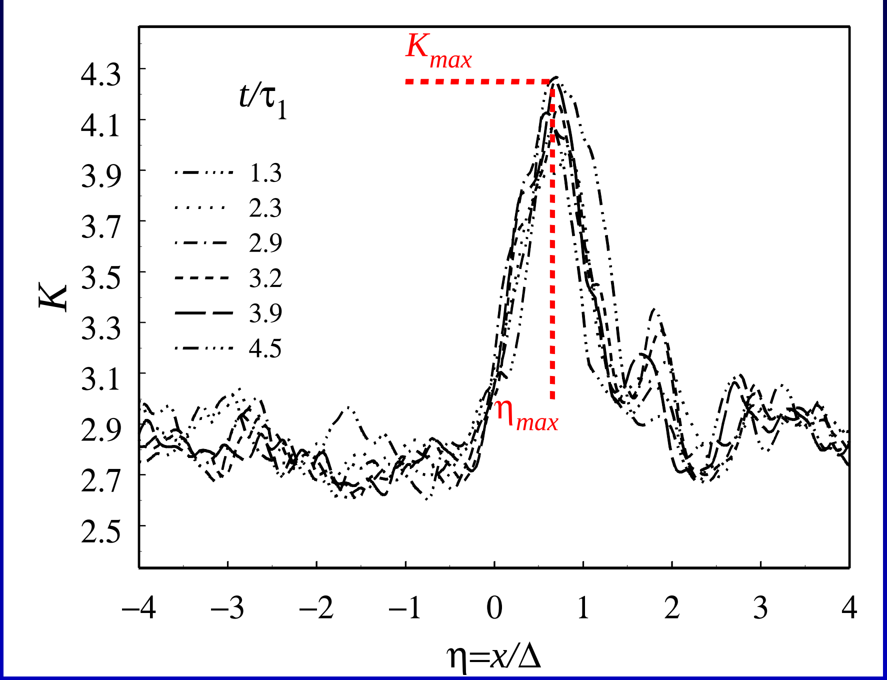
$\eta_{max}$ = position of the maximum in the mixing layer

# Large scale intermittency

$Re_\lambda = 150, \mathcal{E} = 6.7$

$S = \overline{u^3}/\overline{u^2}^{3/2}$ $K = \overline{u^4}/\overline{u^2}^{2}$



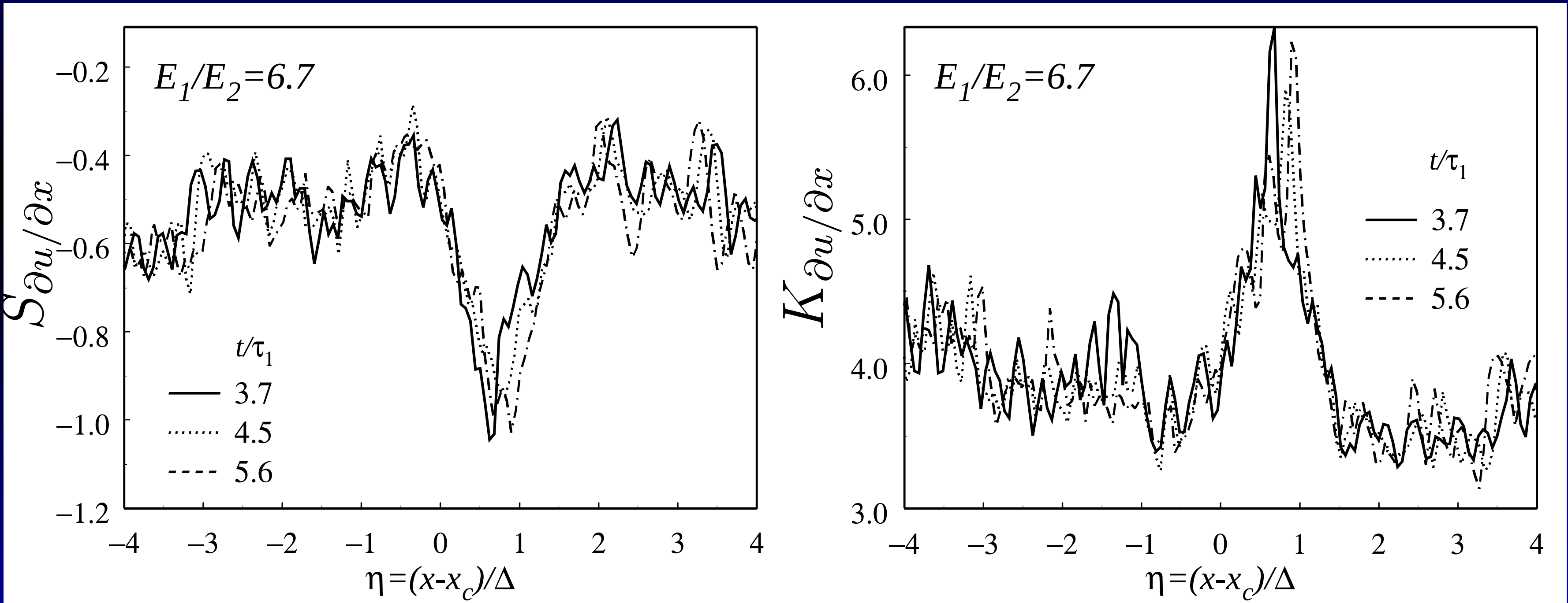




$S_{max}$, $K_{max}$ = maximum of Skewness and Kurtosis in the mixing layer

$\eta_{max}$ = position of the maximum in the mixing layer

# Small scale intermittency

Velocity component in the mixing direction, longitudinal moments: $E_1/E_2 = 6.7$, $\ell_1/\ell_2 = 1$
$Re_\lambda = 45$




