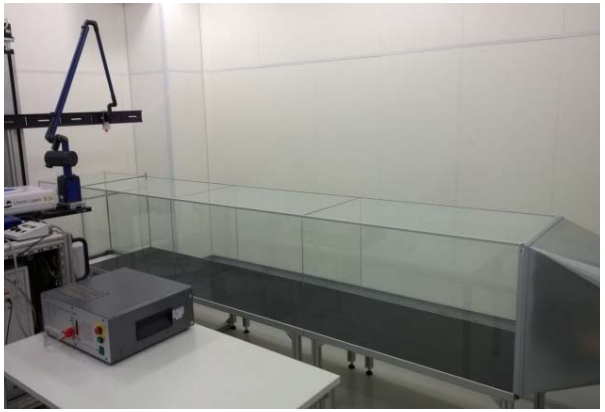

Understanding and Modelling of Airborne Bio-Contamination Process in Manned Spacecraft

MELiSSA Workshop, 8-9 Jun. 2016, Lausanne, Switzerland

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Introduction

- ESA funded project:
  - **Understanding** and **Modelling** of Bio-Contamination Process for Exobiology Spacecraft and Manned Vehicle – **BIOMODEXO**
- Partners:
  - VTT Technical Research Centre of Finland, Finland
  - UEF, University of Eastern Finland, Finland
  - TAS-I, Thales Alenia Space Italia (TAS-I), Italy
  - COMEX, France
  - MEDES Institute of Space Medicine and Physiology, France

Introduction

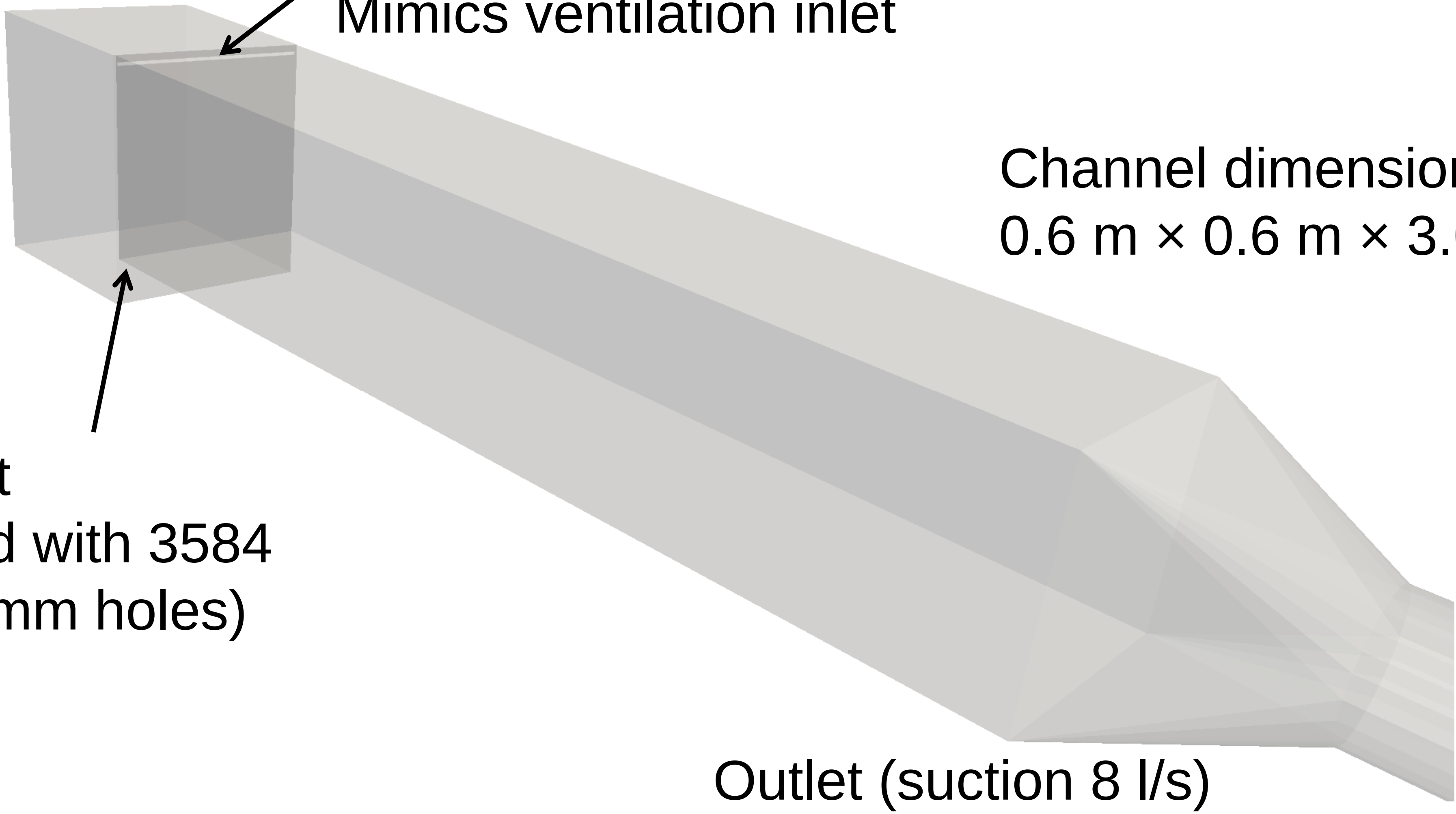
- "Understanding"
- Measurement techniques for gas flow field
  - Particle image velocimetry (PIV) and velocity probes
- Measurement techniques for particle dispersion and deposition
  - PIV, digital microscopy (deposition), optical particle counter, Andersen impactor, Petrifilm contact agars, swap sample

