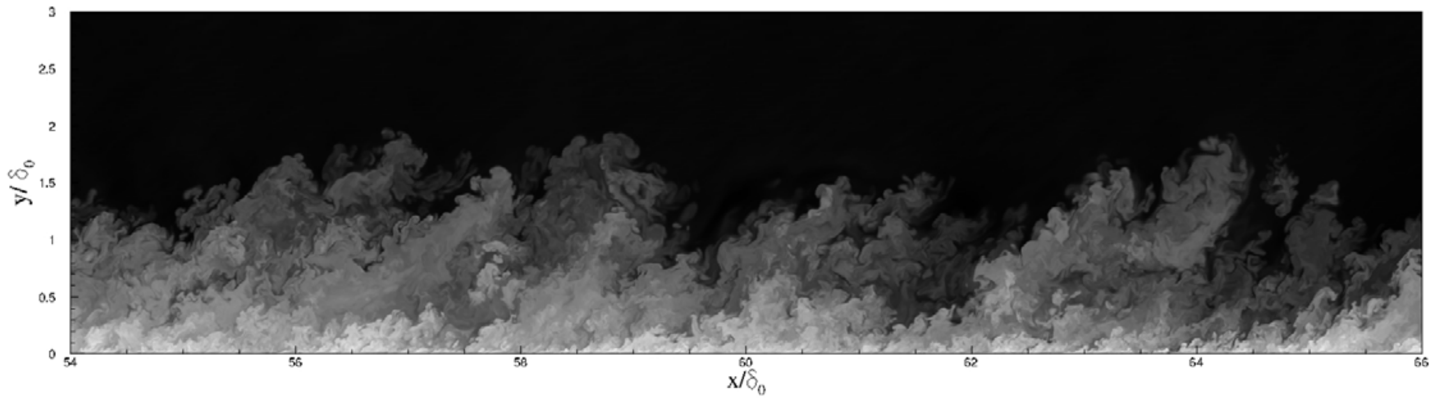
Background

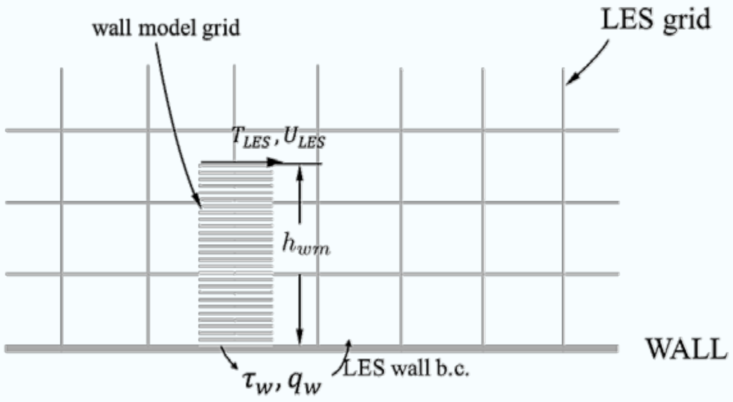
When turbulence meets wall



- Tremendous smaller scales at inner layer
- Chapman (1979): $N_{pts} \sim Re_c^{1.8}$ required to resolve inner layer
- DNS resolution: $N_{pts} \sim Re_c^{2.25}$
- Prohibitive computational cost

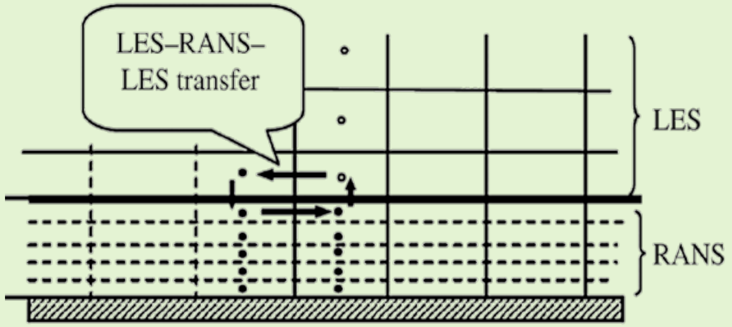
Different wall-modeling techniques

- Wall-Modeled LES



- *LES formulation over the whole domain*
- *Wall shear-stress provided by a wall model and feeding to LES as boundary conditions*
- *Much less model parameters*

- Hybrid RANS/LES



- *LES formulation away from wall*
- *RANS formulation near walls*
- *Interface location shall be carefully selected*
- *Include many parameter in the RANS region*