$\eta$ is the dimensionless coordinate along the mixing
$\Delta$ is the mixing half-width

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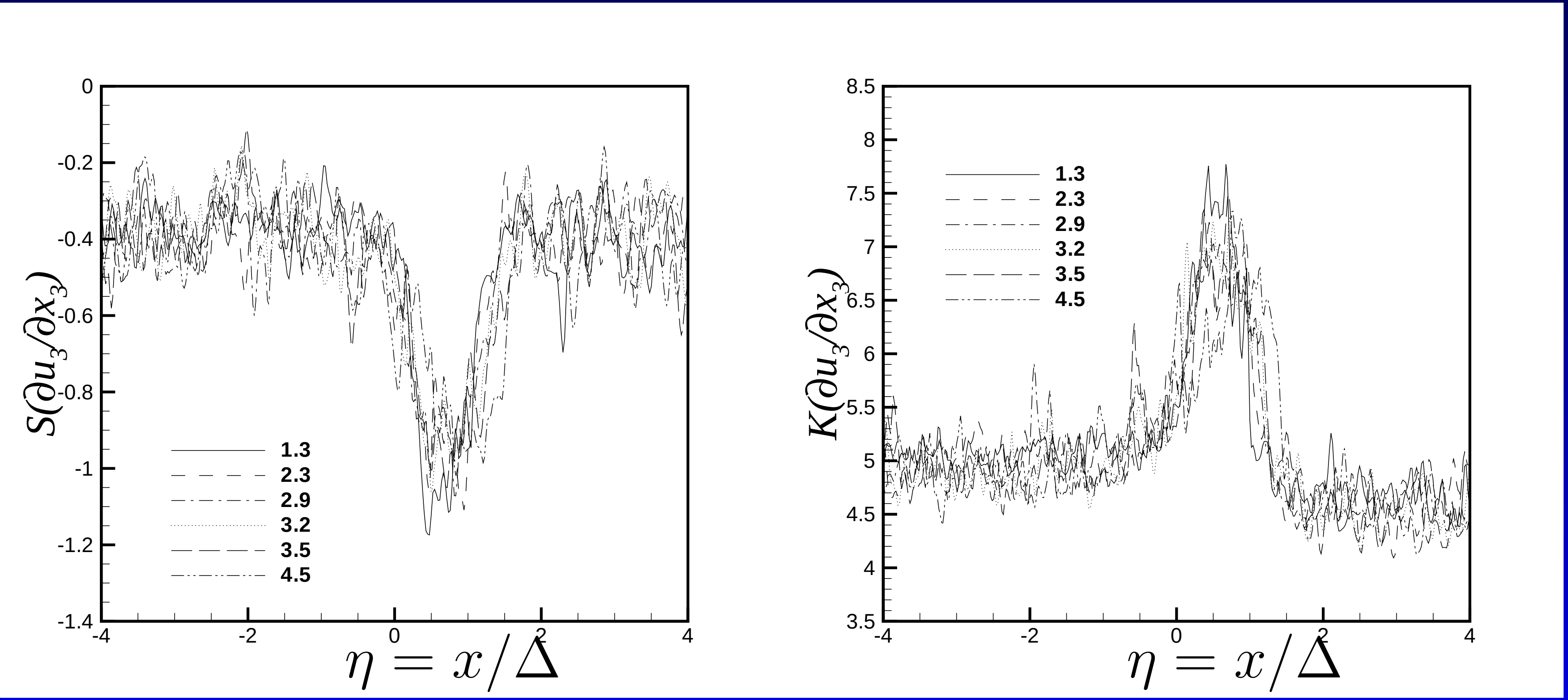


