

A Numerical Simulation of Particle Deposition in Turbulent Pipe Flow

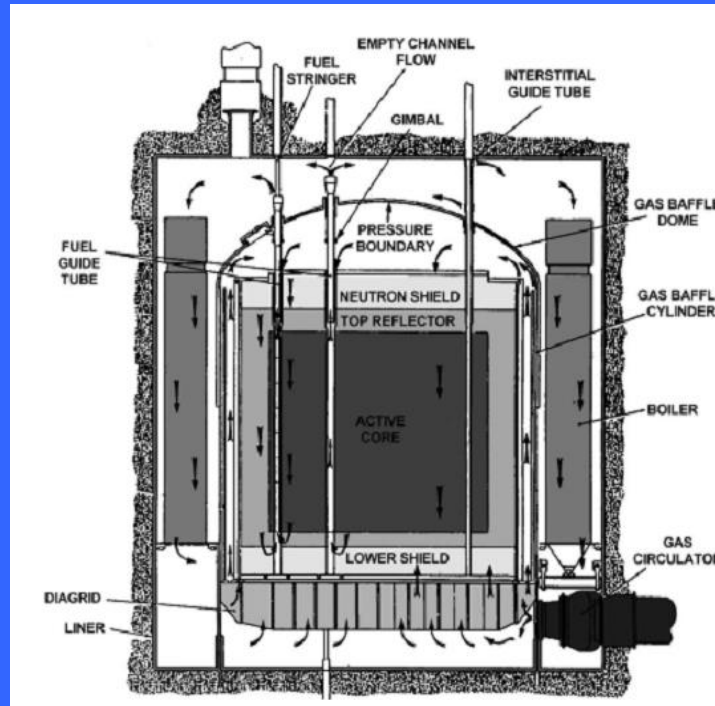
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Motivation

- Prediction of the transport, deposition and resuspension processes of inertial radioactive particles in turbulent flow is important for assessing safety cases in many nuclear applications
 - Transport graphite or U_3O_8 particles in the gas circuit of an AGR



(Courtesy of British Energy)

Particle transport in turbulent flows

❑ Deposition of particles is controlled by transport in turbulent boundary next to depositing surface. Particle deposition in pipe flow provides a suitable benchmark (*Liu & Agarwal 1974*)

❑ Methodology

Lagrangian particle tracking in a prescribed or pre-computed flow field

- Discrete random walk eddy interaction model,
eg. Hutchinson & Hewitt 1970, Gosman & Ioannides 1983, Kallio & Reeks 1989
- Continuous random walk methods based on Langevin equation,
eg. Iliopoulos & Hanratty, 1999, Dehbi 2008
- Methods based on coherent structures in the turbulent boundary layer,
eg. Cleaver and Yates 1975, Marchioli & Soldati 2002, Guingo & Minier 2008