DG-based wall-modeled LES

Physics-based wall-shear-stress model:

- We can view the DG solution as a local modal decomposition

$$U_e(t,x) = \boxed{\sum_{i=1}^{N_p} \widetilde{U}_{e,i}(t)\phi_{e,i}(x)}, \quad x \in \Omega_e$$

Linear basis

$$\tau_w/\rho = \nu \frac{\partial u_{//}}{\partial y}\bigg|_{y=0}$$

linear mode should dominate if the BL is resolved up to the viscous sublayer

Remaining part projected to log basis

log mode should dominate if the wall-adjacent cell is situated in log-law region

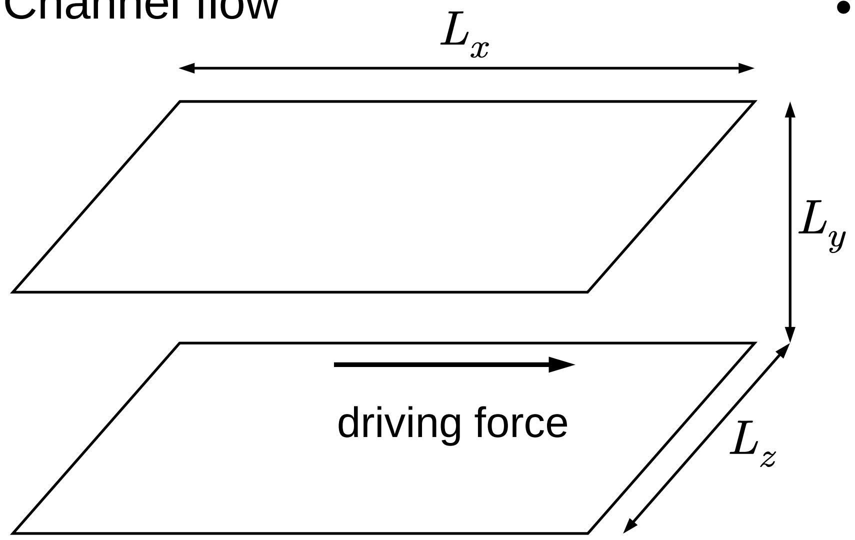
$$u_{//} = \frac{u_\tau}{\kappa}\log\left(\frac{y}{y_0}\right)$$

$$\tau_w/\rho = u_\tau^2$$

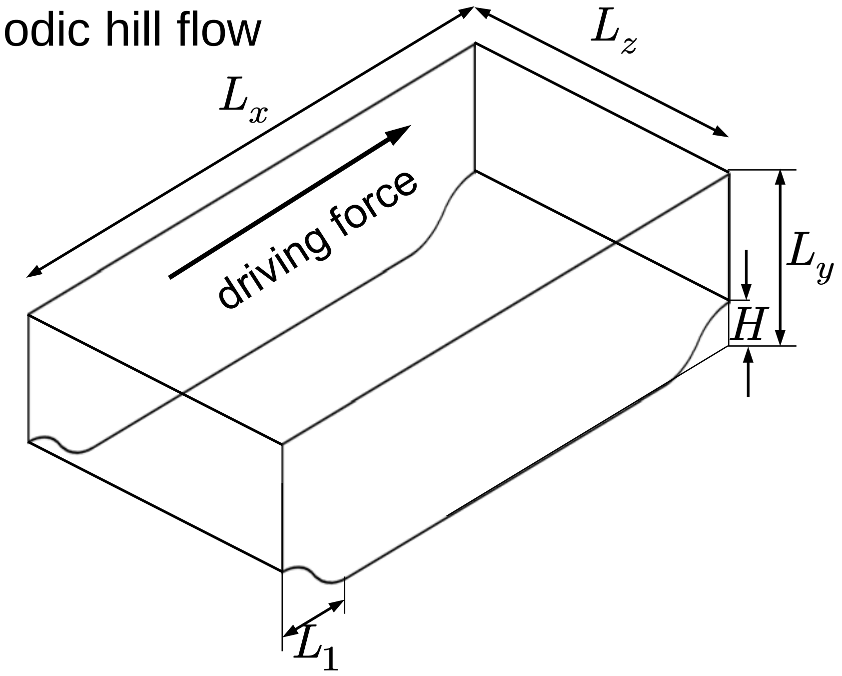
- The modeled wall-shear-stress is the sum of both contributions

