LMECA1321 : Low-Prandtl Turbulent Heat Transfer

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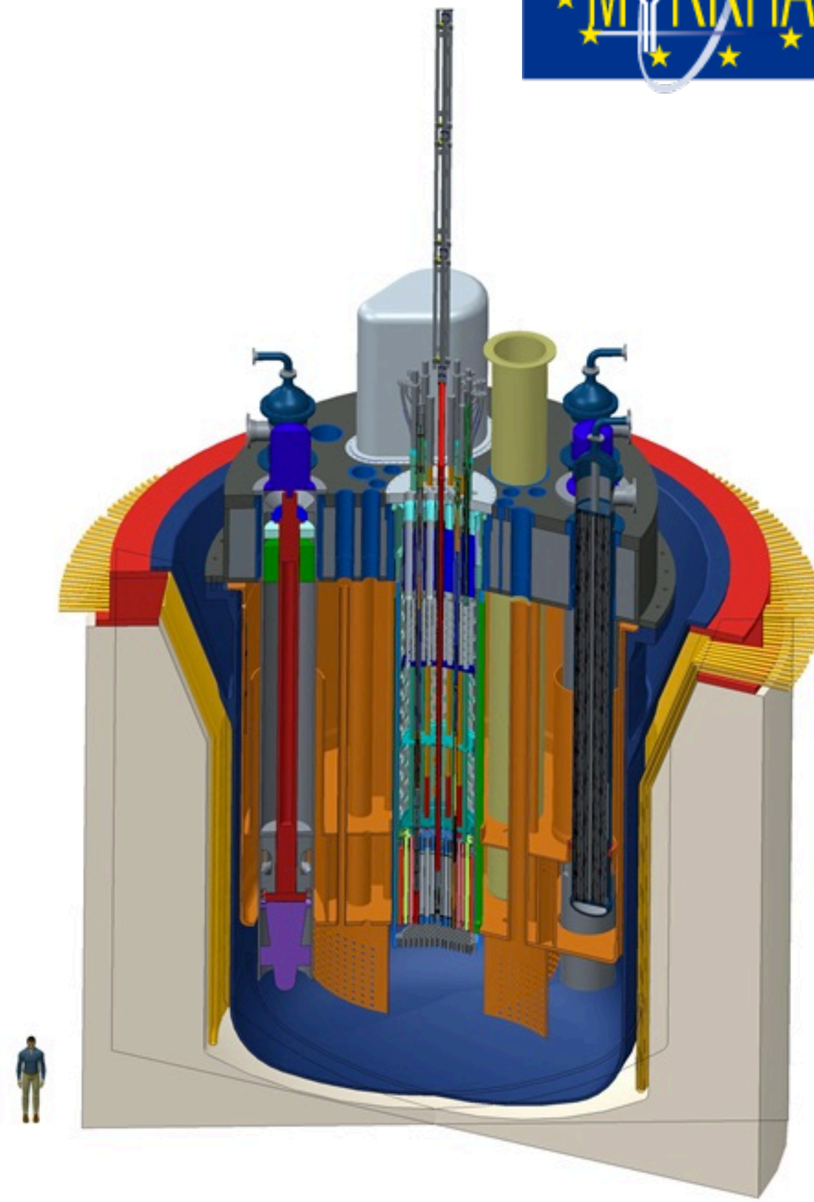
Flows with low Prandtl Fluids