Numerical Investigation

□ Particle equation of motion

$$\frac{dU_i^p}{dt} = \frac{1}{\tau_p} C_D \frac{Re_p}{24} (U_i - U_i^p)$$

Particle velocity

Fluid velocity

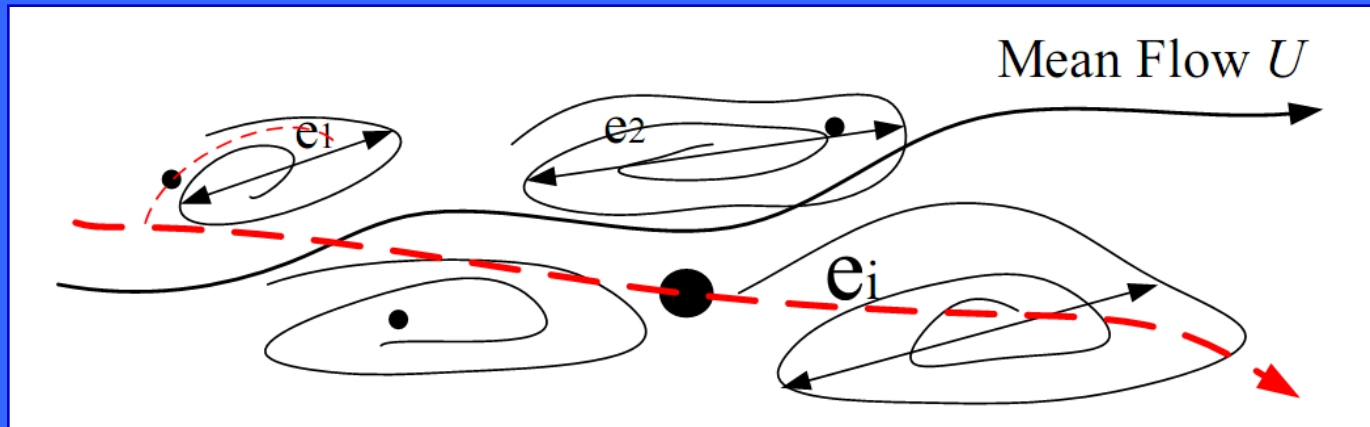
$$dX_i^p = U_i^p dt$$

$$\tau_p = \frac{\rho_p d_p^2}{18\mu}$$

