

# Anisotropy and intermittency in the turbulent shearless mixing

*61<sup>st</sup> APS-DFD 2008, APS-DFD Meeting,  
San Antonio, November 23-25, 2008*

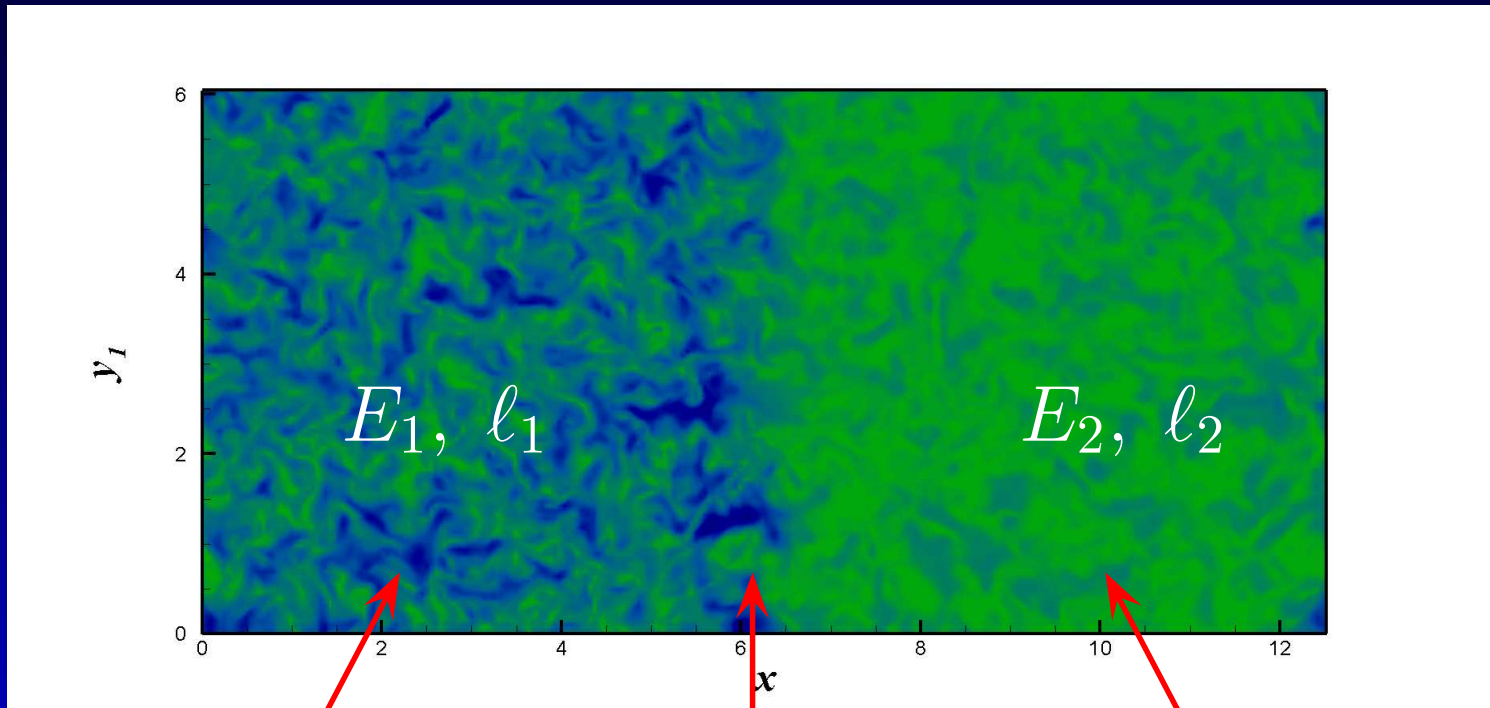
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# Turbulent shearless mixing