- "Modelling"
- Simulation techniques for gas flow field
  - CFD (Computational Fluid Dynamics)
- Simulation techniques for particle dispersion and deposition
  - DEM (Discrete Element Method)

Test case

Also case with heated or cooled static object or dynamic object is investigated

Slot, height = 10 mm
Mimics ventilation inlet



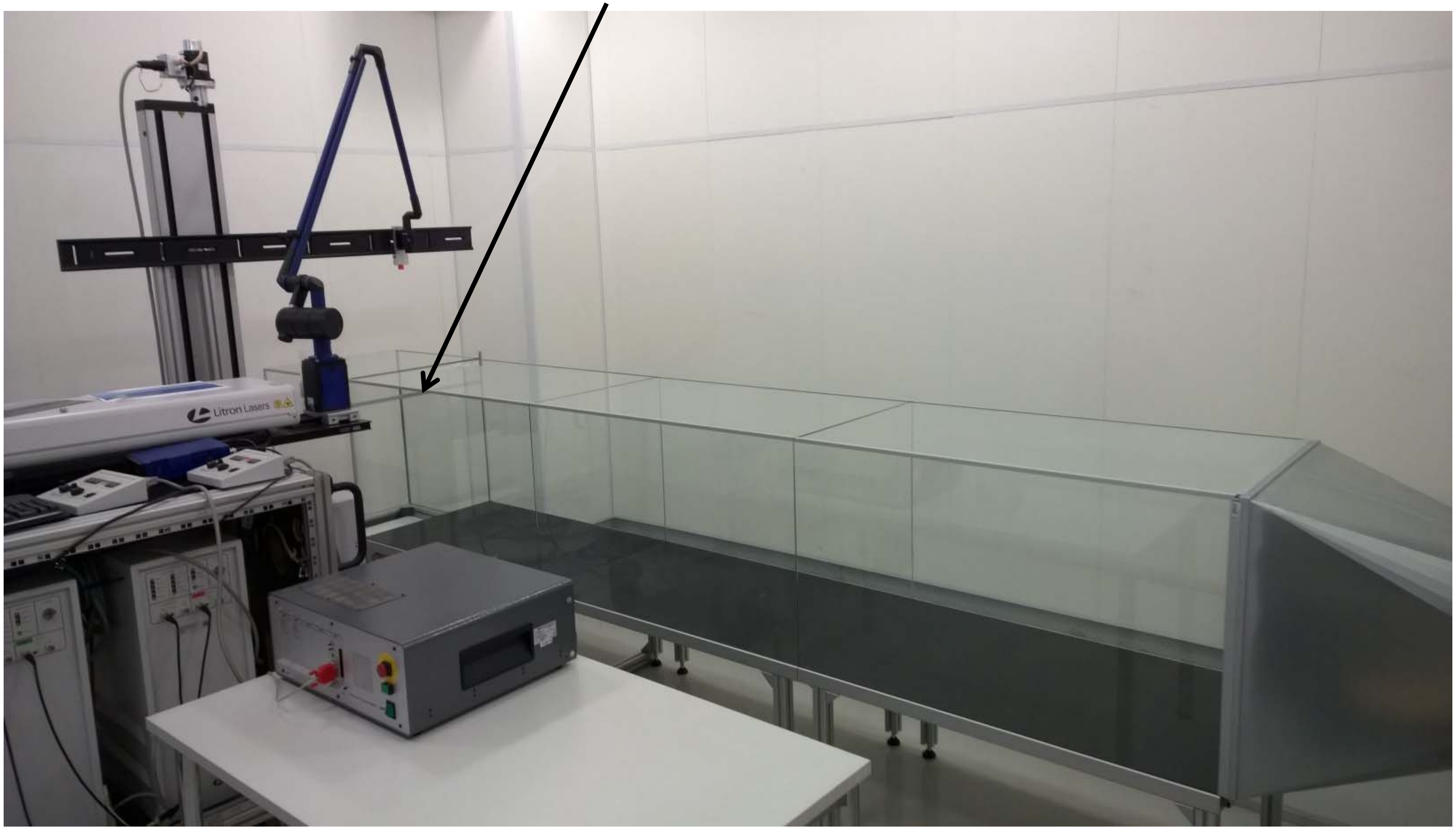
Channel dimensions
0.6 m × 0.6 m × 3.0 m