Particle respond to a change of fluid velocity

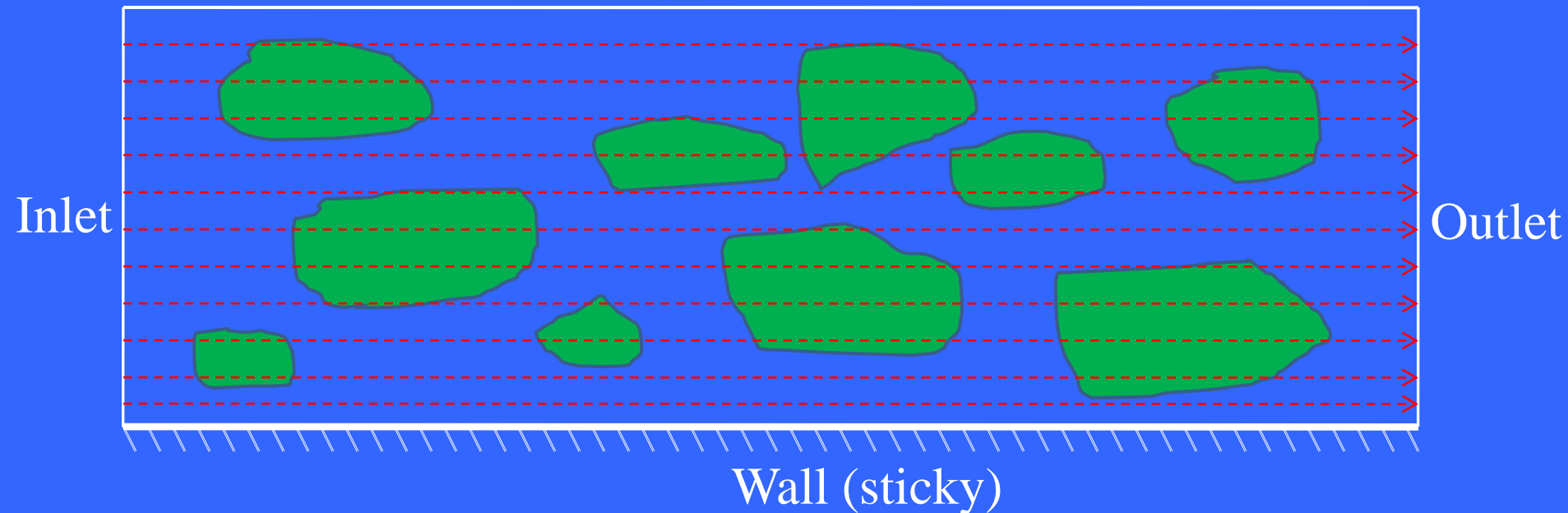
$$Re_p = \frac{d_p |U_i - U_p|}{\nu}$$

Eddy interaction model

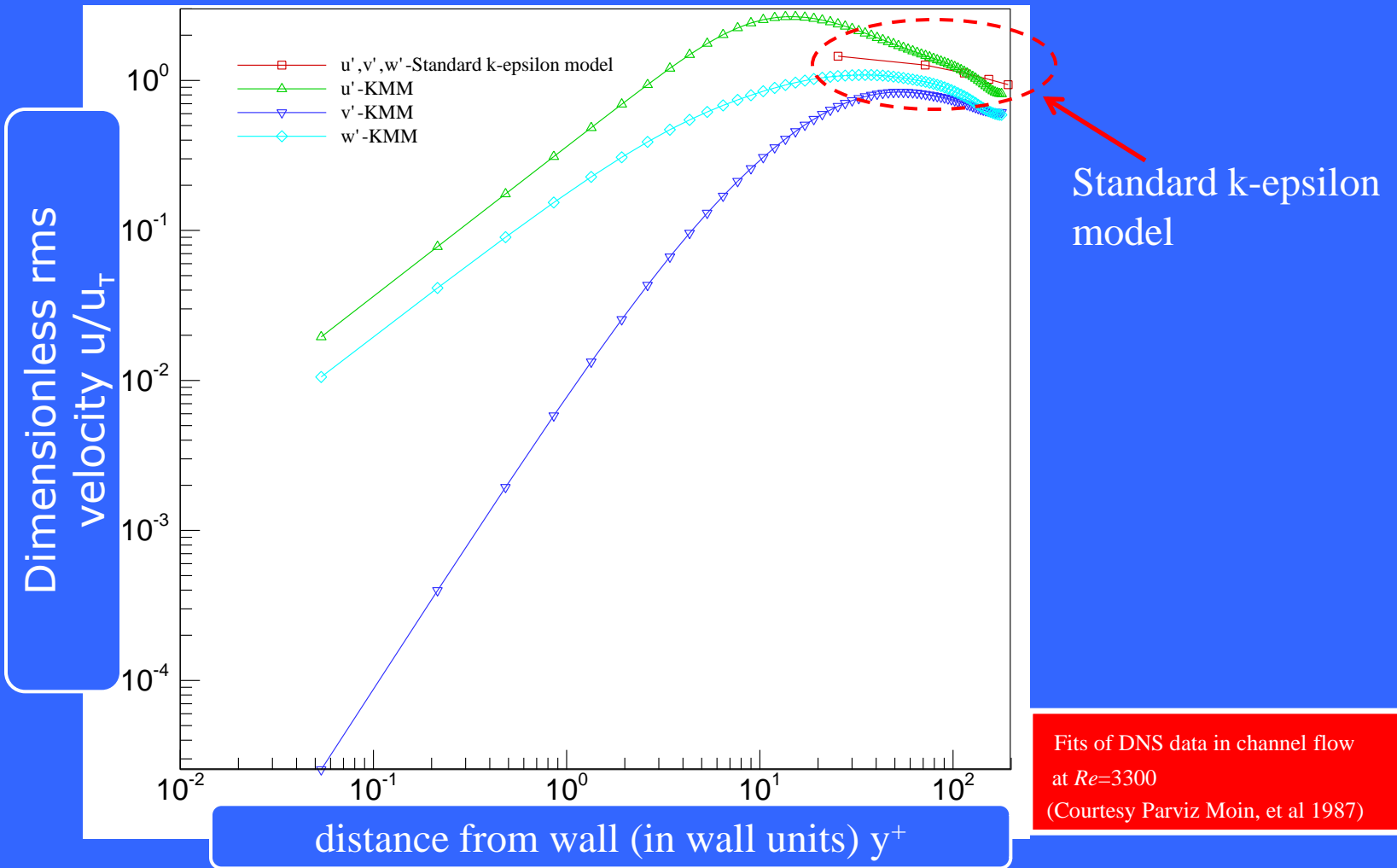


Computation domain (a real turbulent boundary layer)