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



Run Movie:  $E, u$

1-High energy turbulence

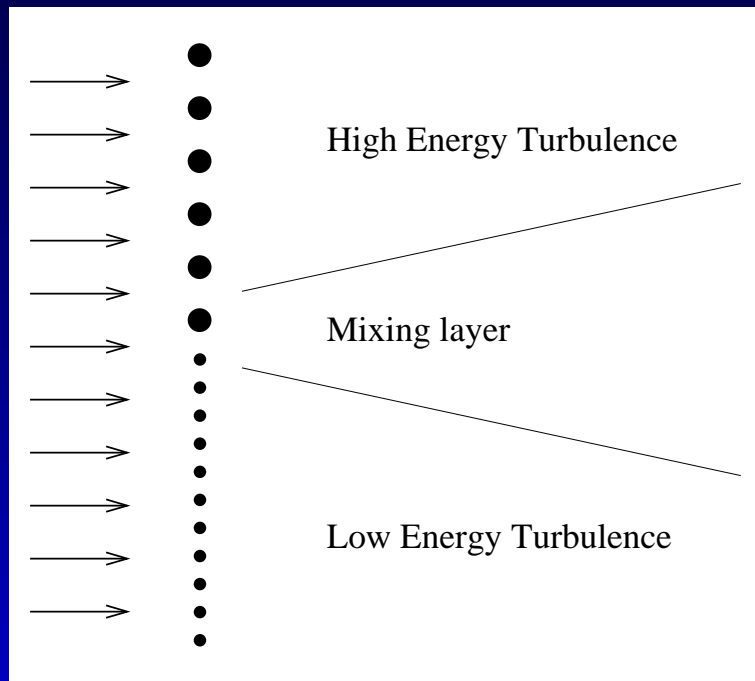
2-Low energy turbulence

Mixing layer

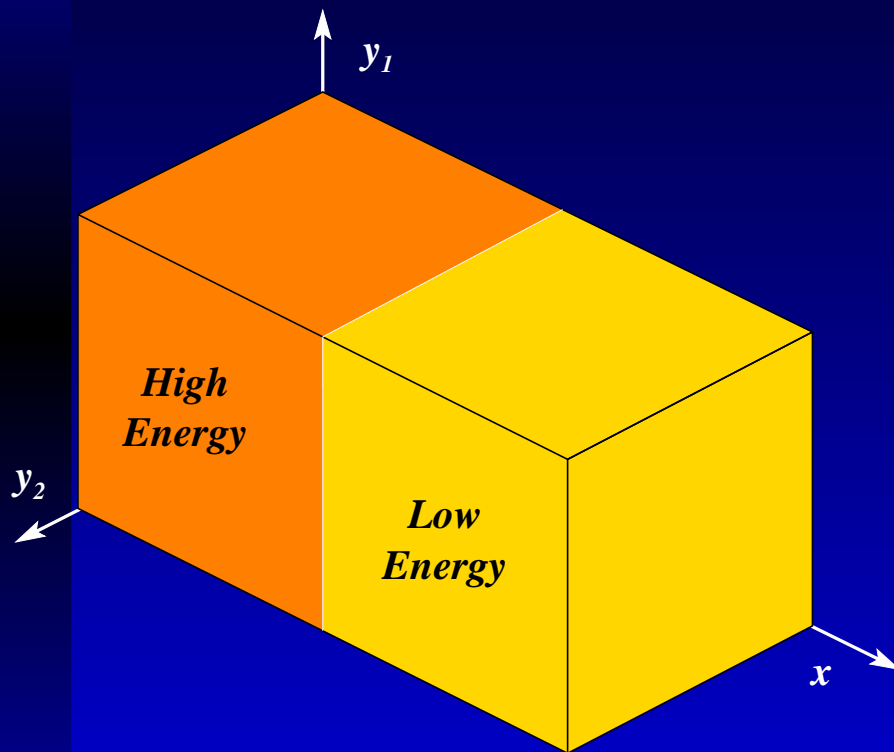


# State of the art

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



# State of the art



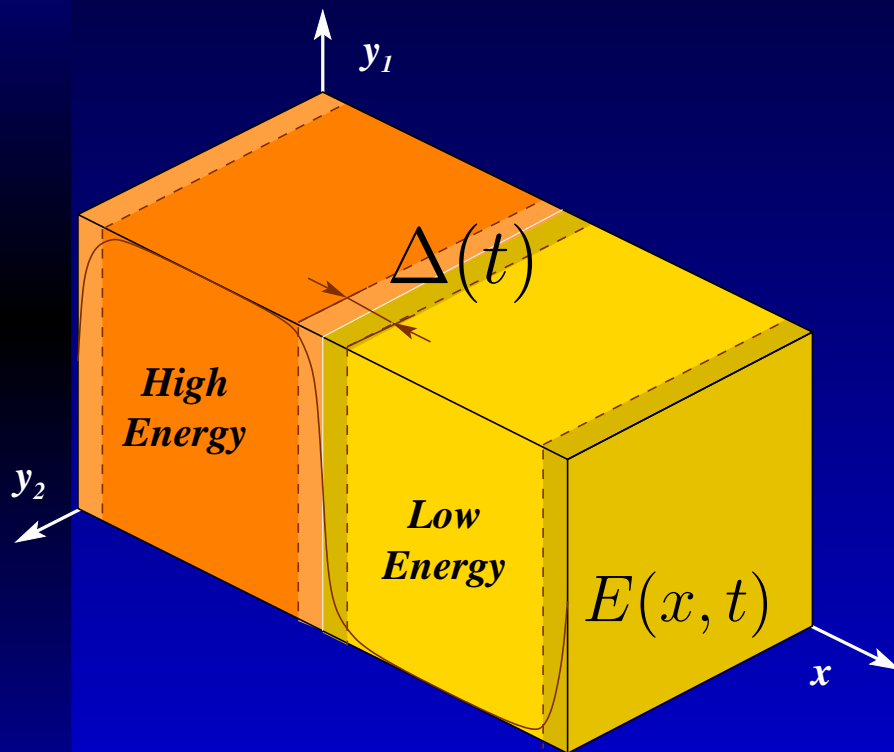
–Periodic b.c.

–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



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# 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
  - ▶ explicit RK-4 time integration

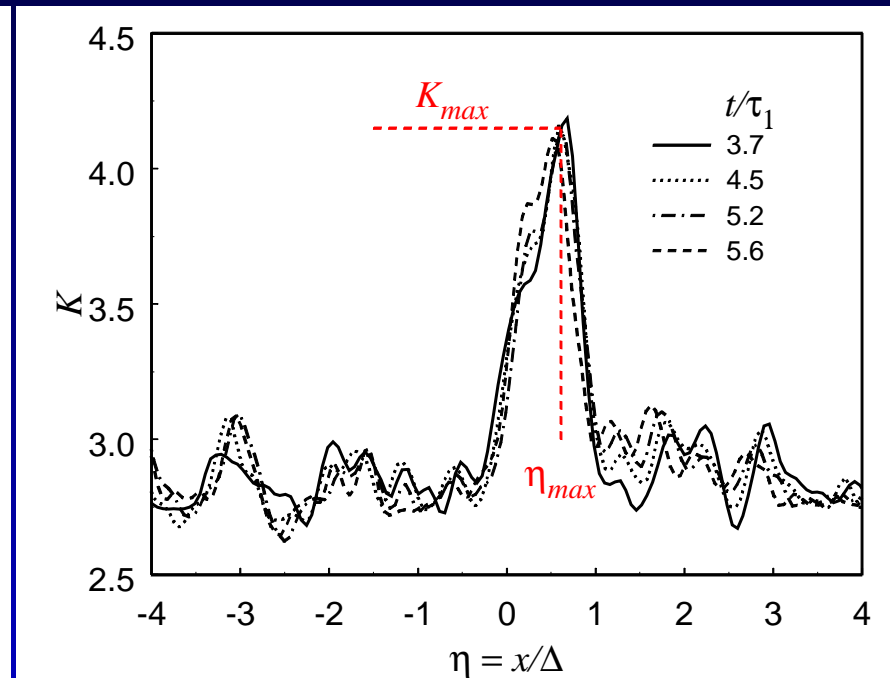
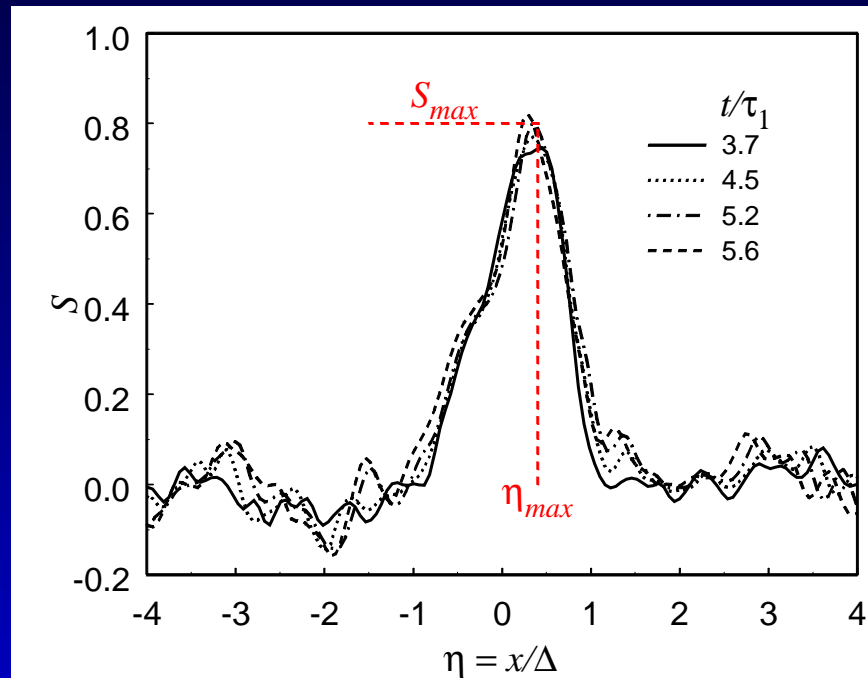