Validation study

- Channel flow



- Periodic hill flow



Domain ○ $L_x \times L_y \times L_z \in 2\pi h \times 2h \times 2\pi h$

○ $L_x \times L_y \times L_z = 9H \times 3.036H \times 4.5H,$

$L_1 = 1.929H$

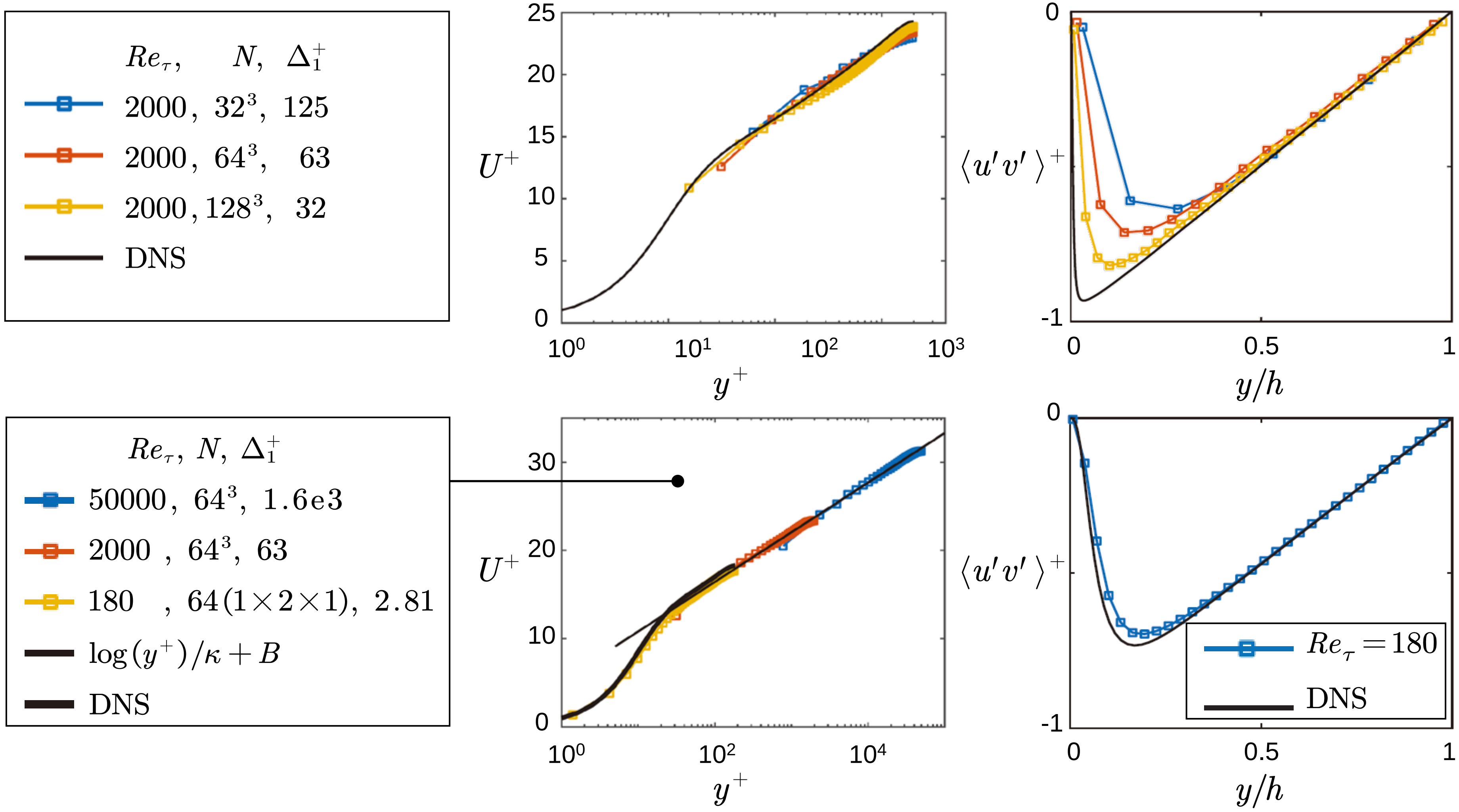
Mesh size (DGP3) $DoF = n_x \times n_y \times n_z = 32^3, 64^3, 128^3$