$y^+ = 200$



Anisotropic of turbulence in the real boundary layer

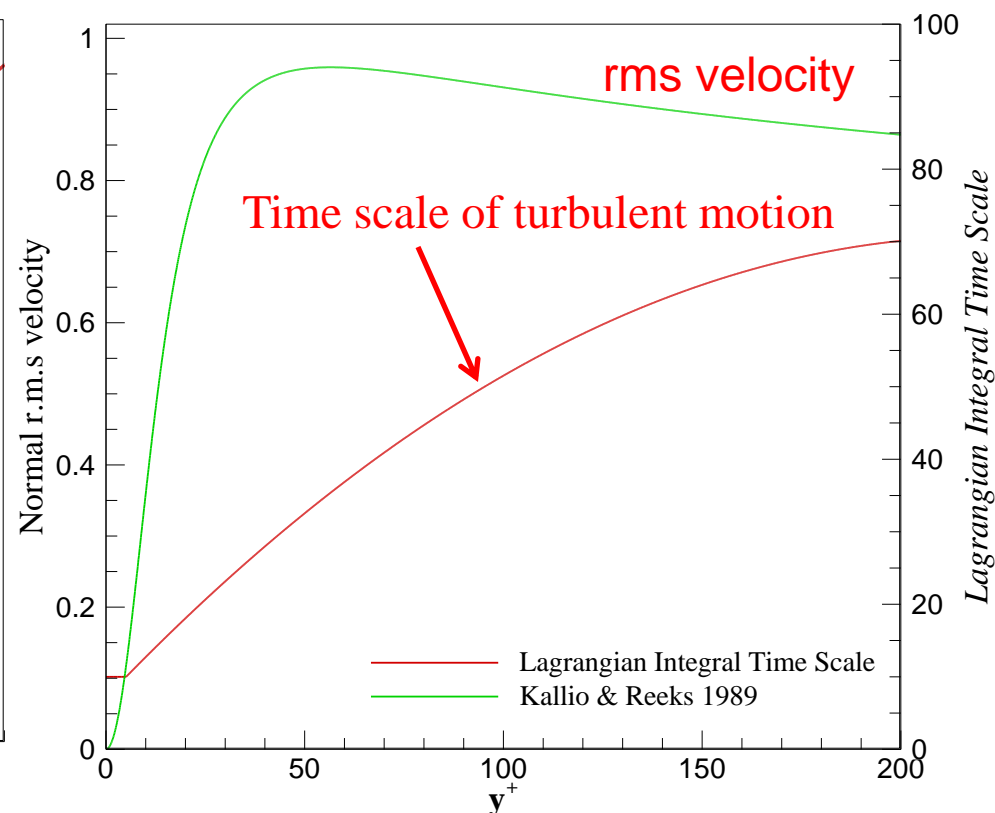
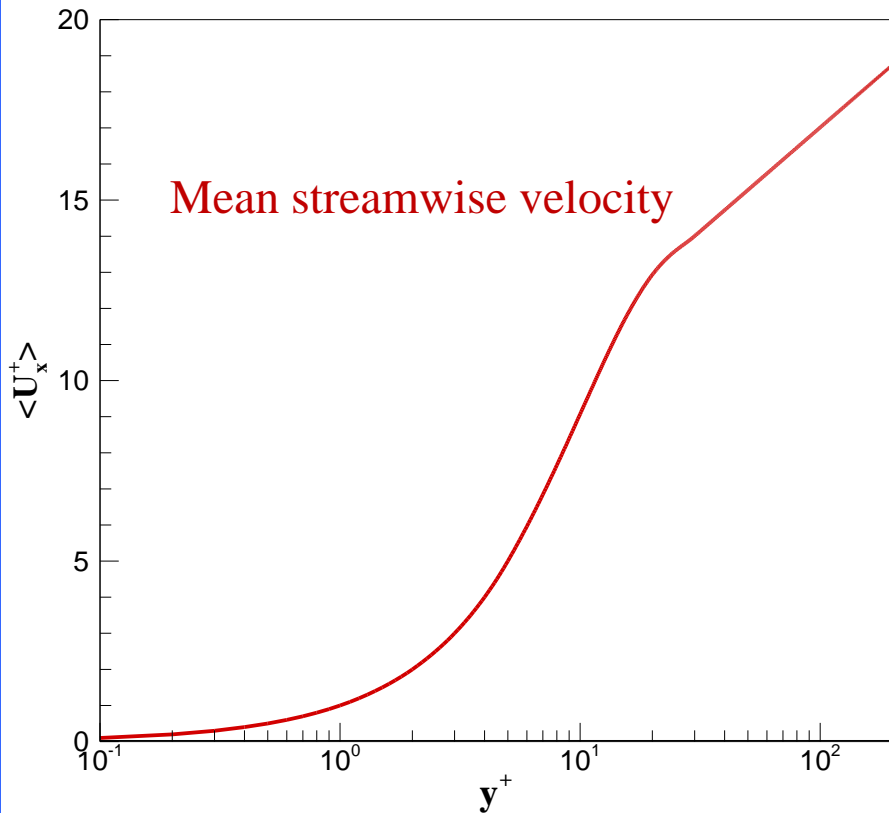