# Large scale intermittency

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

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

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



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

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



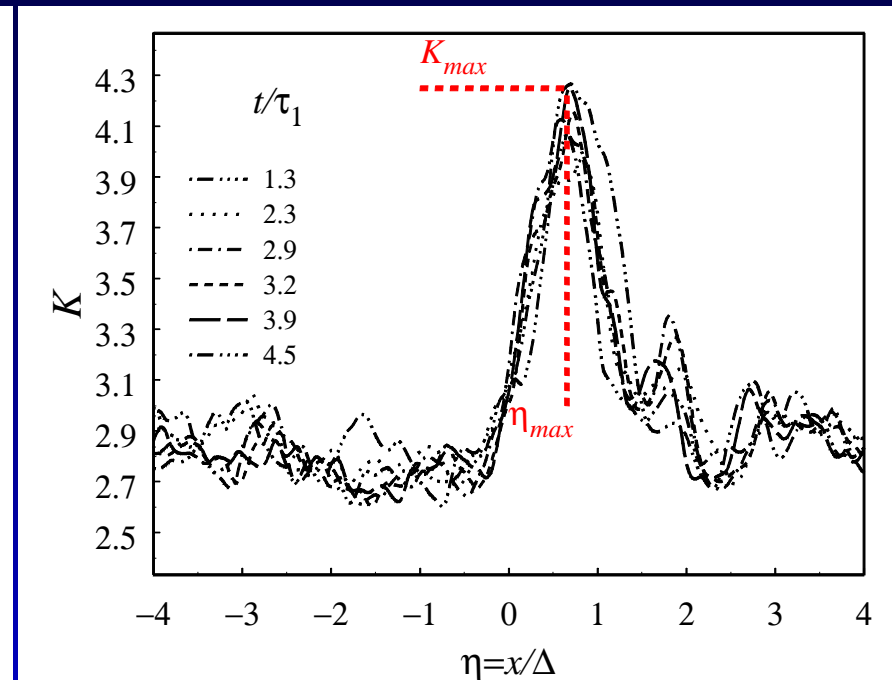
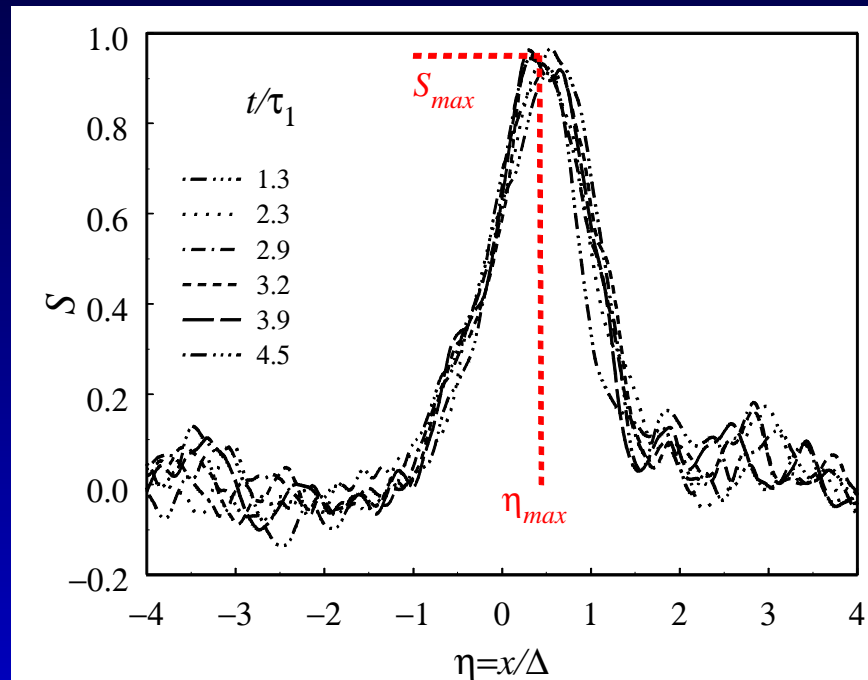


# Large scale intermittency

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

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

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



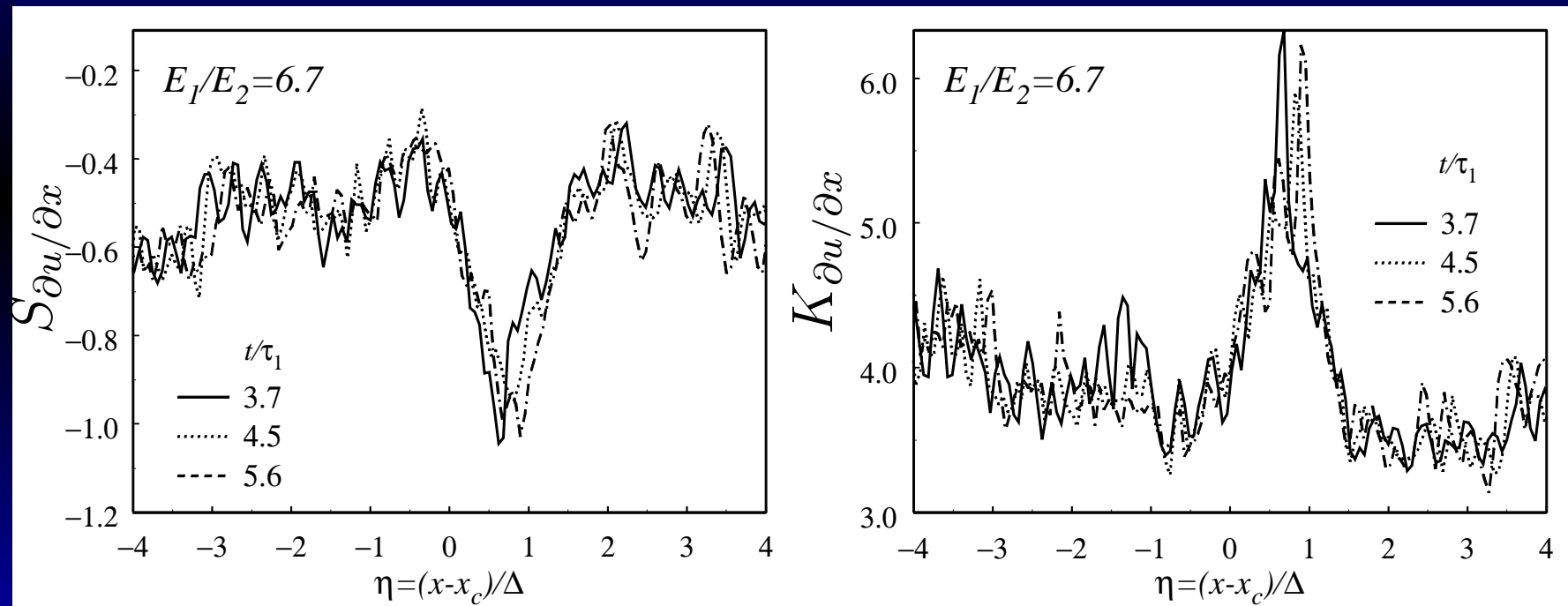
$S_{max}$ ,  $K_{max}$  = maximum of Skewness and Kurtosis in the mixing layer