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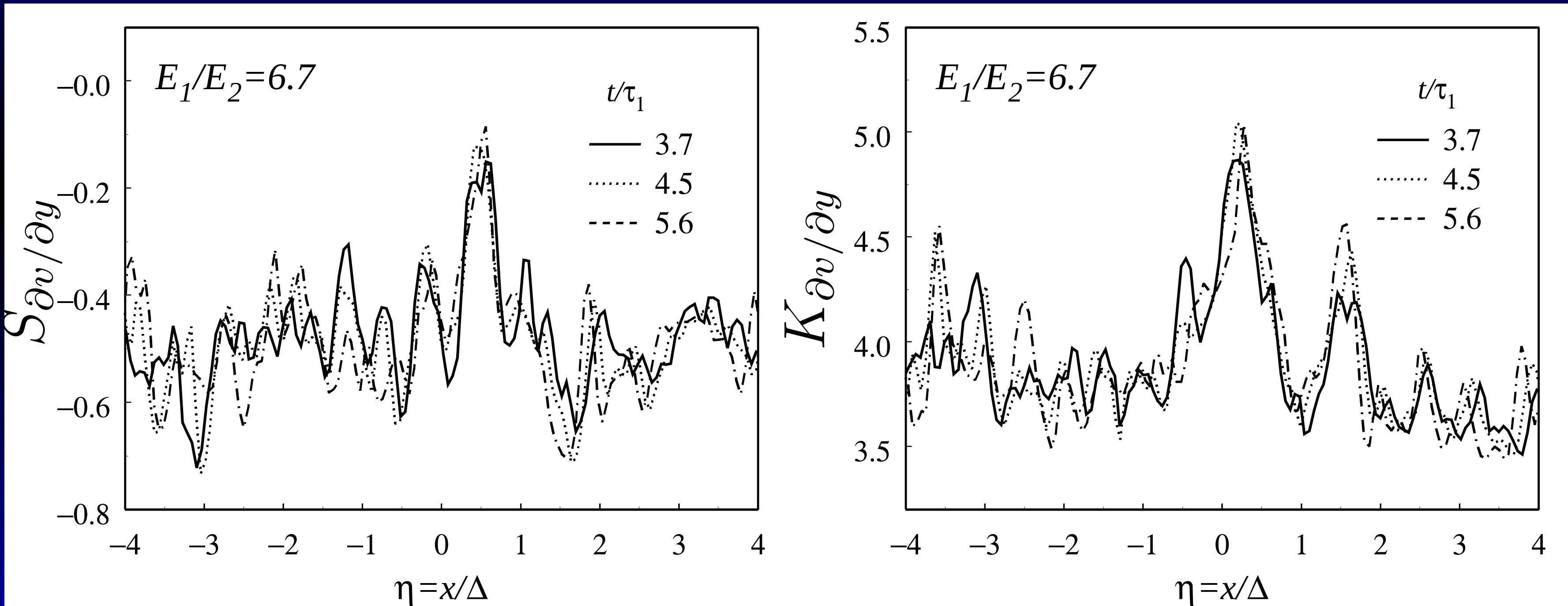
# Small scale intermittency

Velocity component normal to the mixing direction, longitudinal moments: $E_1/E_2 = 6.7$, $\ell_1/\ell_2 = 1$
$Re_\lambda = 45$

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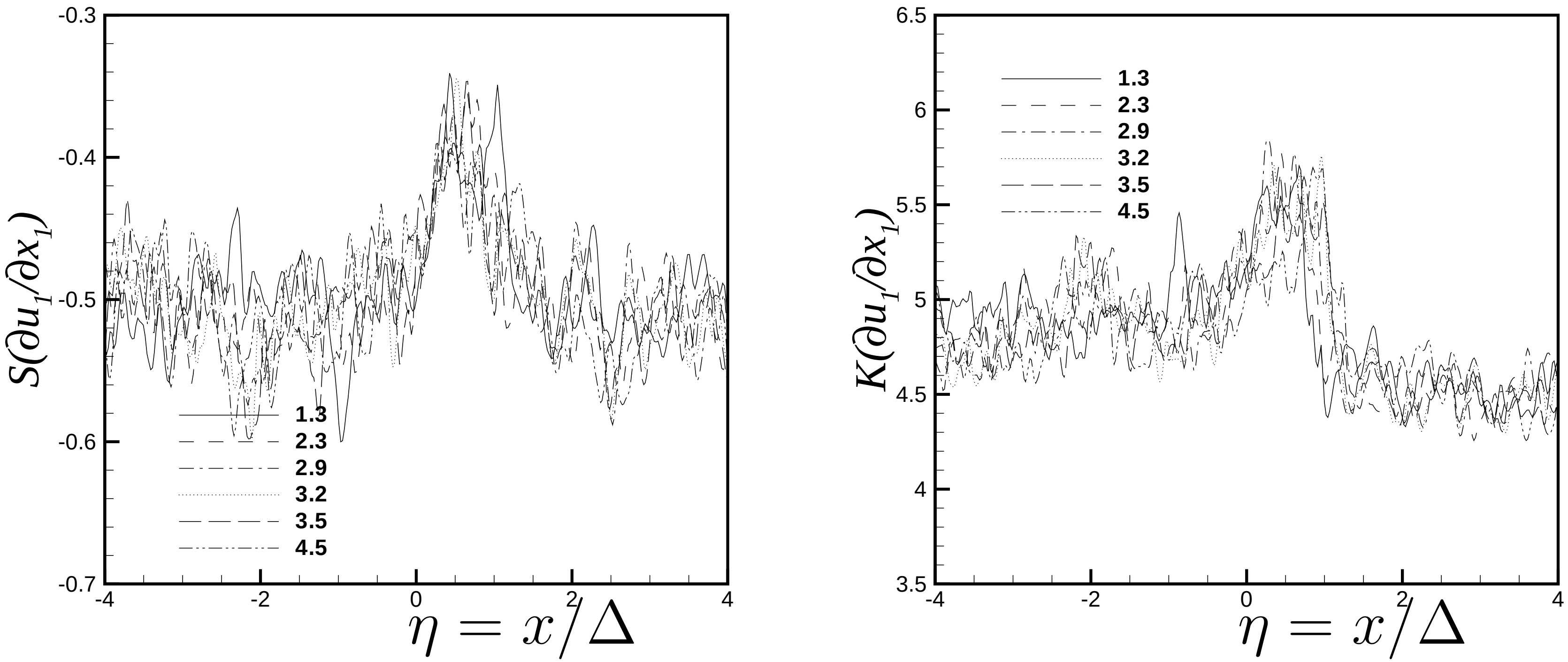
# Small scale intermittency