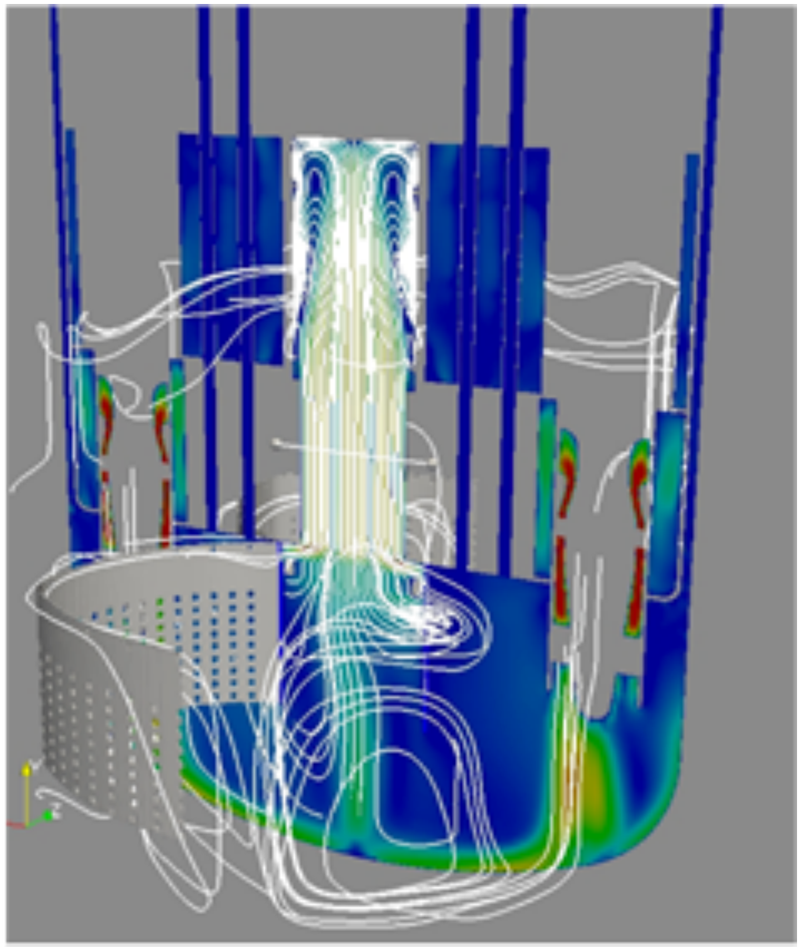
- Liquid Metals
- Example of Application
  - MYRRHA Reactor
    - Developed by SCK-CEN
    - Coolant : Lead-Bismuth Eutectic
      - Pr ~ 0.01 - 0.025
    - Subcritical, accelerator-driven
    - Production of medical isotopes
    - Minor Actinide Transmutation



Simulation of turbulent flows

- DNS (Direct Numerical Simulation)
  - Direct simulation of the Navier-Stokes equations
  - High-fidelity but very costly; hence limited moderate Re
- LES (Large-Eddy Simulation)
  - Simulation of the Navier-Stokes equations on a grid too coarse to perform a DNS
  - Need to add a subgrid-scale (SGS) model
  - Can still be of fairly high fidelity, at least when « wall-resolved »
- RANS (Reynolds-Averaged Navier-Stokes)
  - Simulation of the Reynolds-Averaged Navier-Stokes equations
  - All the turbulence must be modelled
  - Lower-fidelity, but affordable for industrial applications