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



# Small scale intermittency

Velocity component in the mixing direction,  
longitudinal moments:  $E_1/E_2 = 6.7$ ,  $l_1/l_2 = 1$   
 $Re_\lambda = 45$

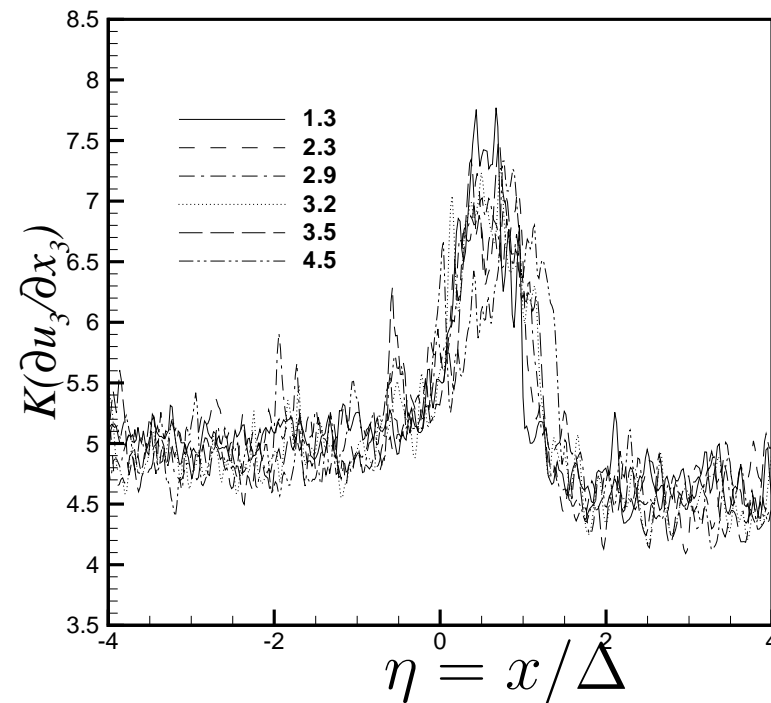
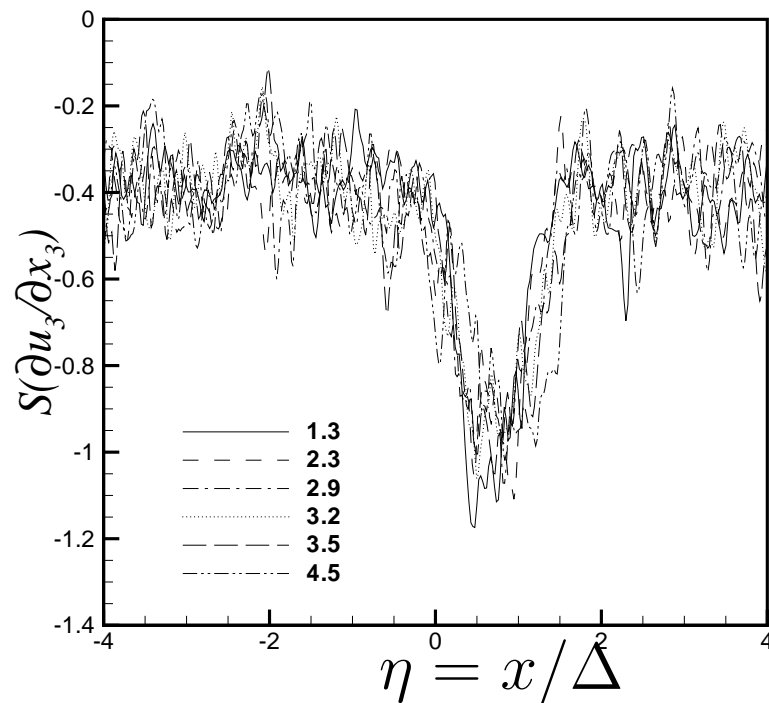


$\eta$  is the dimensionless coordinate along the mixing  
 $\Delta$  is the mixing half-width



# Small scale intermittency

Velocity component in the mixing direction,  
longitudinal moments:  $E_1/E_2 = 6.7$ ,  $l_1/l_2 = 1$   
 $Re_\lambda = 150$



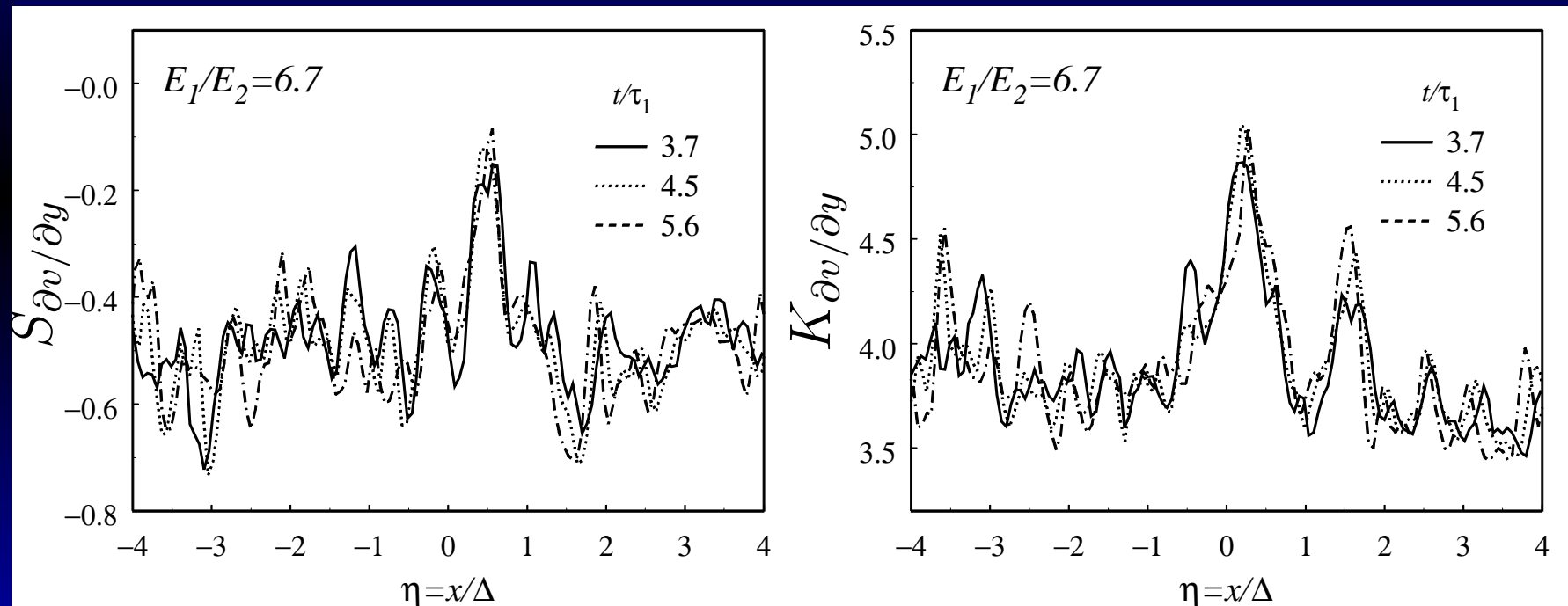
$\eta$  is the dimensionless coordinate along the mixing  
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# Small scale intermittency