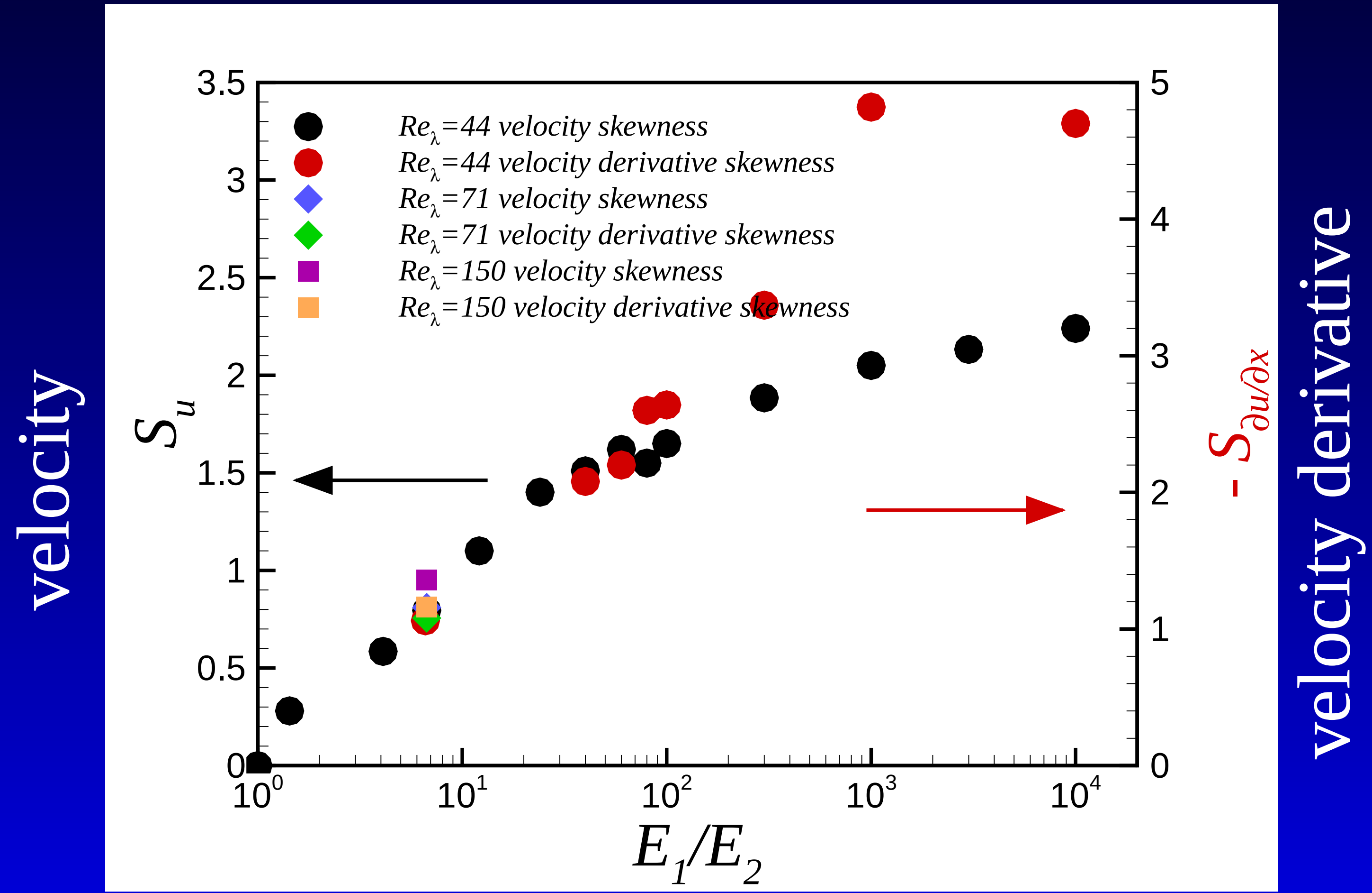
Velocity component normal to the mixing direction, longitudinal moments: $E_1/E_2 = 6.7$, $\ell_1/\ell_2 = 1$
$Re_\lambda = 150$




$\eta$ is the dimensionless coordinate along the mixing
$\Delta$ is the mixing half-width

# Asymptote for $E_1/E_2 \to +\infty$

Skewness:

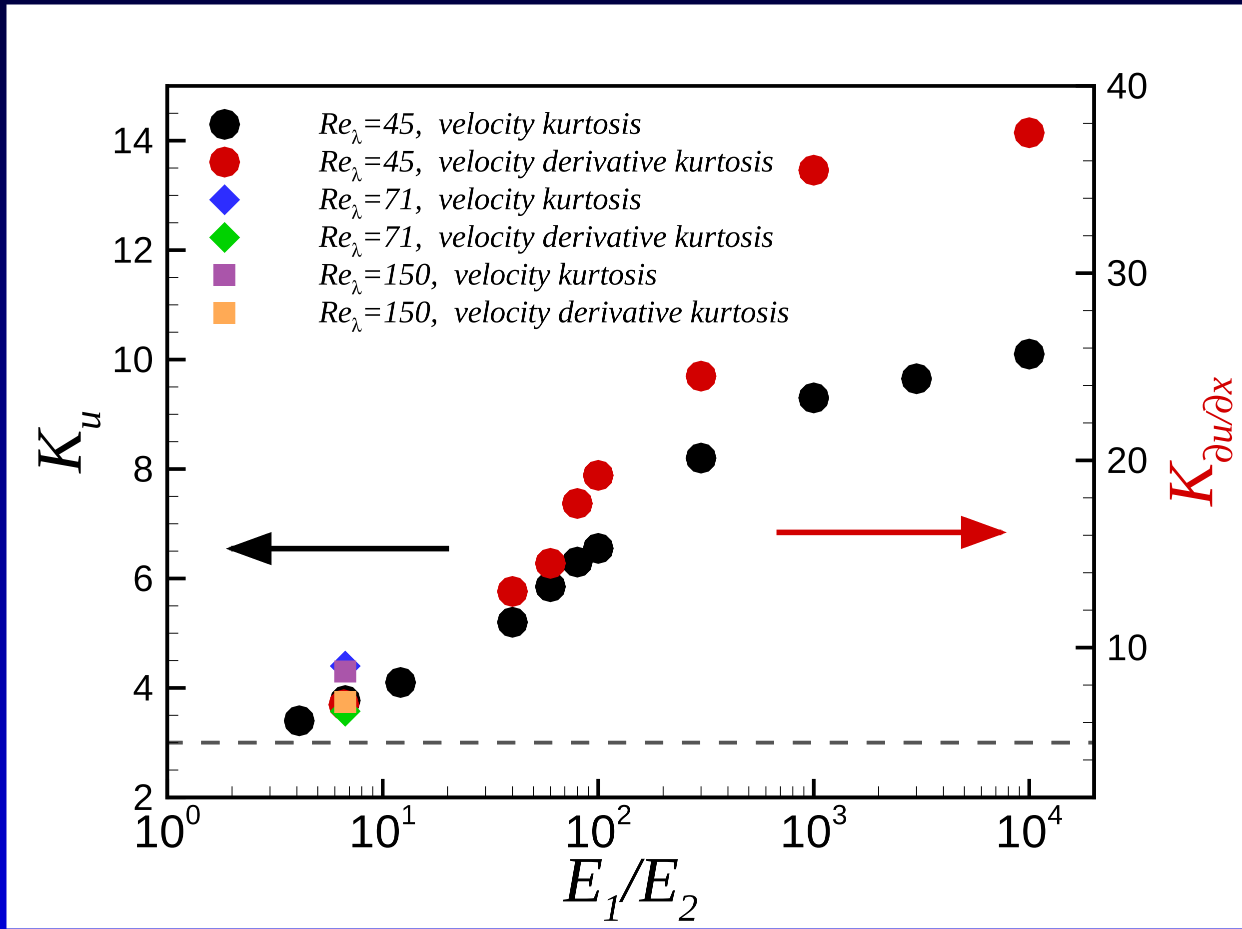



$u$, $x$ in the mixing direction

# Asymptote for $E_1/E_2 \to +\infty$

Kurtosis:

velocity

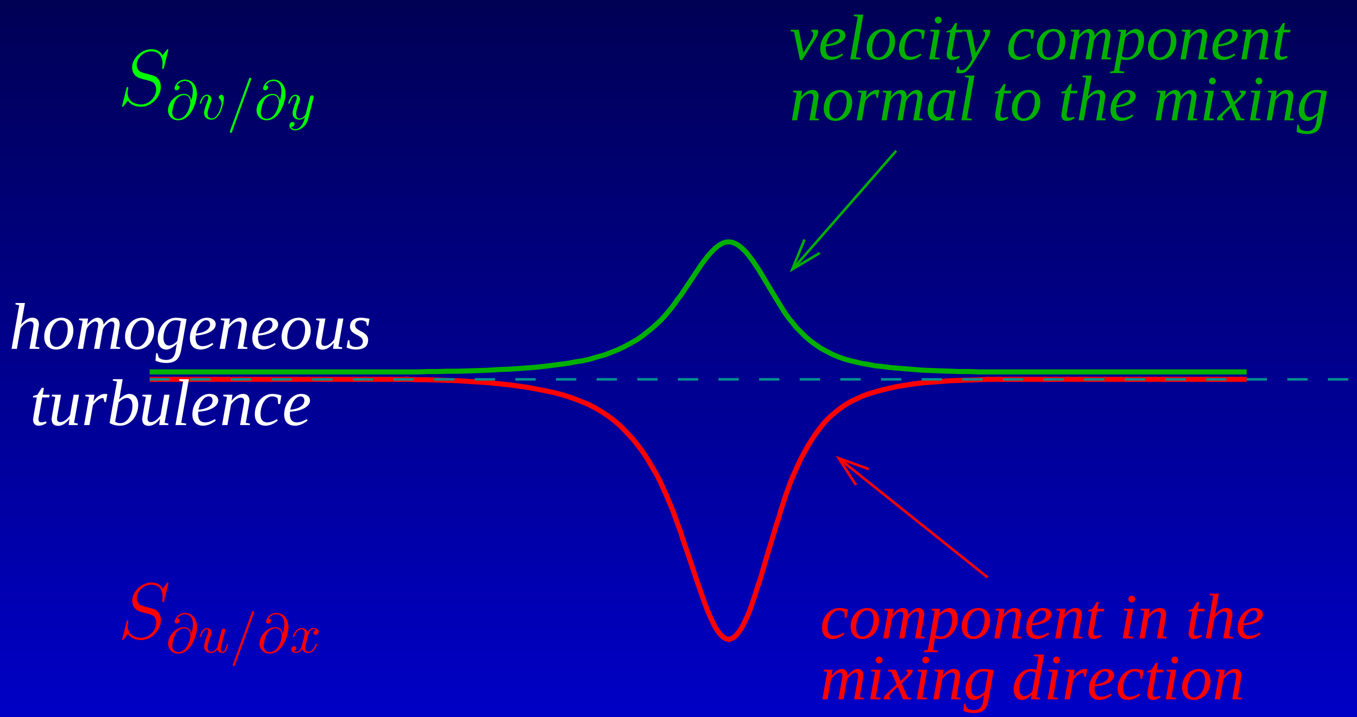



velocity derivative

$u$, $x$ in the mixing direction

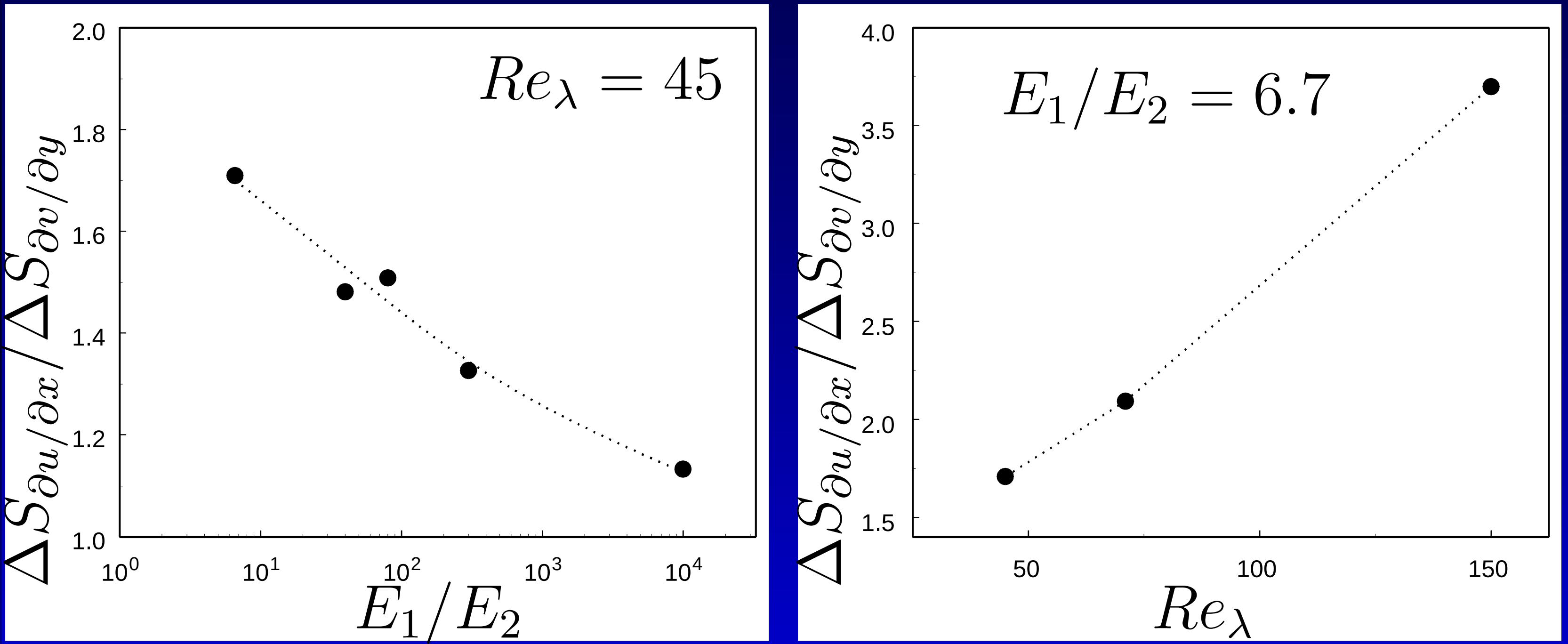
# Longitudinal skewness

Scheme of the general behaviour



# Longitudinal skewness

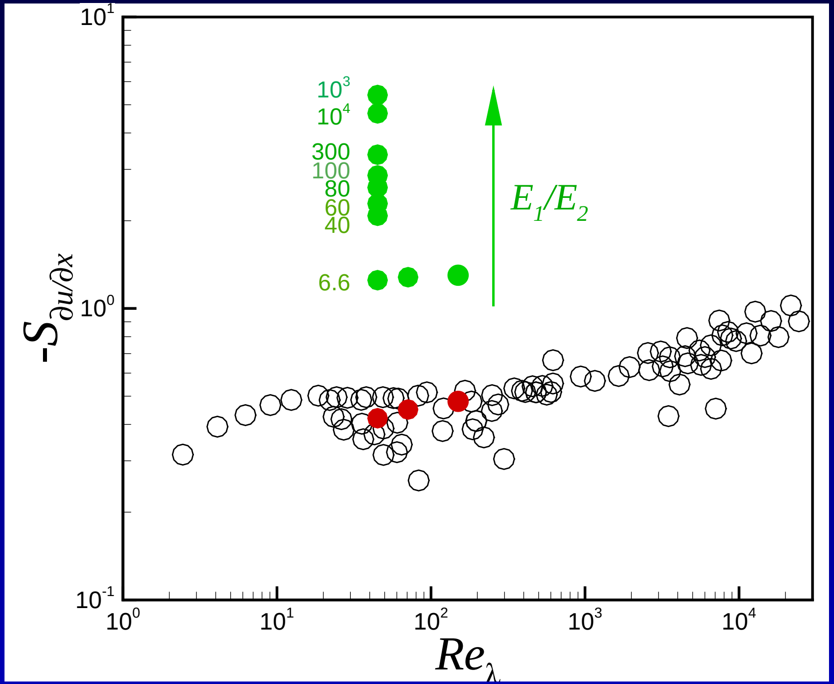
Comparison between the variation of the longitudinal