$DoF = n_x \times n_y \times n_z = 32(2 \times 1 \times 1), 64^3$

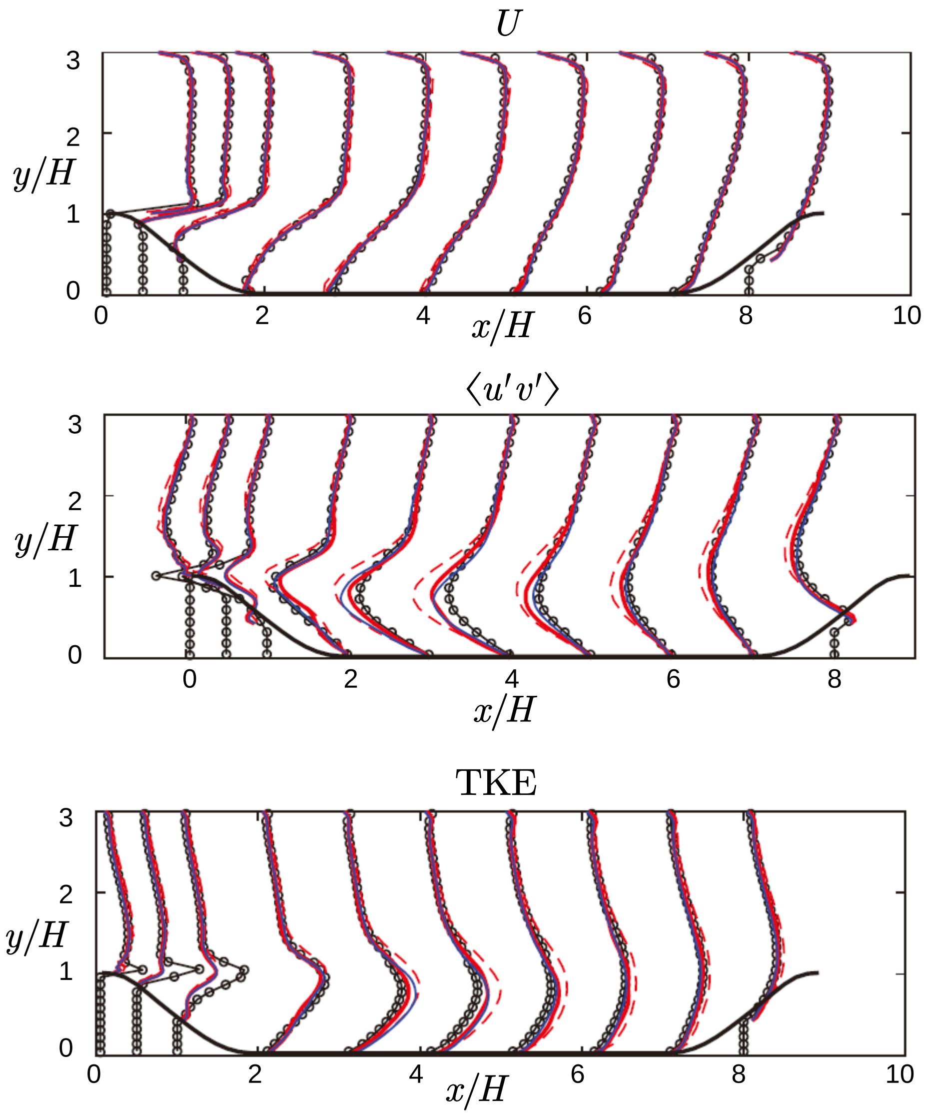
Reynolds No. ○ $Re_\tau = 180, 2000, 50000$