□ Modelled statistics of turbulent boundary layer

$$u = \bar{u} + u'$$

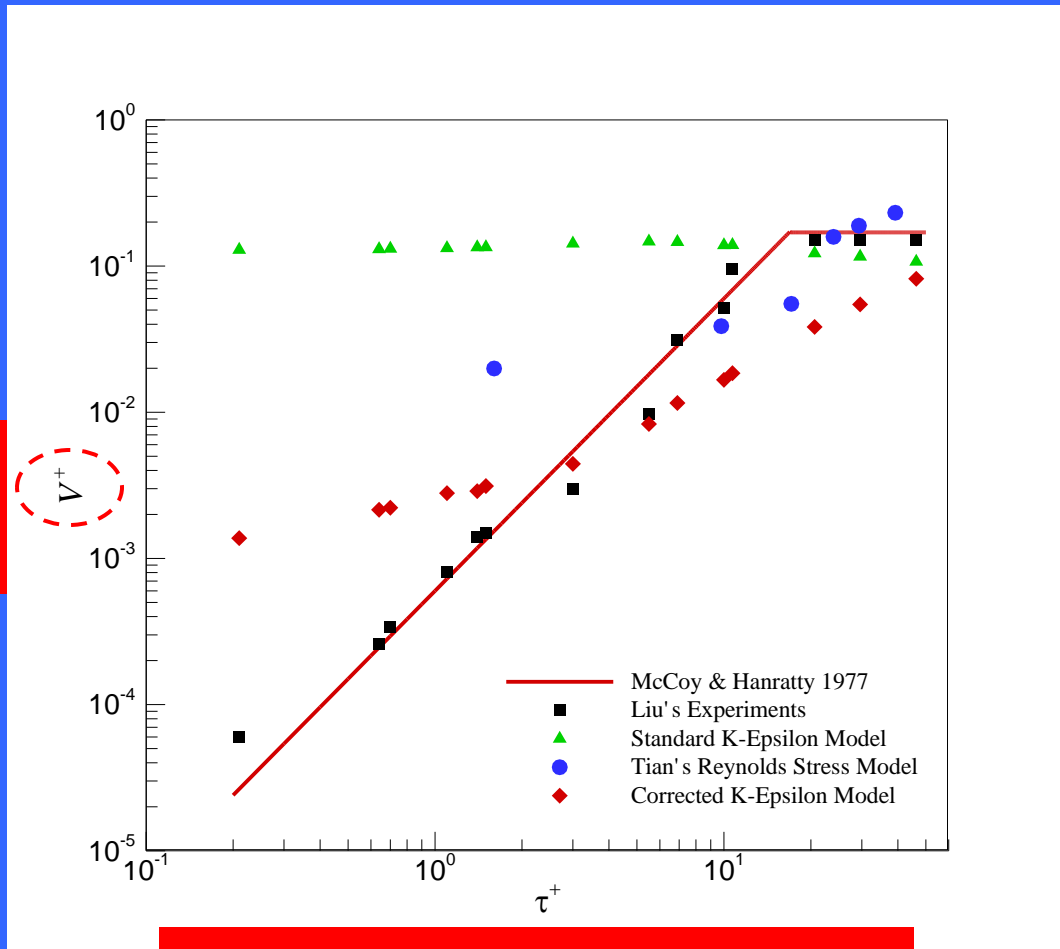
$$u' = \zeta \sqrt{\overline{u'^2}} \quad \zeta \sim N(0,1)$$

$$T_L = C_L \frac{k}{\varepsilon}$$



Results for particle deposition from basic models

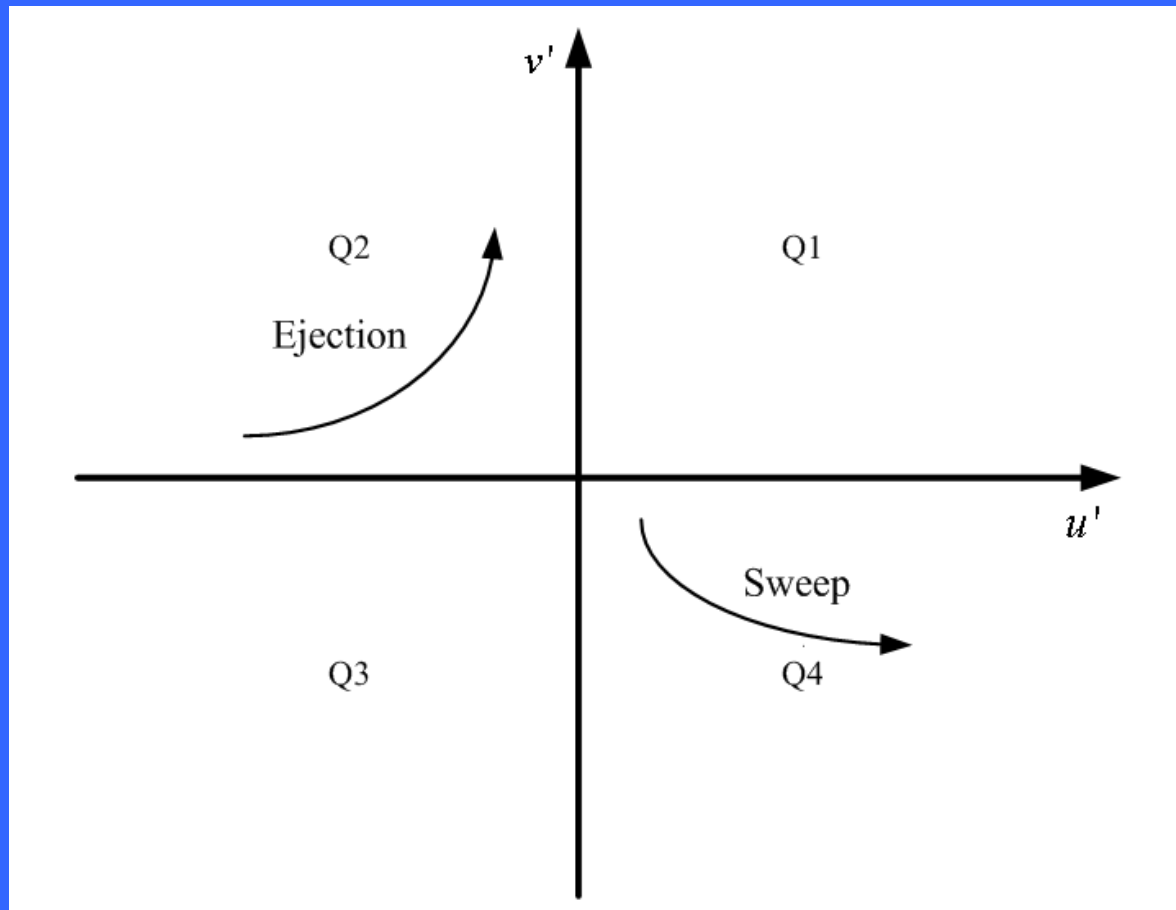
Dimensionless
particle deposition
velocity