derivative skewness of the component along the mixing and normal to the mixing

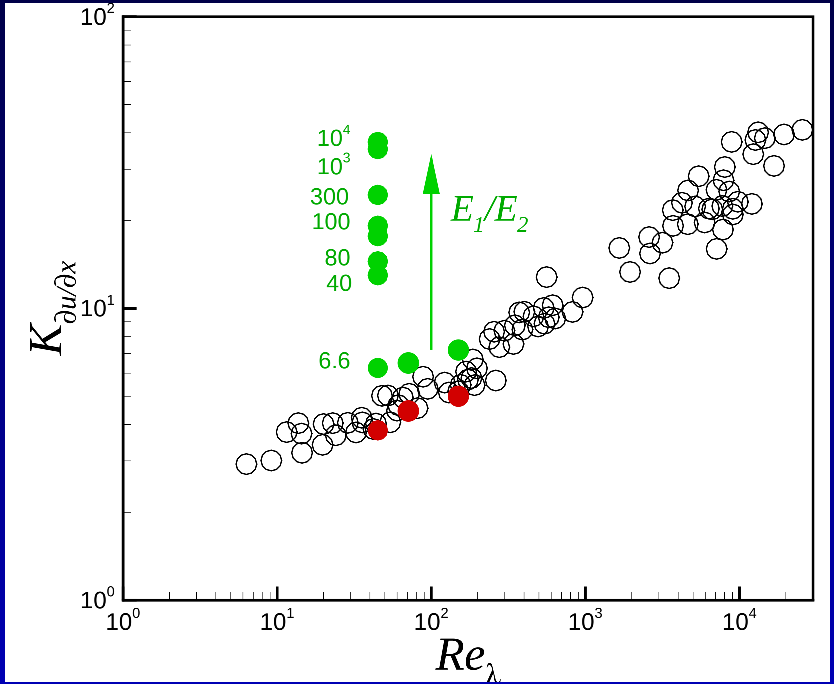



$$\Delta S = | S_{mixing} - S_{HIT} |$$

# Comparison with homogeneous turbulence

Comparison of longitudinal moments inside the mixing with longitudinal moments in homogeneous and isotropic turbulence