○ $Re_\mathrm{b} = HU_\mathrm{b}/\nu = 10595$

Validation study on WMLES—channel flow



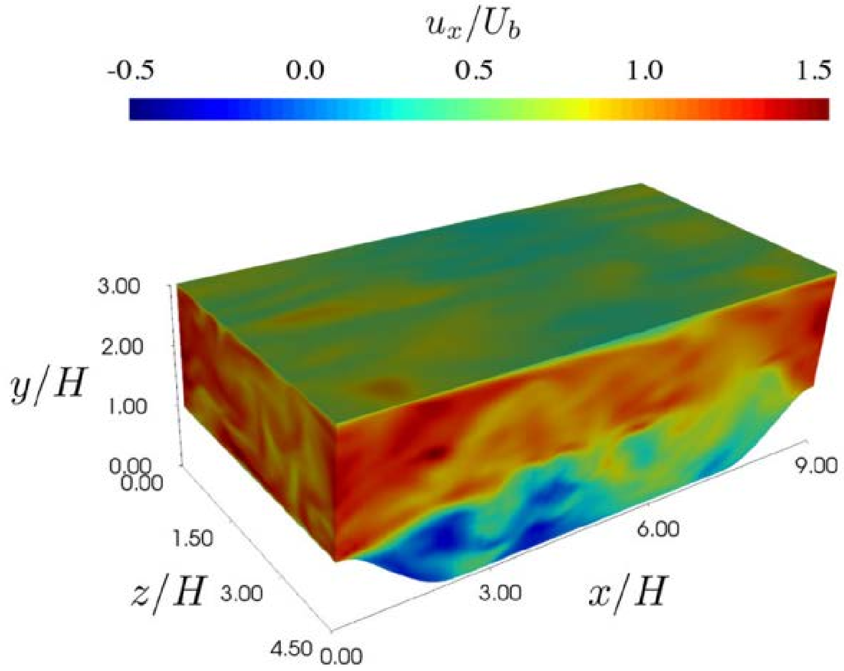
Validation study on WMLES—periodic hill flow



DoF = 64^3

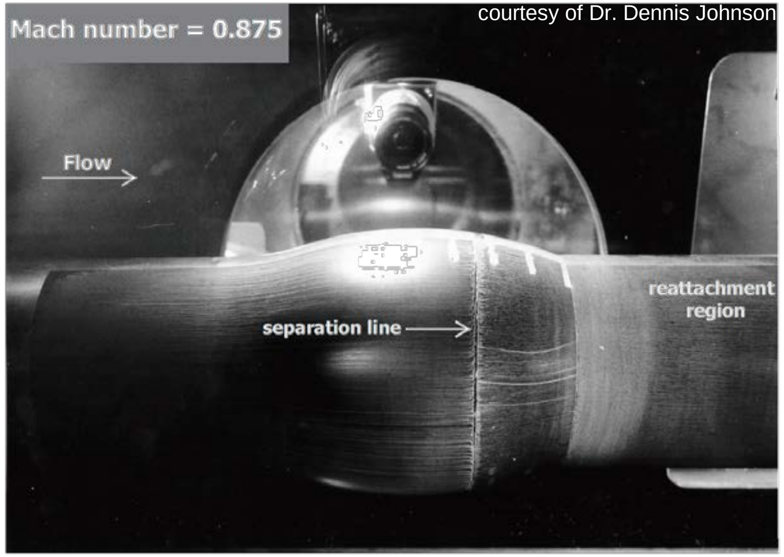
DoF = 64 x 32 x 32

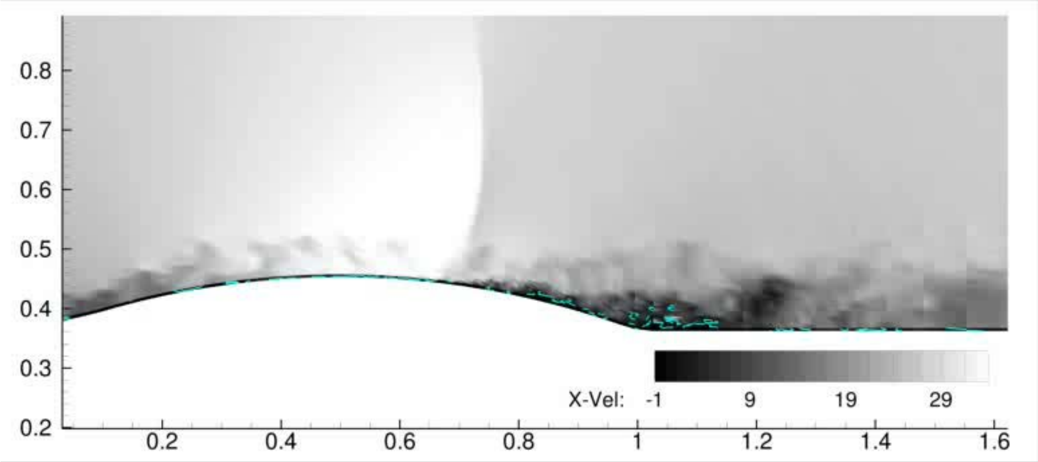
Wall-resolved results



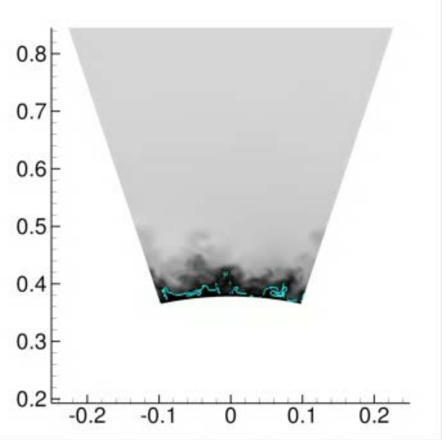
WMLES of NASA transonic bump configuration