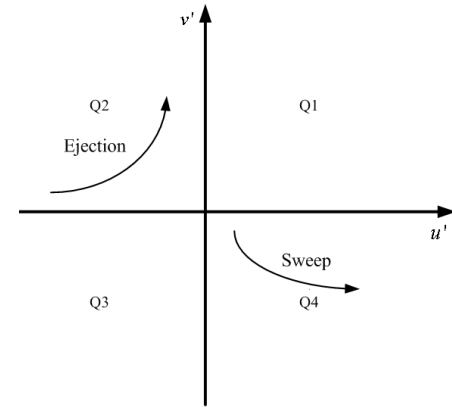
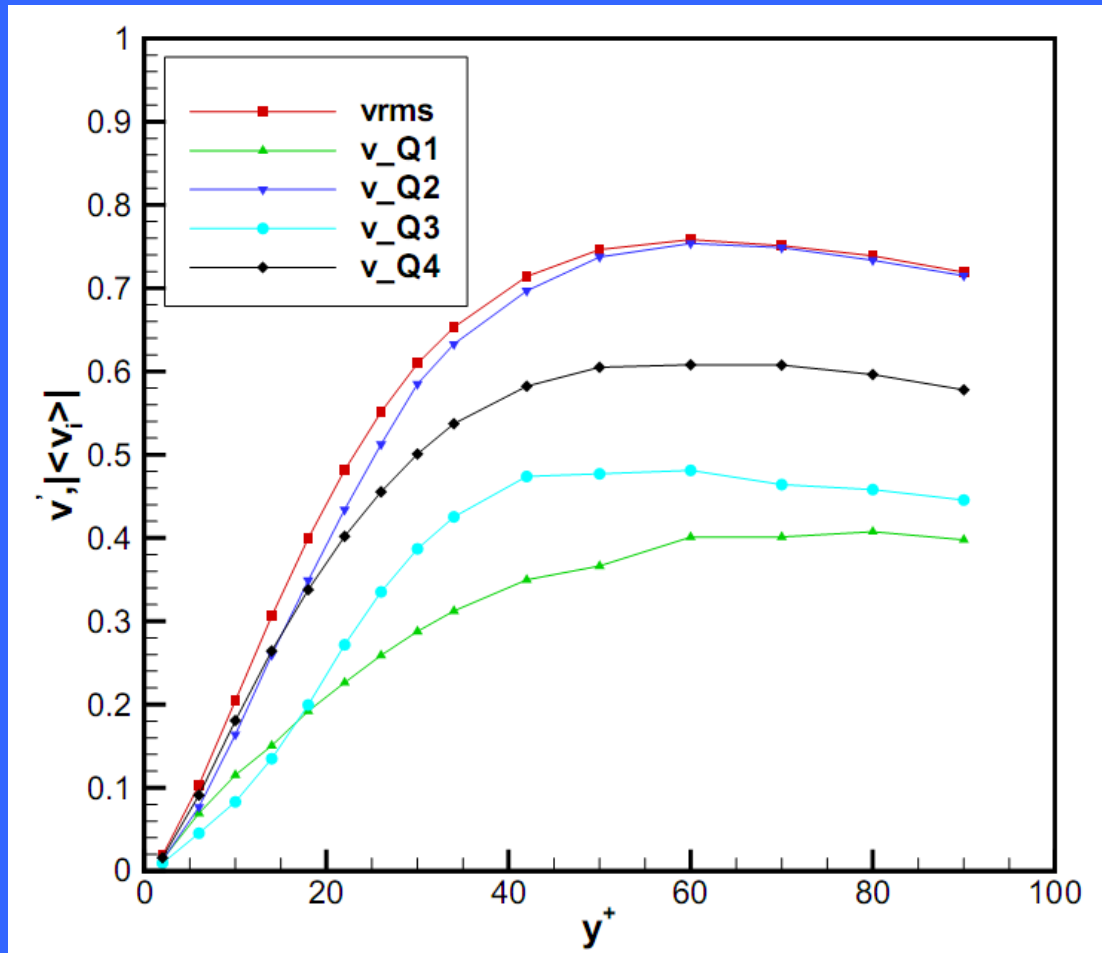
Dimensionless particle response time