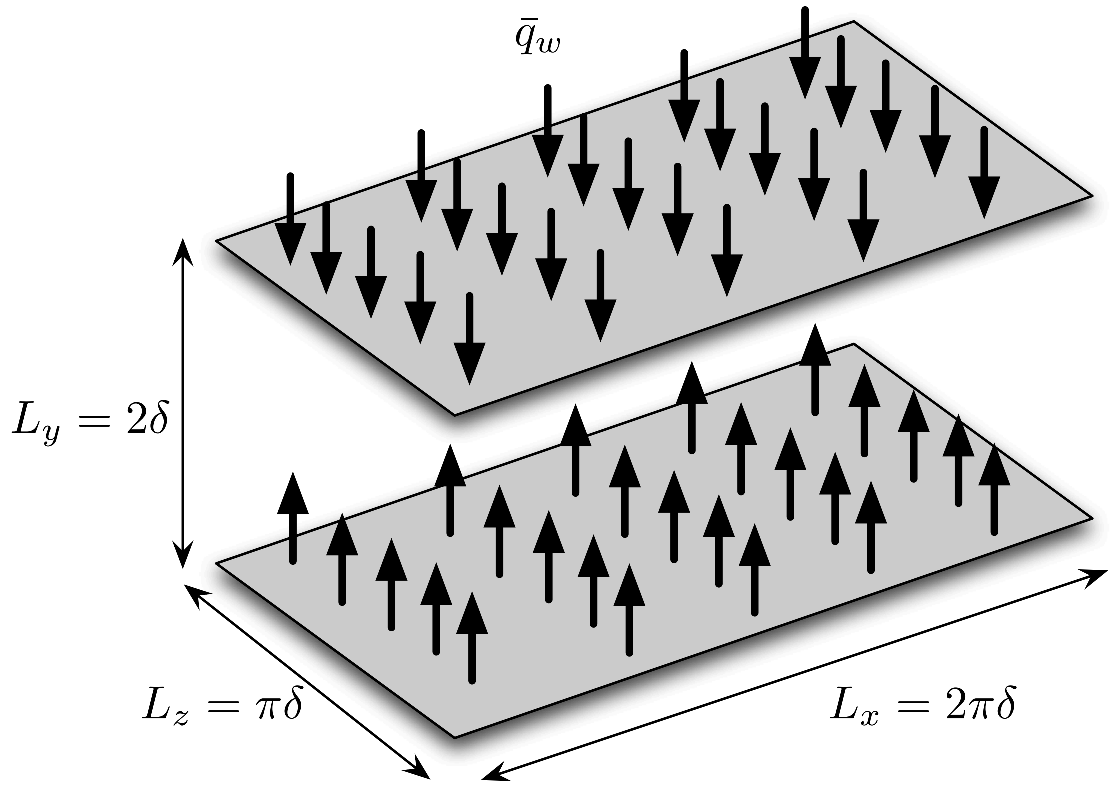
RANS simulation of the MYRRHA reactor



http://sesame-h2020.eu/vki-lecture-series-in-april-2017/

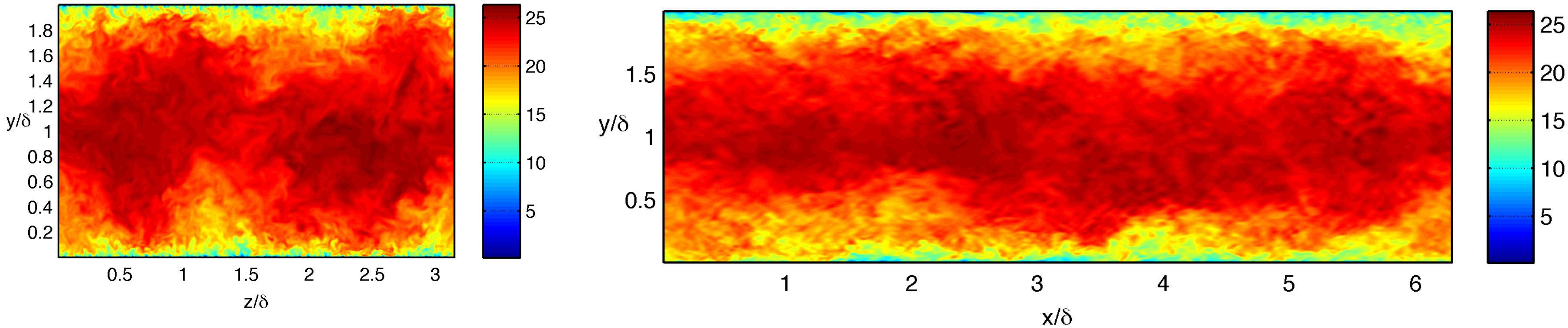
DNS and LES of channel flows

- 4th order finite difference incompressible flow solver
- Unsteady simulation
- Periodic streamwise and spanwise
- Fluid with constant physical properties
- Imposed flow rate
- Imposed mean uniform heat flux at the walls