- NASA transonic bump configuration





- Key flow features： separation bubble; weak shock
- Computational setup:
  - ➢DGP3; tensor basis; hexahedron
  - ➢218,000 elements; 64 DoF per element; 14M DoF



WMLES of NASA transonic bump configuration

- Existing RANS results

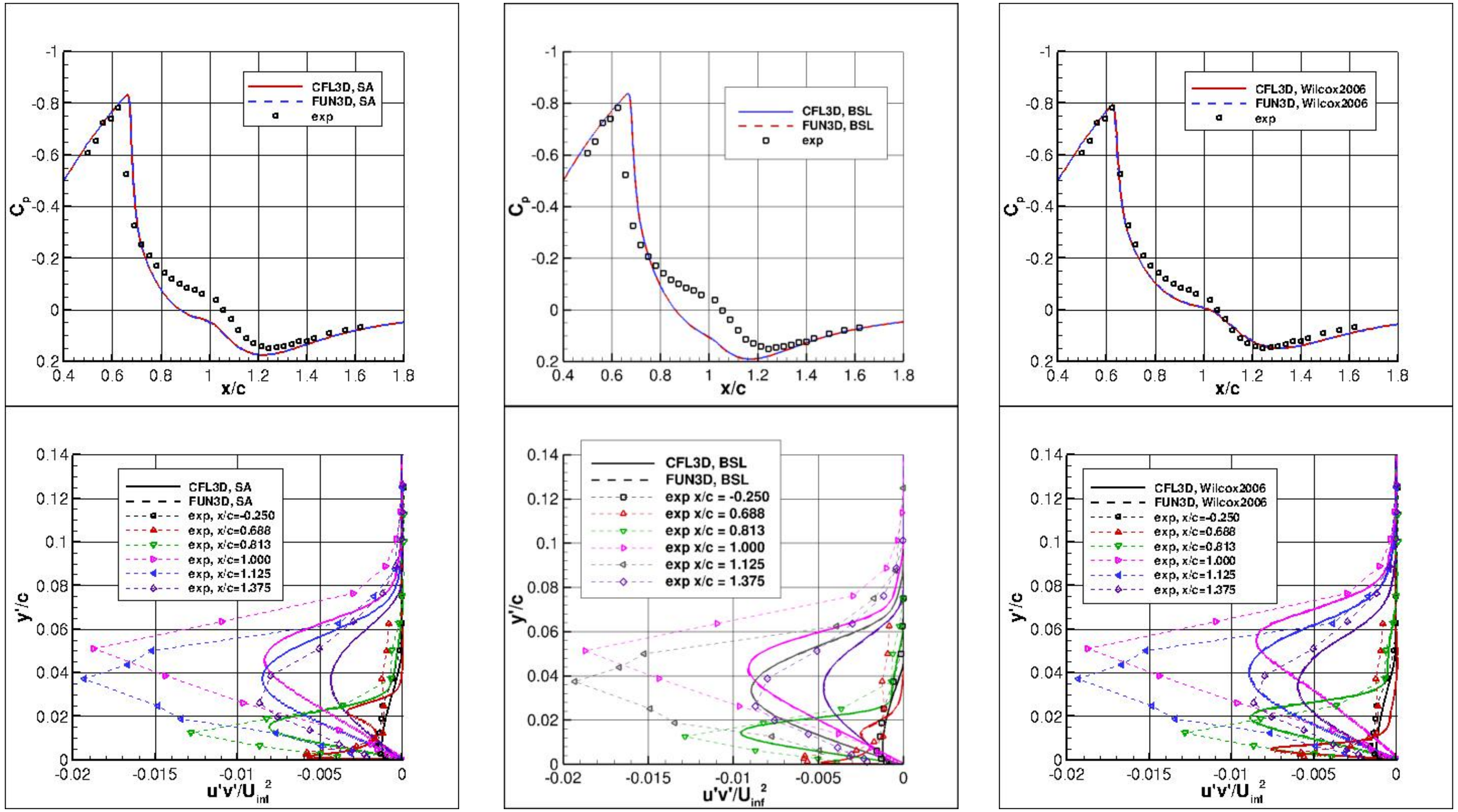