Velocity component normal to the mixing direction,  
longitudinal moments:  $E_1/E_2 = 6.7$ ,  $l_1/l_2 = 1$

$$Re_\lambda = 45$$

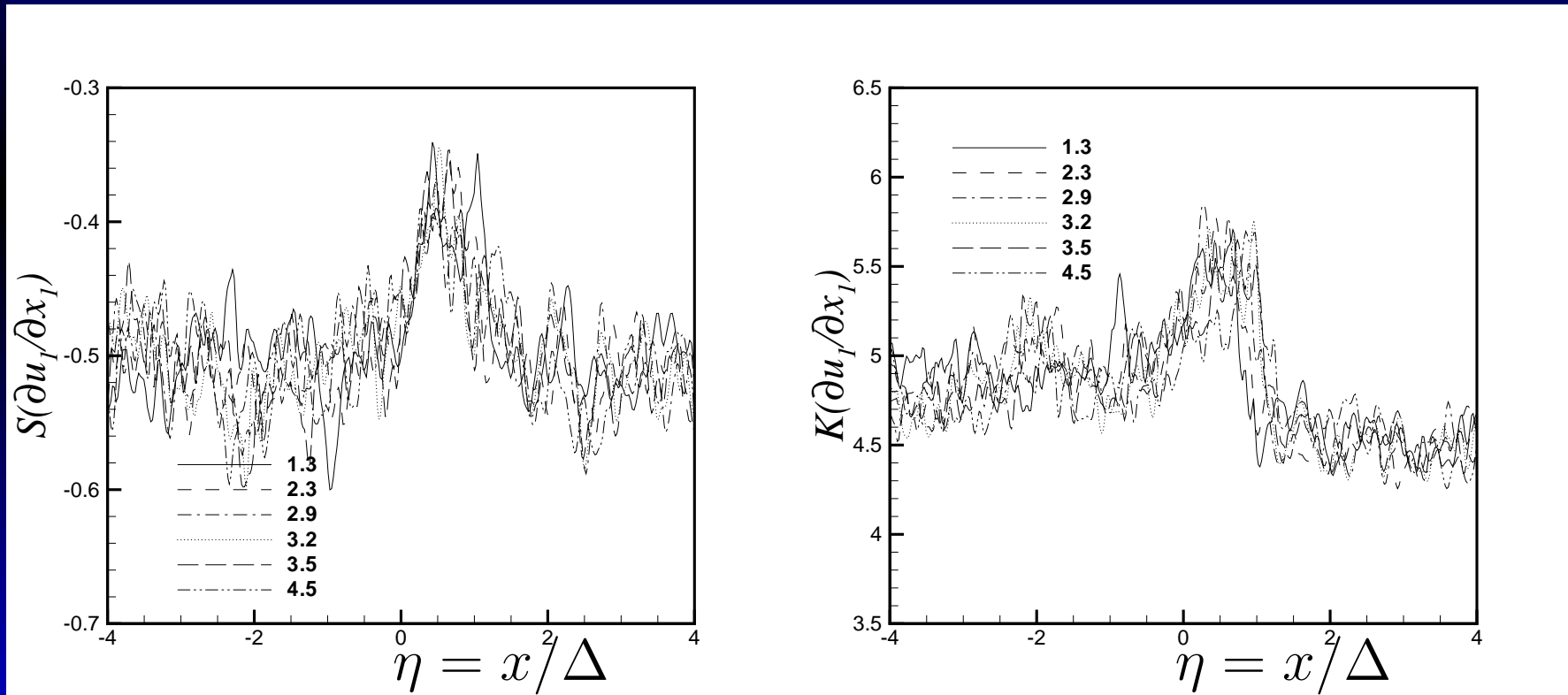


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# Small scale intermittency

Velocity component normal to the mixing direction,  
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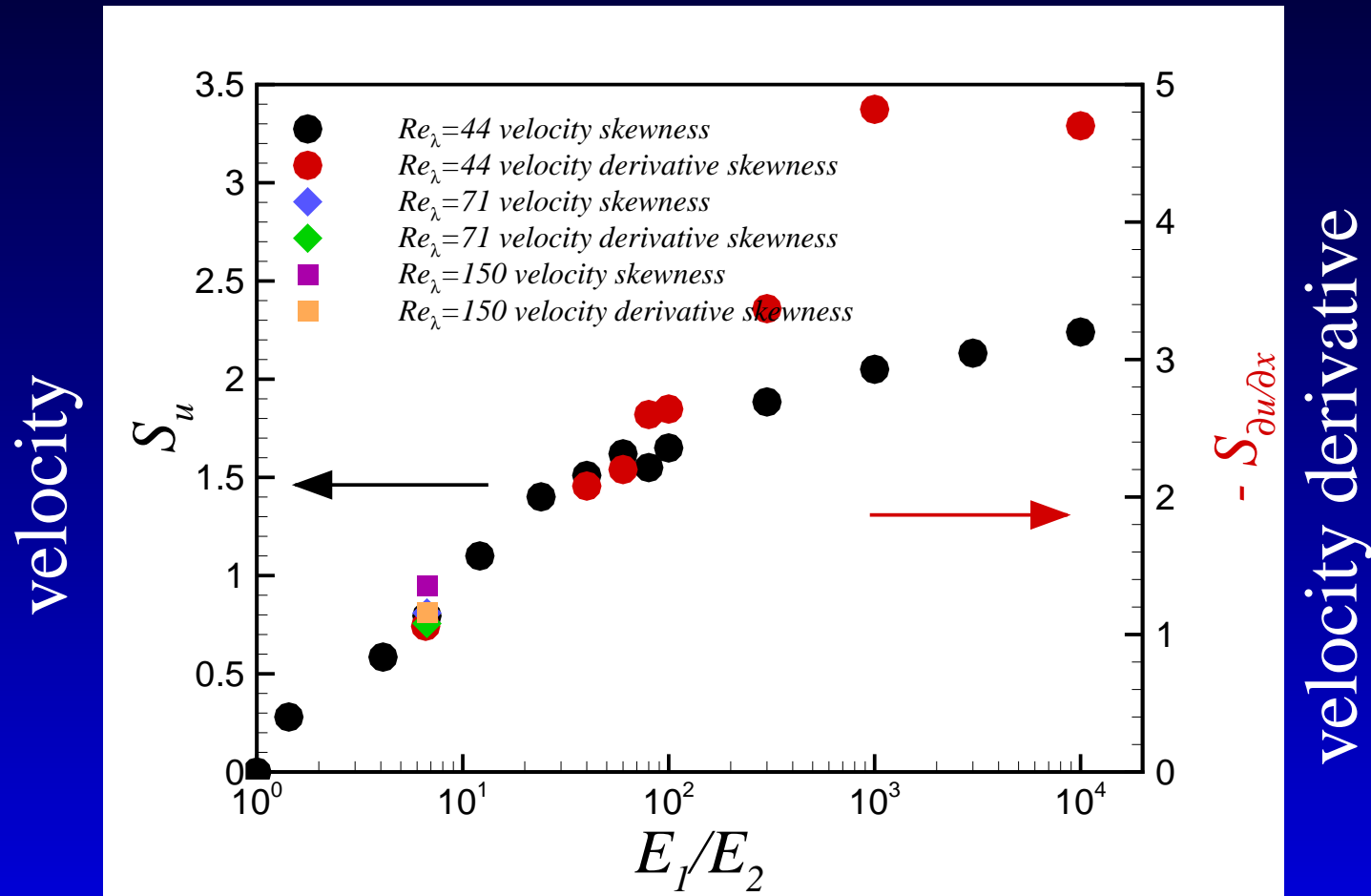