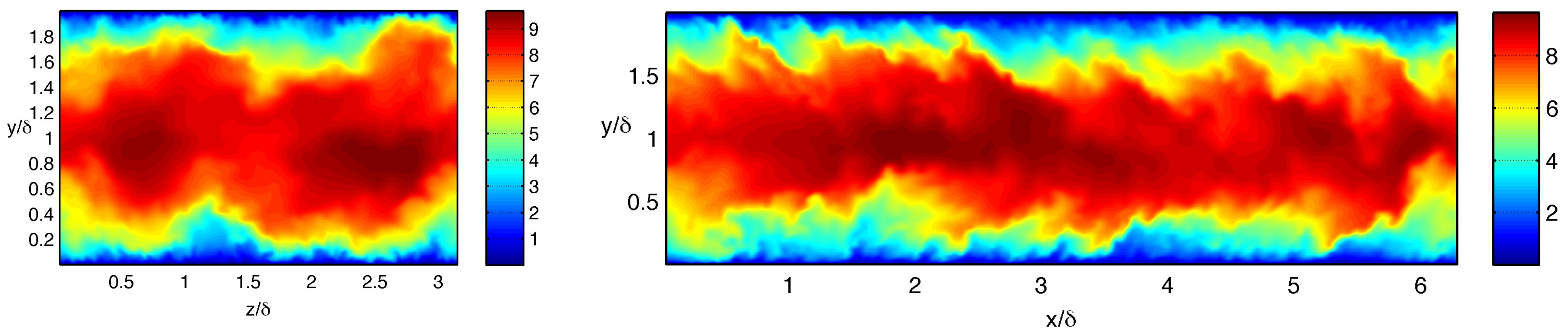


Re_τ = 2000 channel with heat transfer

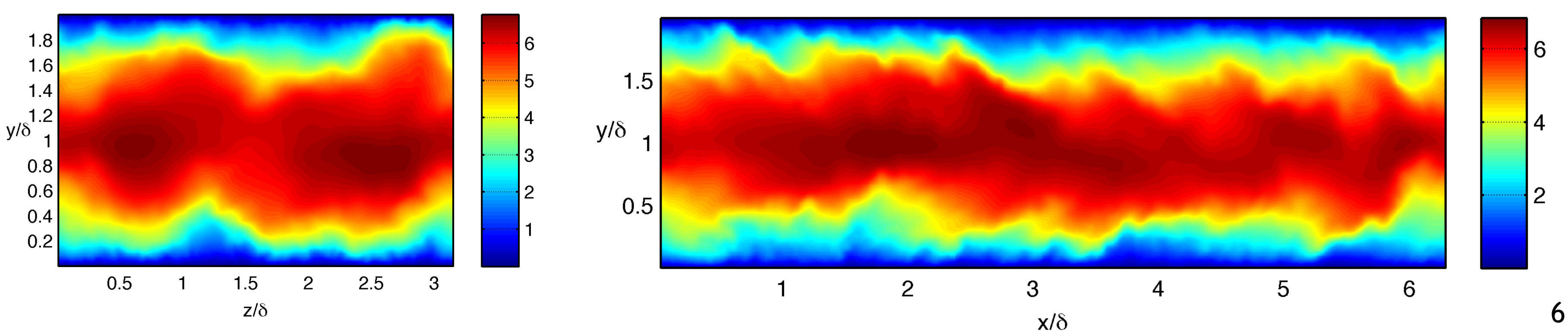
Velocity



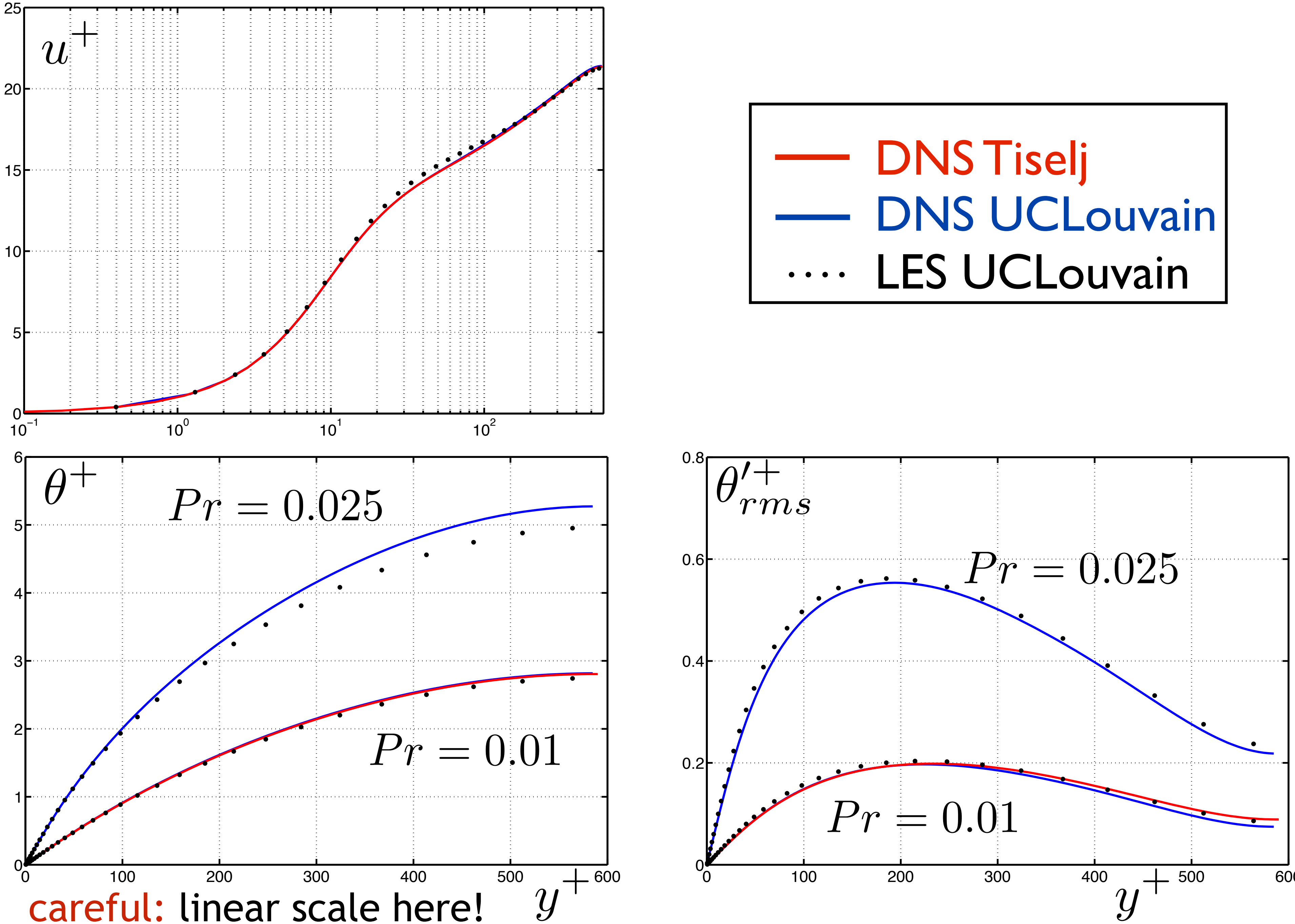