SA model

SST model

Wilcox-Kim model

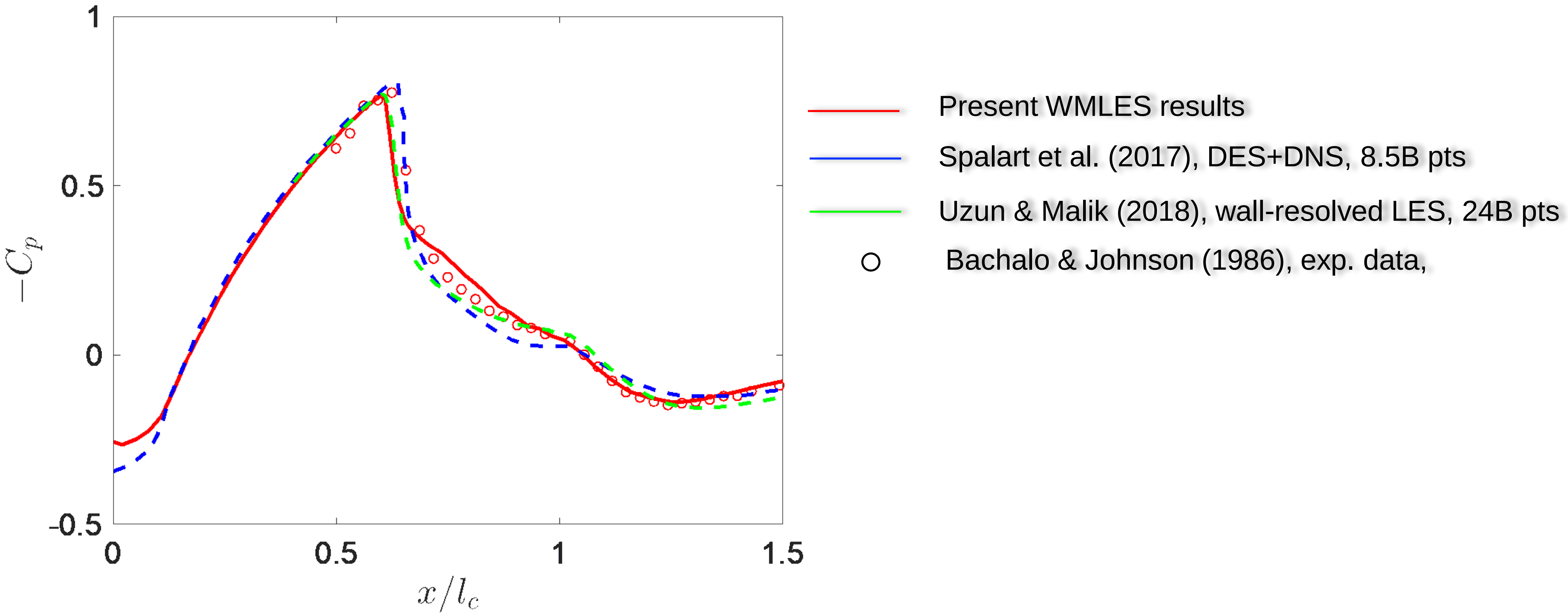
Pressure coefficient

Reynold stress



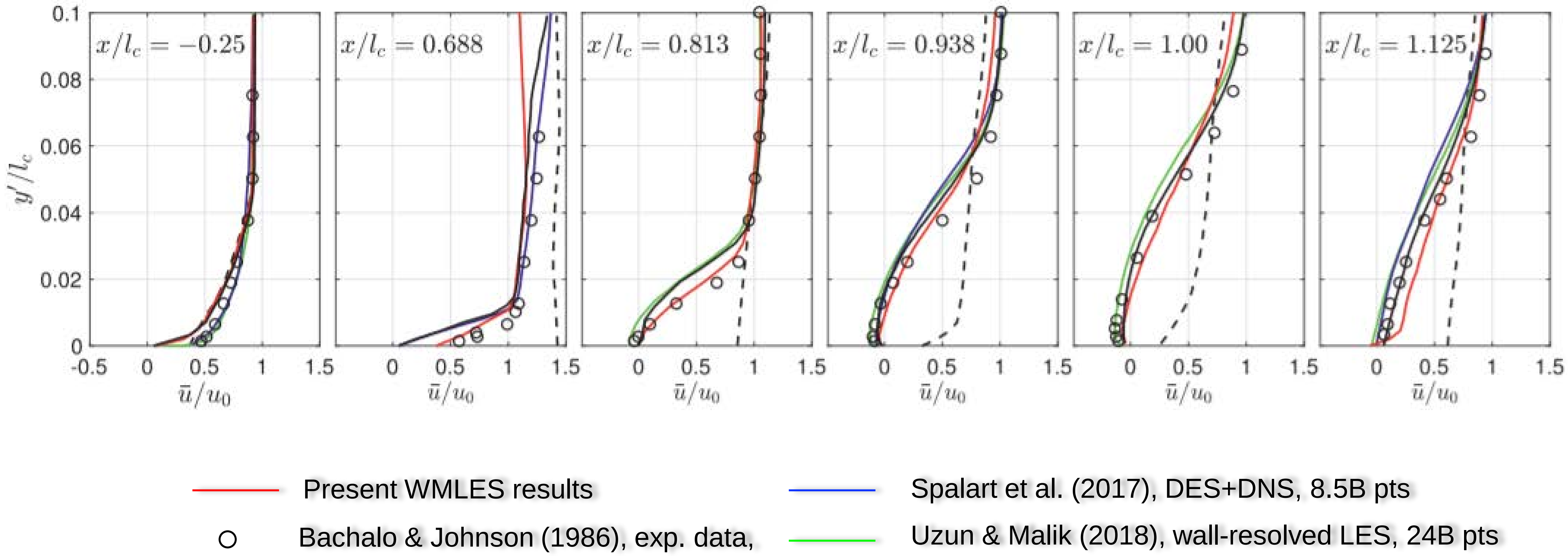
WMLES of NASA transonic bump configuration

- LES results: pressure coefficient



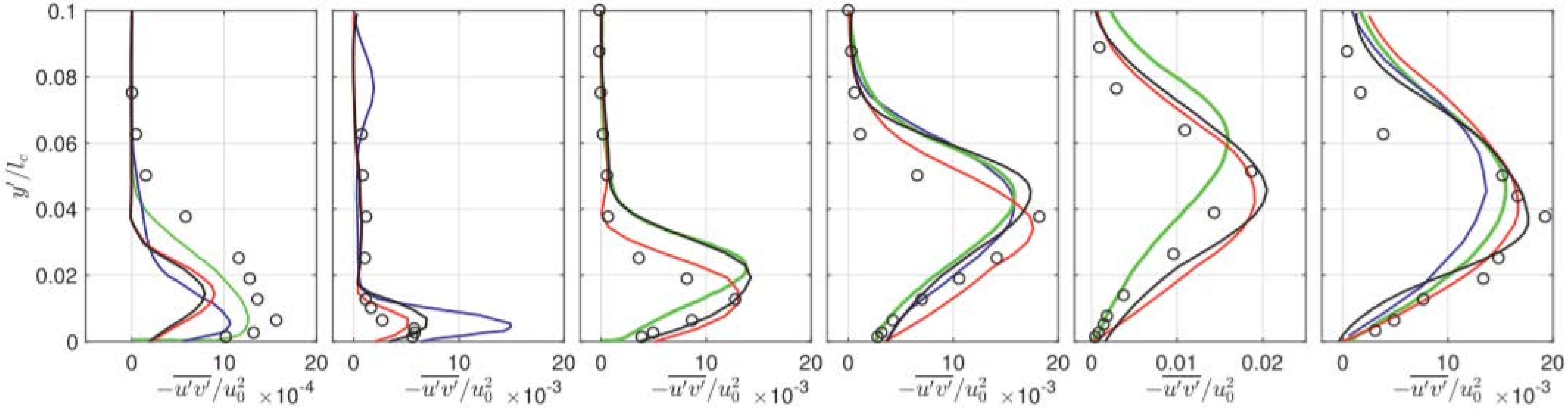
WMLES of NASA transonic bump configuration

- LES results: time-averaged streamwise velocity



WMLES of NASA transonic bump configuration

- LES results: Reynold stress



— Present WMLES results

— Spalart et al. (2017), DES+DNS, 8.5B pts

○ Bachalo & Johnson (1986), exp. data,

— Uzun & Malik (2018), wall-resolved LES, 24B pts