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# Asymptote for $E_1/E_2 \rightarrow +\infty$

Skewness:

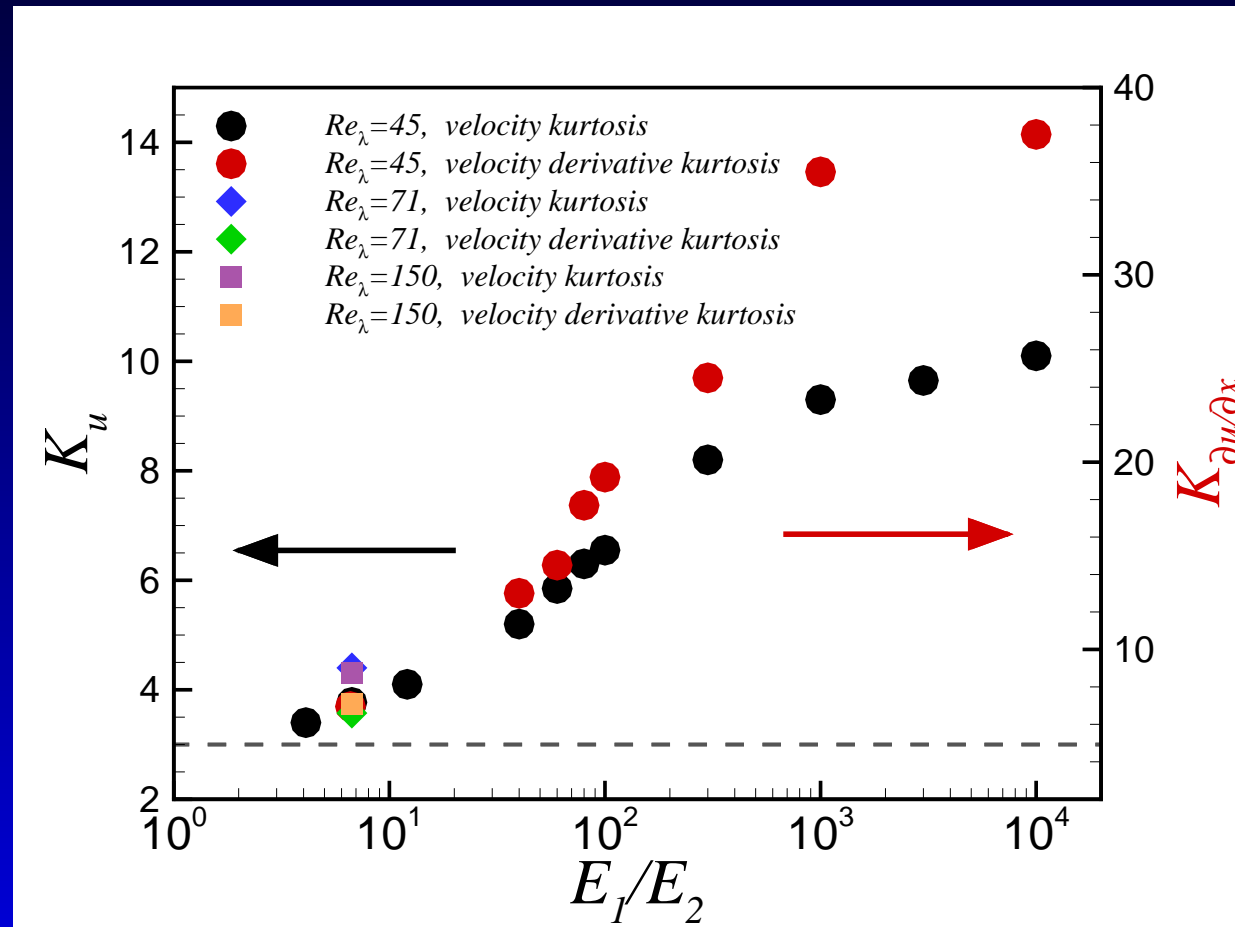


$u, x$  in the mixing direction



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

Kurtosis:

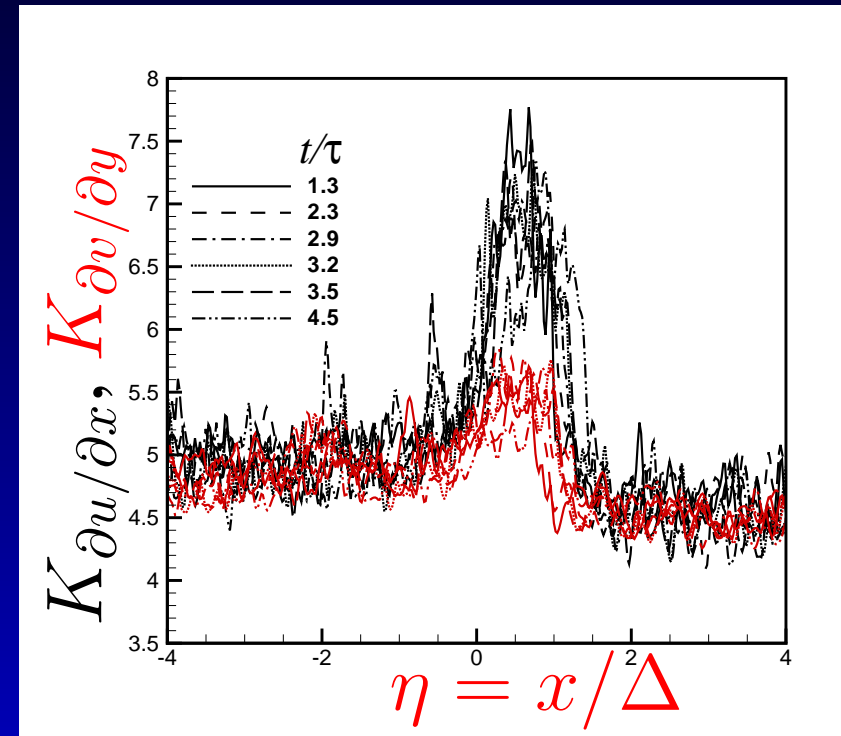
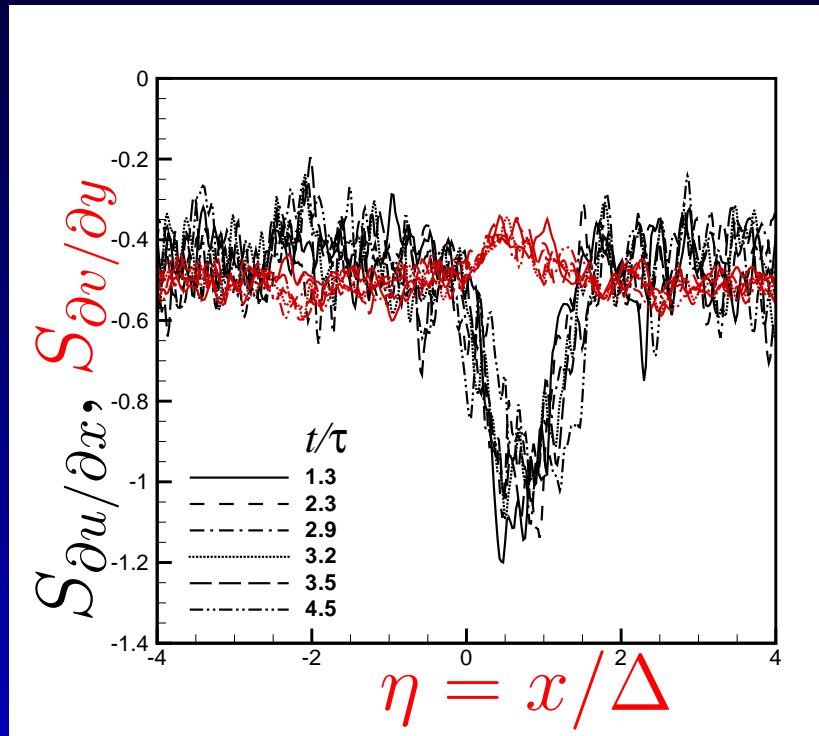