Coherent structures --- **Willmarth's** quadrant analysis 1972

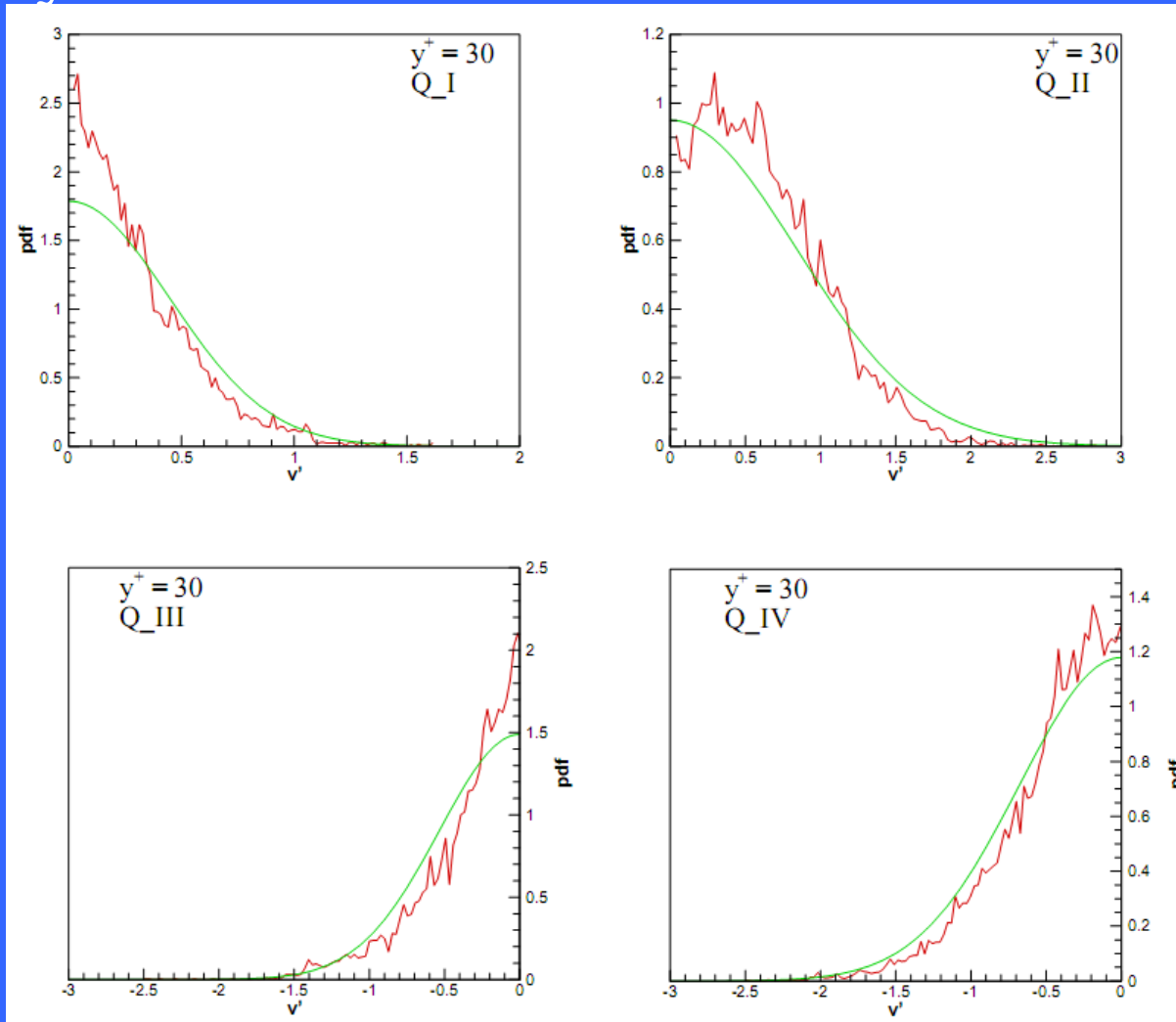
- Ejections and sweeps in turbulent boundary layer