Temperature at Pr = 0.025



Temperature at Pr = 0.01

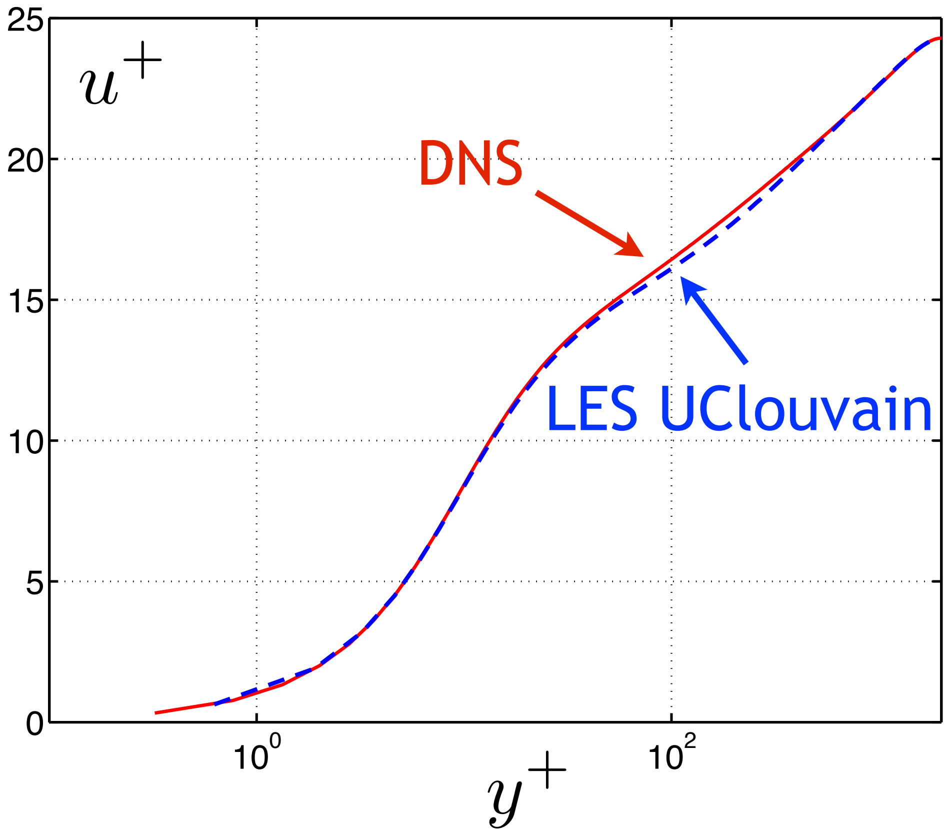


Re_τ = 590 channel: velocity and temperature



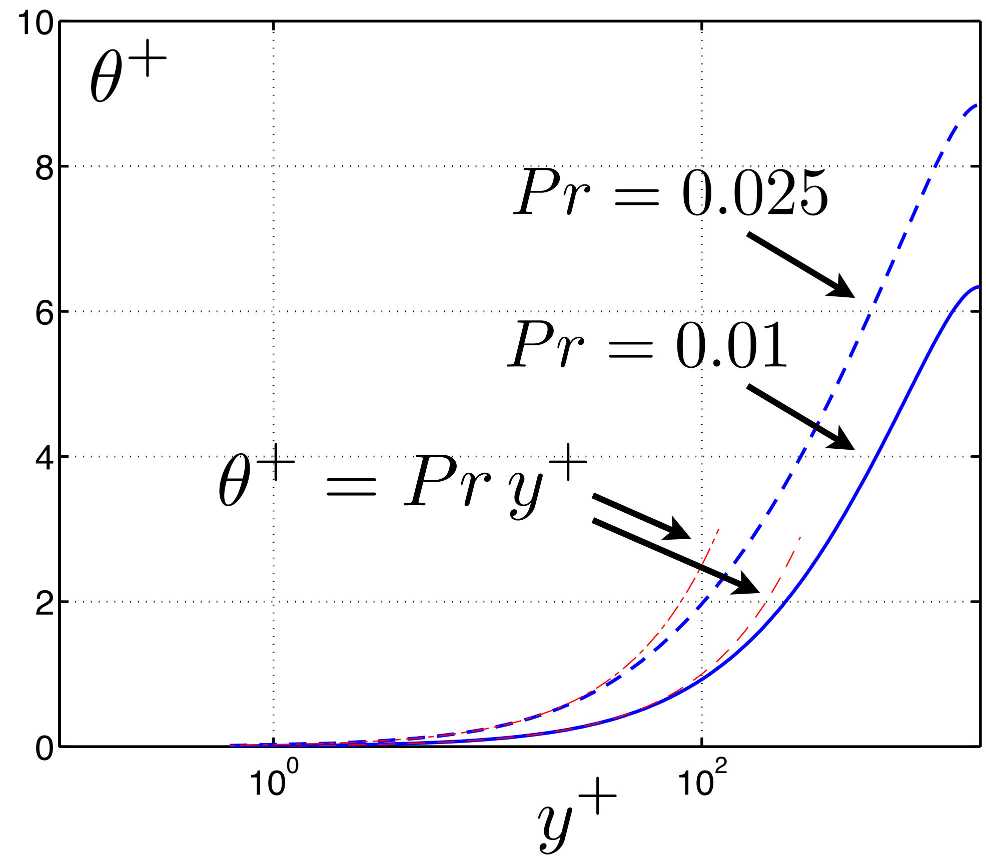
careful: linear scale here!