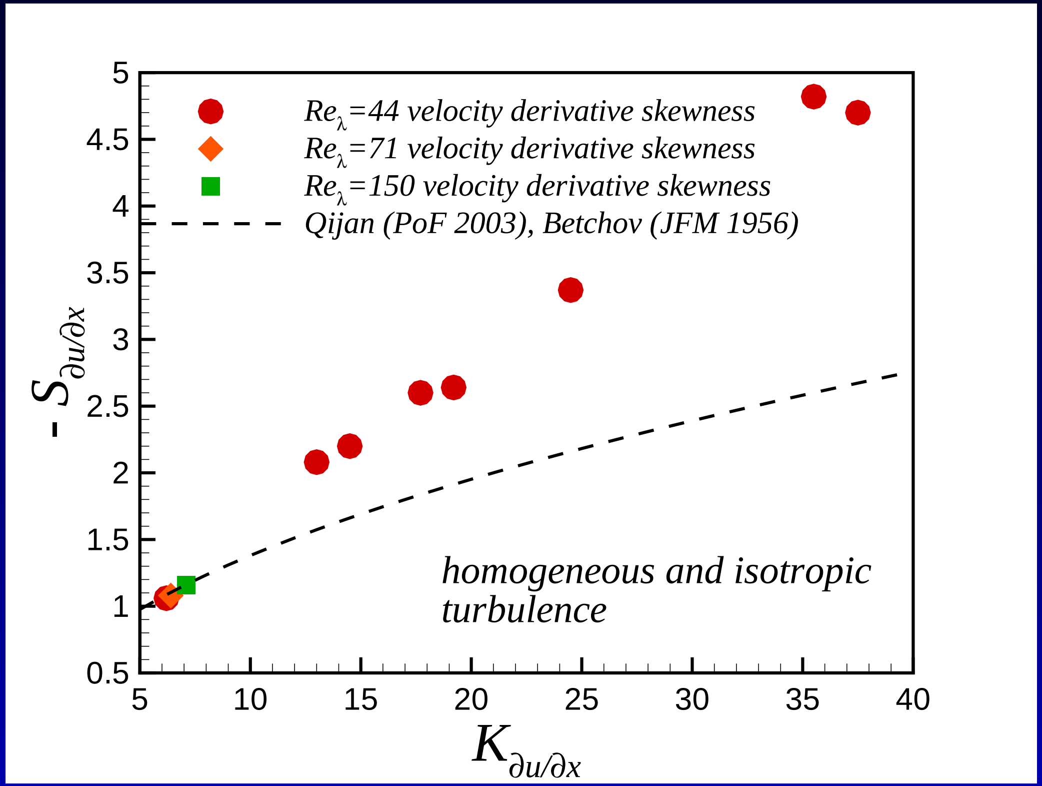




● *HIT, present simulations*

● *Shearless mixings, present simulations*

○ *HIT, data from Sreenivasan and Antonia, Ann.Rev.Fluid Mech 1997*

# Comparison with homogeneous turbulence (II)




Comparison with the upper bound

$$-S_{\partial u/\partial x} \leq 2\left(\frac{K_{\partial u/\partial x}}{21}\right)^{\frac{1}{2}}$$

of the longitudinal skewness in homogeneous turbulence

# Conclusions

Over a range of energy ratios, for Re=45, $7 \leq \mathcal{E} \leq 10^4$, and for $Re_\lambda$ 71 and 150, $\mathcal{E} = 7$, we observed:

- an intermittency increase with the energy ratio:
  - velocity Skewness and Kurtosis as large as 2.3 and 11, respectively
  - longitudinal derivative Skewness and Kurtosis as large as -5 and 50
- anisotropy quantitative data:
  - velocity: negligible for the second moments, significant for triple moments, for higher moments **?**
  - longitudinal velocity derivatives ($3^{\text{rd}}$ and $4^{\text{th}}$ moments): significant, it increases with the Reynolds number.

# Appendix: Shearless mixing statistics

| | $\overline{u_i u_i u_3}/\overline{u_3^2}^{3/2}$ | | | Velocity Kurtosis | | | Long. derivative skewness | | | Long. derivative kurtosis | | | Trans. Moments | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | i=1 | i=2 | i=3 | $K_{u_1}$ | $K_{u_2}$ | $K_{u_3}$ | $S_{\partial_1 u_1}$ | $S_{\partial_2 u_2}$ | $S_{\partial_3 u_3}$ | $K_{\partial_1 u_1}$ | $K_{\partial_2 u_2}$ | $K_{\partial_3 u_3}$ | $S_{\partial_1 u_3}$ | $K_{\partial_1 u_3}$ |
| $E_1/E_2$ : | Mixings with $\ell_1/\ell_2 = 1$, $R_\lambda = 45$ | | | | | | | | | | | | | |
| 6.6 | 0.34 | 0.36 | 0.82 | 3.6 | 3.4 | 4.07 | -0.11 | -0.10 | -1.04 | 5.0 | 4.85 | 6.95 | 0.29 | 6.55 |
| 40 | 0.54 | 0.59 | 1.34 | 5.6 | 6.0 | 5.56 | 0.52 | 0.70 | -2.08 | 7.1 | 6.77 | 12.0 | 0.50 | 8.50 |
| 80 | 0.63 | 0.69 | 1.57 | 6.4 | 6.7 | 6.67 | 0.95 | 1.1 | -2.60 | 8.5 | 8.6 | 17.1 | 0.60 | 13.0 |
| 300 | 0.78 | 0.87 | 1.91 | 7.5 | 8.2 | 8.93 | 1.5 | 2.0 | -3.37 | 16 | 14 | 24.5 | 1.0 | 13.6 |
| $10^4$ | 0.92 | 0.95 | 2.20 | 7.8 | 8.2 | 11.6 | 3.4 | 3.2 | -4.70 | 20 | 26 | 37.3 | 1.05 | 23.1 |
| Mixings with $\ell_1/\ell_2 = 1$, $R_\lambda = 71$ | | | | | | | | | | | | | | |
| 6.6 | 0.42 | 0.37 | 0.81 | 3.65 | 3.55 | 4.8 | -0.15 | -0.19 | -1.08 | 4.45 | 4.65 | 6.20 | 0.20 | 5.95 |
| Mixings with $\ell_1/\ell_2 = 1$, $R_\lambda = 150$ | | | | | | | | | | | | | | |
| 6.7 | – | – | 0.96 | – | – | 4.30 | -0.30 | -0.28 | -1.16 | 5.7 | 5.8 | 7.20 | 0.12 | 7.30 |
| Veeravalli and Warhaft(1989), $E_1/E_2 \approx 7$, $\ell_1/\ell_2 \approx 1.5 \div 1.7$ | | | | | | | | | | | | | | |
| bars | == | == | 1.06 | 4.36 | 4.23 | 5.53 | == | == | == | == | == | == | = | = |
| plate | == | == | 0.63 | 3.47 | 3.49 | 4.07 | == | == | == | == | == | == | = | = |

**Legend:**

3 = inhomogeneous direction, 1,2 = homogeneous directions

$S_{u_i}$, $K_{u_i}$ = skewness and kurtosis of $u_i$

$S_{\partial_j u_i}$, $K_{\partial_j u_i}$ = skewness and kurtosis of $\partial u_i/\partial x_j$