Verification and argumentation of Willmarth's quadrant data by LES (FLUENT v6.3.26)

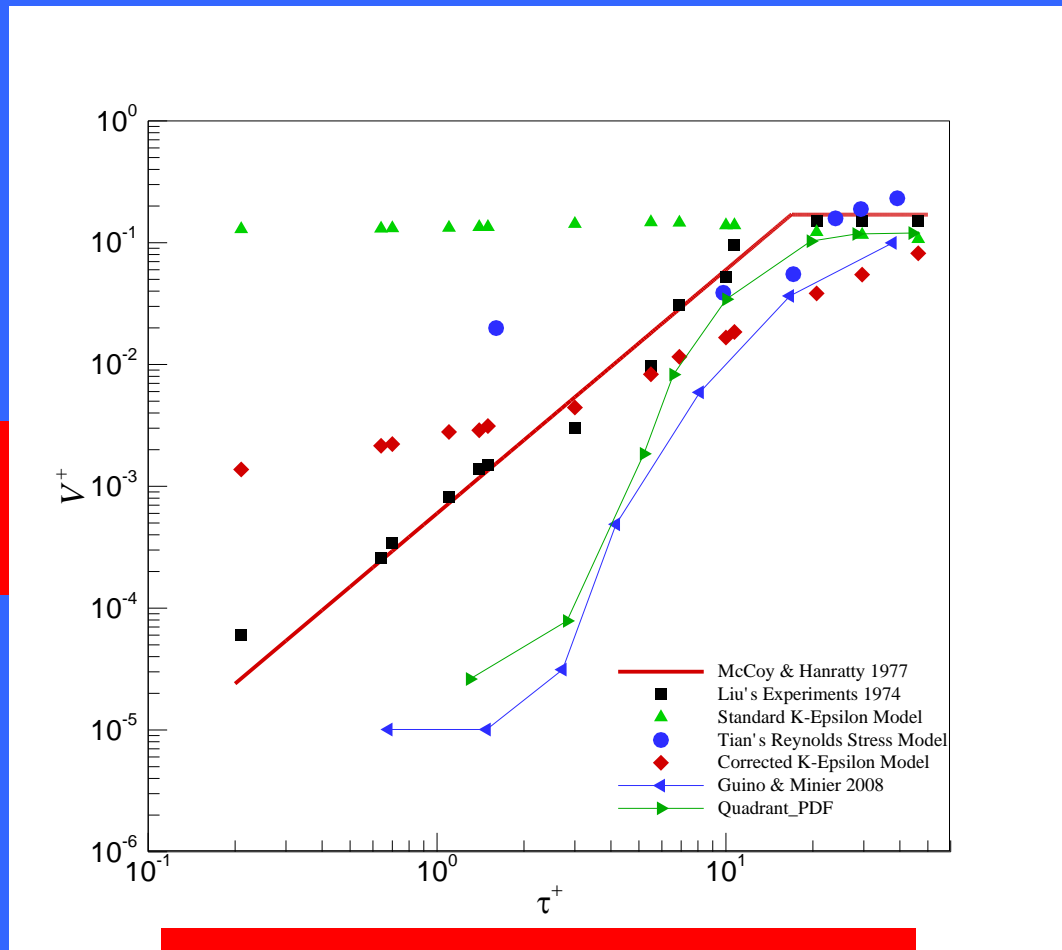


Implementation of quadrant pdf model in discrete eddy interaction model



Results of quadrant pdf model and comparisons

Dimensionless
particle deposition
velocity



Dimensionless particle response time

Conclusions

- ❑ The present model based on quadrant pdf method improves deposition prediction, giving similar results like *Guingo & Minier 2008*
- ❑ However the model still under predicts the deposition velocity for small particles - a “worst case” scenario for making a safety case
- ❑ The possible reasons
 - Over prediction of efficiency of ejection events removing particles from near wall region in my model (*Marchioli & Soldati 2002*)
 - discrete fluid velocity between two eddies, not physically correct
 - does not satisfy well-mixed condition

Future work

- ❑ Integration of the present model to CFD package (FLUENT v6.3.26)
- ❑ Investigation of the relative efficiency of sweeps and ejections on particle deposition
- ❑ Employing continuous random walk model (Langevin equation) to address the issue of discrete fluid velocity and well-mixed condition