Re_τ = 2000 channel: velocity and temperature

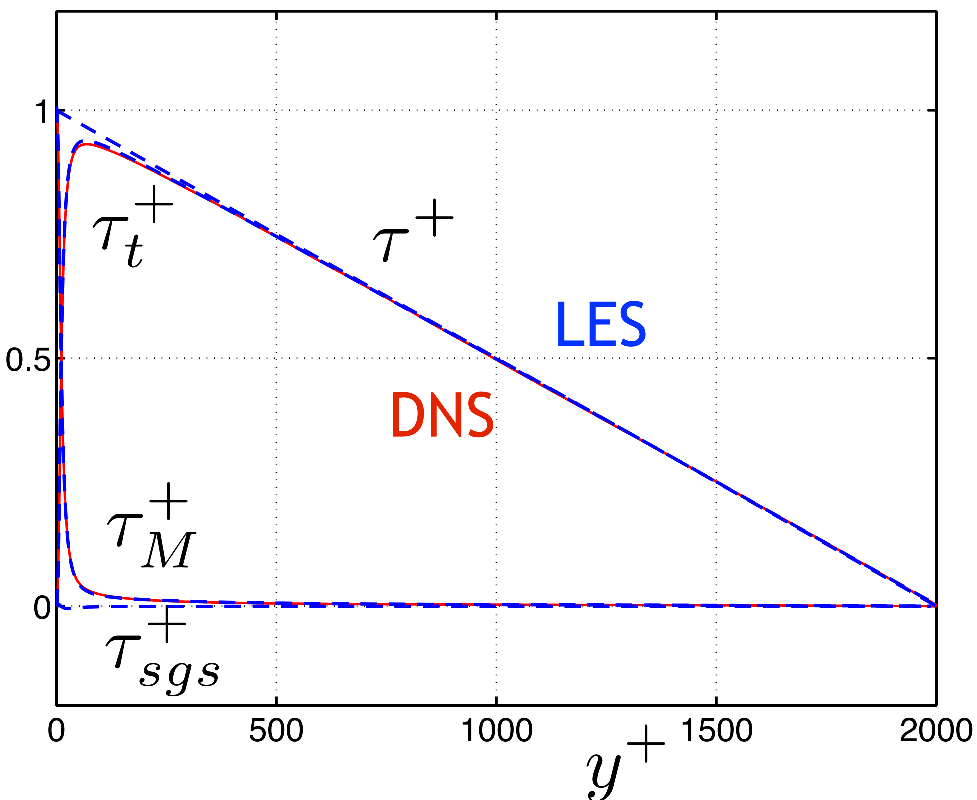


Mean velocity :
log law
good agreement of LES with DNS

Mean temperature :
no log law!