$u, x$  in the mixing direction



# Longitudinal derivatives

General behaviour in all situations



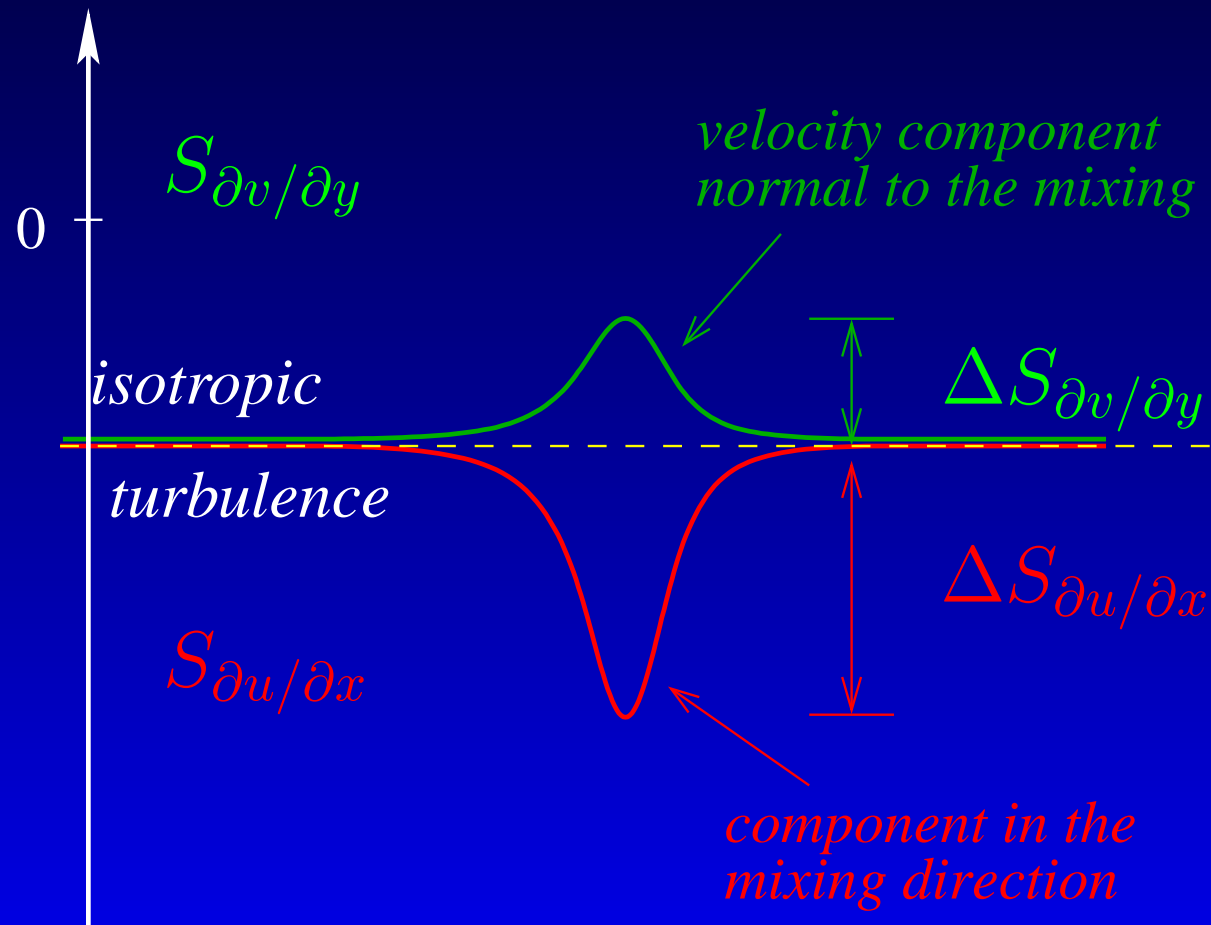
(data at  $Re_\lambda = 150$ ,  $E_1/E_2 = 6.7$ ).