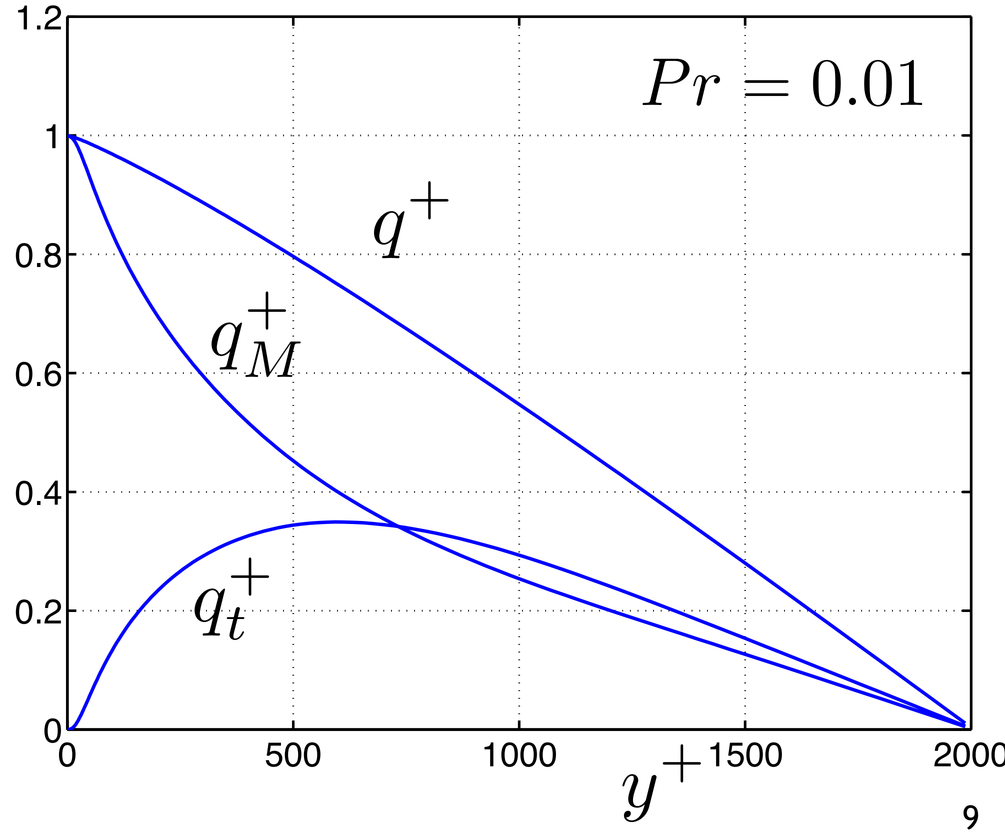


Re_τ = 2000 channel: stresses and heat fluxes



Mean stress:
negligible molecular stress,
except in near-wall layer;
negligible SGS stresses

Mean heat flux :
turbulent and molecular fluxes
of same order of magnitude



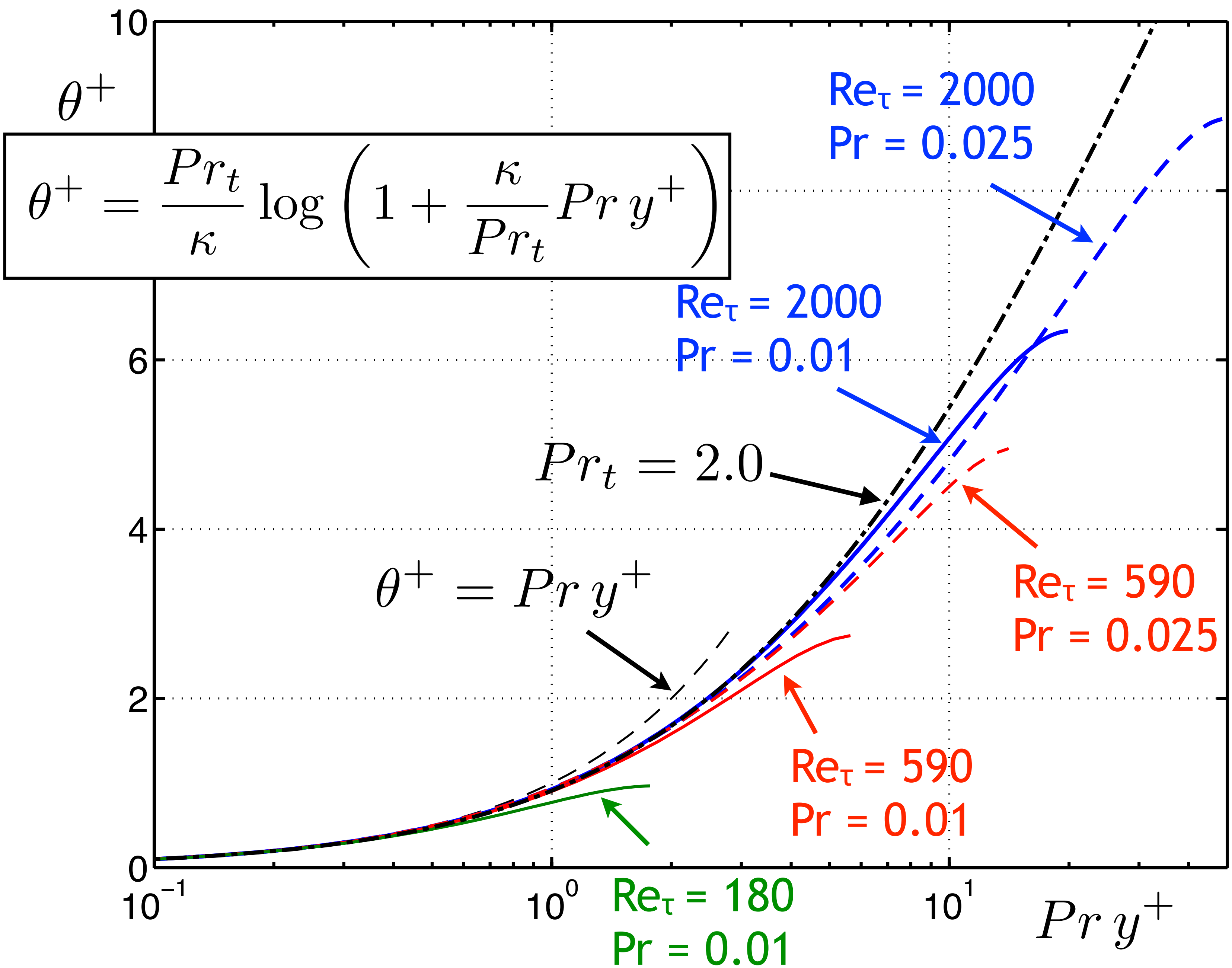
Near-wall temperature profile model

$$
\begin{aligned}
&\bar{q} + \bar{q}^t = \bar{q}_w \\
\Leftrightarrow & -k\frac{d\bar{T}}{dy} + (\rho c\overline{T'v'}) = \bar{q}_w \\
\Leftrightarrow & -k\frac{d\bar{T}}{dy} - k_t\frac{d\bar{T}}{dy} = \bar{q}_w \\
\Leftrightarrow & (\alpha + \alpha_t)\frac{d\bar{T}}{dy} = -\frac{\bar{q}_w}{\rho c} \\
\Leftrightarrow & \left(\frac{\nu}{Pr} + \frac{\nu_t}{Pr_t}\right)\frac{d\bar{T}}{dy} = -\bar{T}_\tau \bar{u}_\tau \\
\Leftrightarrow & \left(1 + \frac{Pr}{Pr_t}\frac{\nu_t}{\nu}\right)\frac{d\left((\bar{T}_w - \bar{T})/\bar{T}_\tau\right)}{d\left((y\bar{u}_\tau)/\nu\right)} = Pr \\
\Leftrightarrow & \left(1 + \frac{Pr}{Pr_t}\kappa y^+\right)\frac{d\bar{T}^+}{dy^+} = Pr
\end{aligned}
$$

$$
\Rightarrow \bar{T}^+ = \frac{Pr_t}{\kappa}\log\left(1 + \frac{\kappa}{Pr_t}Pr\, y^+\right)
$$

Valid for zones I - II - IIIa

Temperature profiles



Turbulent diffusivity