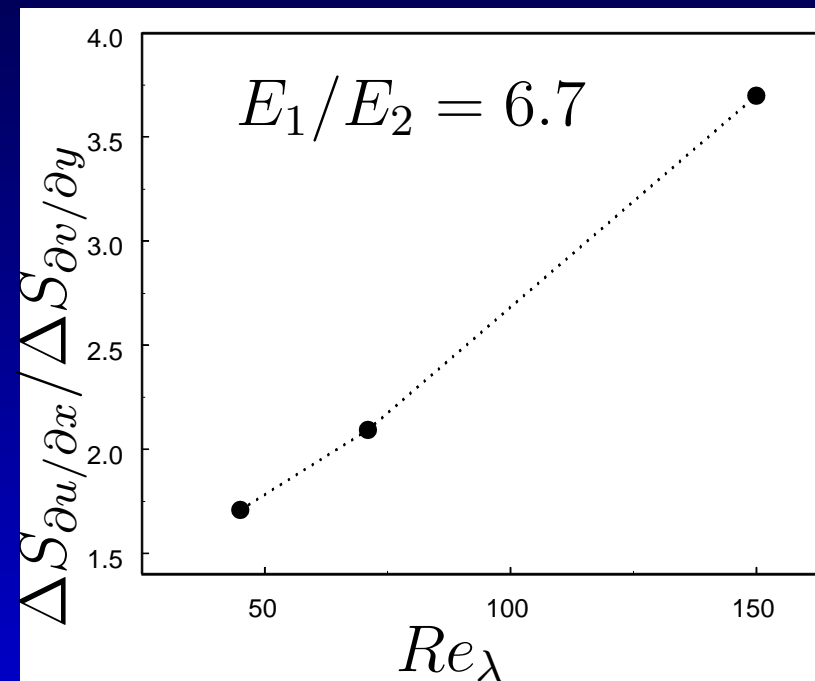
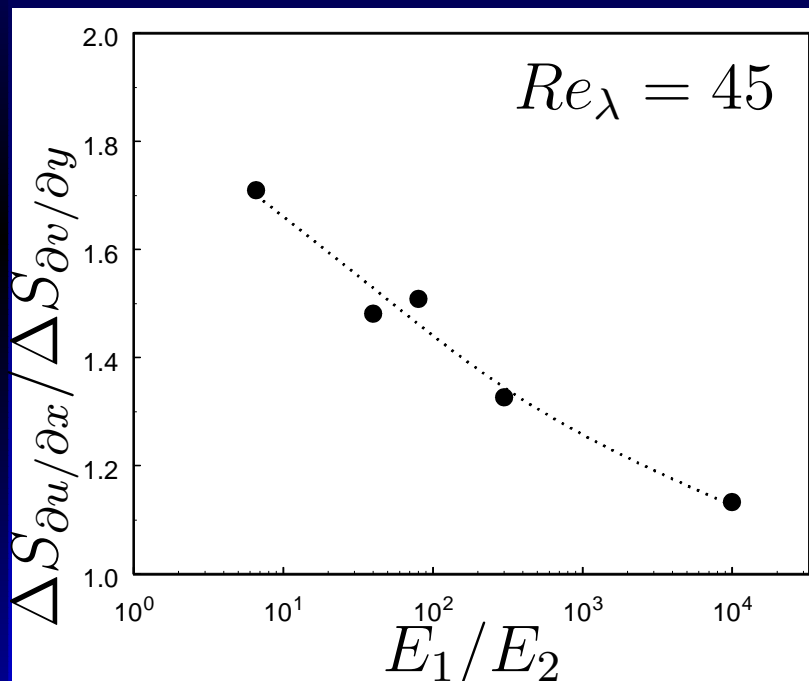
# Longitudinal derivatives

Scheme of the general behaviour for the longitudinal skewness



# Longitudinal skewness

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

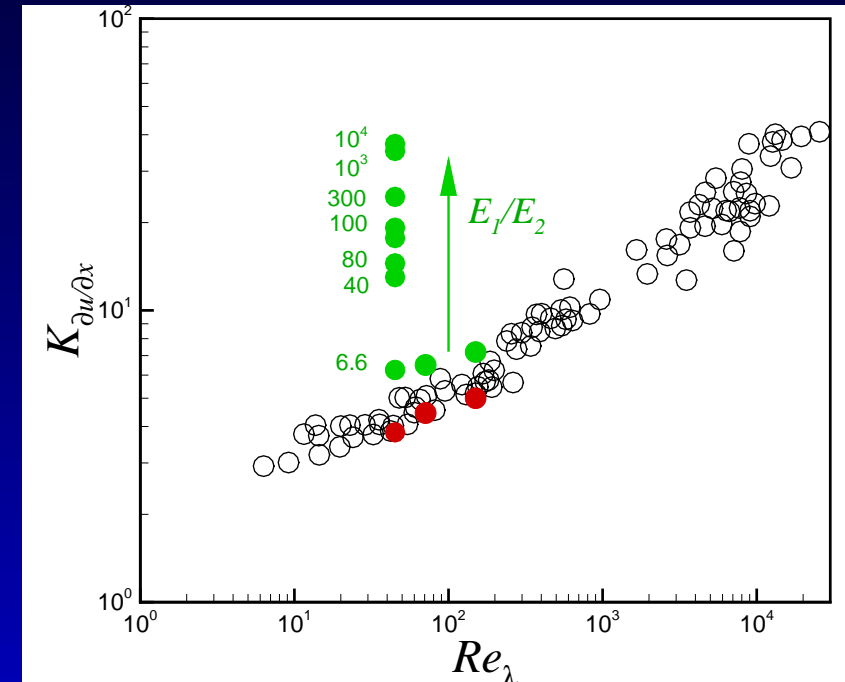
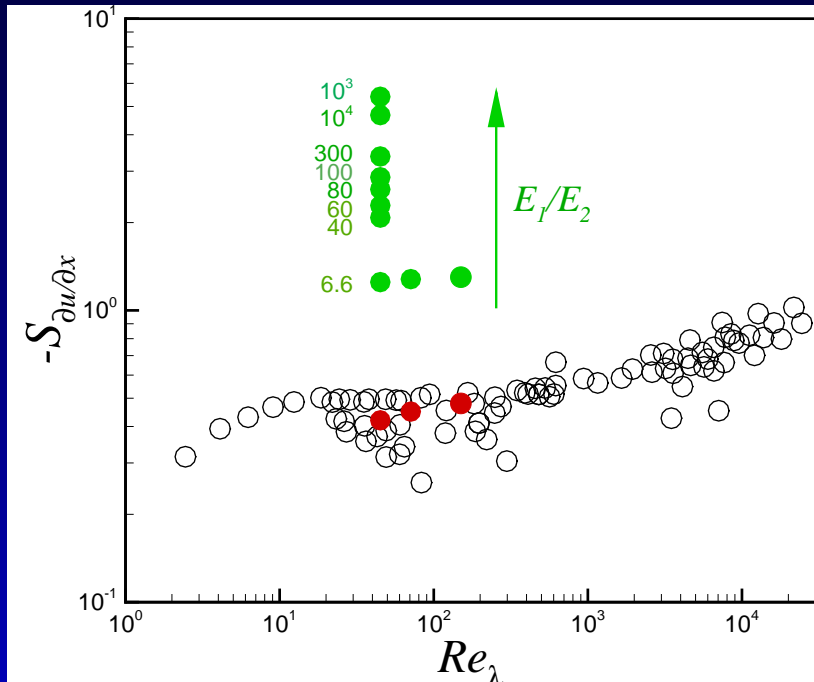


$$\Delta S = | S_{mixing} - S_{HIT} |$$



# 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*



# 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 third order moments
  - ▶ longitudinal velocity derivatives (3<sup>rd</sup> and 4<sup>th</sup> 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 $l_1/l_2 = 1, R_\lambda = 45$													
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 $l_1/l_2 = 1, R_\lambda = 71$													
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 $l_1/l_2 = 1, R_\lambda = 150$													
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), $E_1/E_2 \approx 7, l_1/l_2 \approx 1.5 \div 1.7$													
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  $\partial u_i / \partial x_j$