Inlet
(grid with 3584
ø2 mm holes)

Outlet (suction 8 l/s)
Velocity range close to spacecraft

Test case

Slot



PIV (Particle Image Velocimetry)

- In PIV technique, flow is seeded with **tracer particles**
- Tracer particles are illuminated with **a laser light sheet** and **two snapshot images** of tracer particles are recorded at very short time interval
- Velocity field is calculated based on the figures using a **cross-correlation** method
- DEHS (Di-Ethyl-Hexyl-Sebacat) are utilized as PIV tracer particles

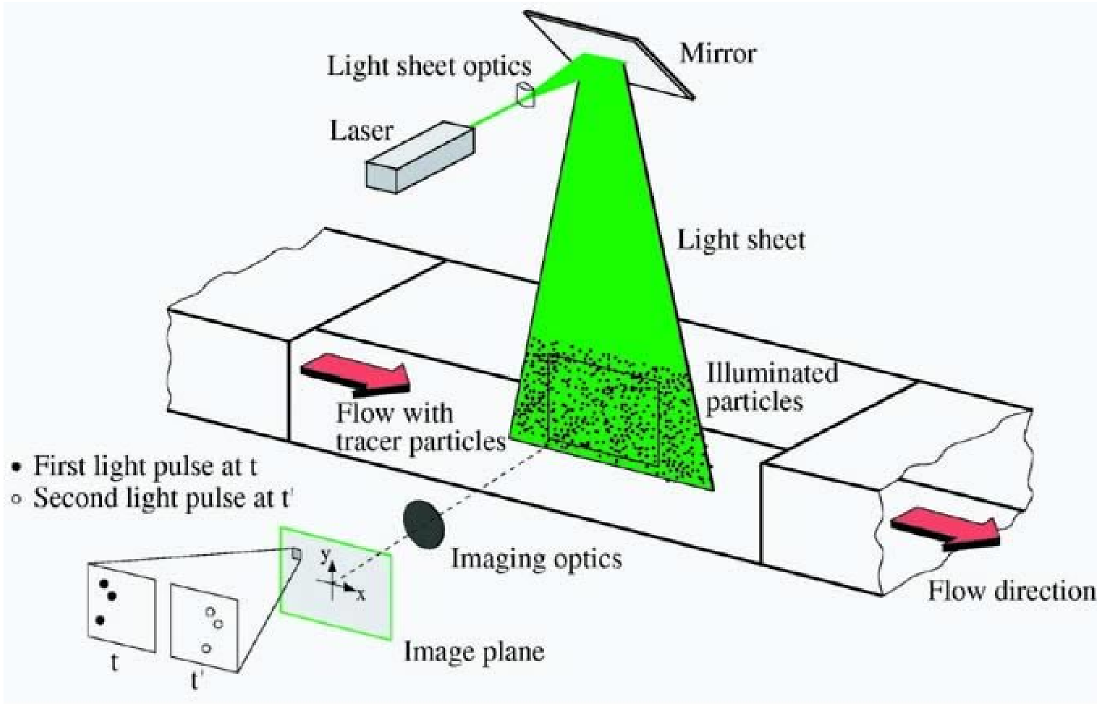
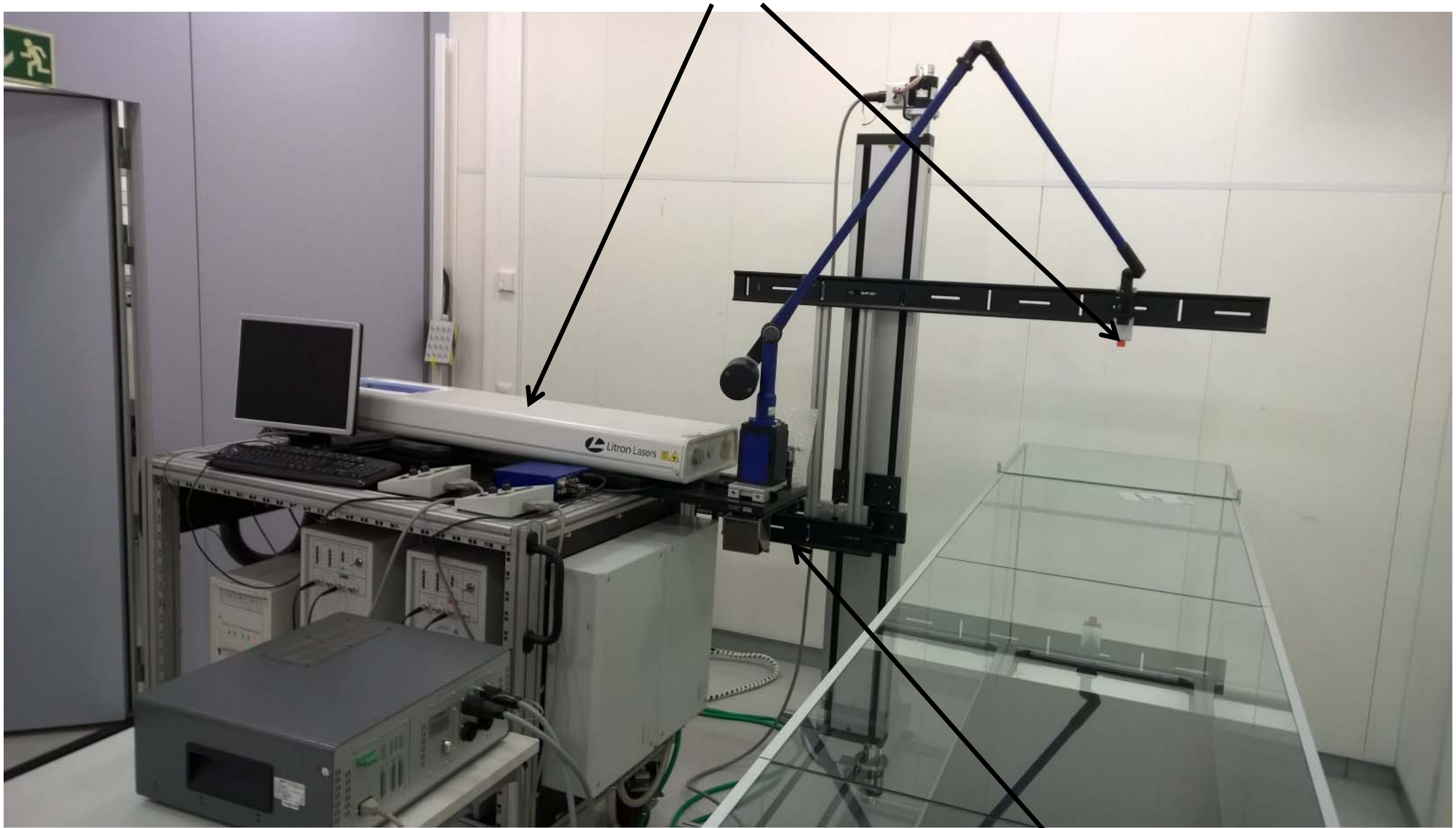


Figure: www.dlr.de

PIV measurement setup

Laser



Camera (not shown)

CFD → DEM, one-way coupling

- If the flow of one phase affects the other while there is no reverse effects, the flow is said to be **one-way coupled**
- In the particle-laden gas flow, this means that the particle concentration should be low enough
- If this is the case, the **particle simulation can be done as a post processing** after the gas flow field simulation
- →**Two-stage method**:
  1. Gas flow field simulation (**CFD**, computational fluid dynamics)
  2. Particle simulation (**DEM**, discrete element method, or DPM, discrete parcel method)

Gas flow field

- The situation is unsteady by nature and some of the unsteady structures are not turbulence, hence, traditional turbulence modelling approach fails → need for **unsteady simulation**
- Unsteady gas flow field
  - Simulated 120 s to obtain statistically steady field
  - After that, simulated 420 s and time-averaged and time-averaged flow field is used in the particle simulation.
- Turbulence: URANS?… or LES?... or even without turbulence model (can be called also implicit LES, ILES)?
  - In major part of the domain case is very close to laminar
- Four different method are investigated: **ILES, SST *k*-*ω*, SST *k*-*ω* SAS and WALE (LES)**

Particle simulation

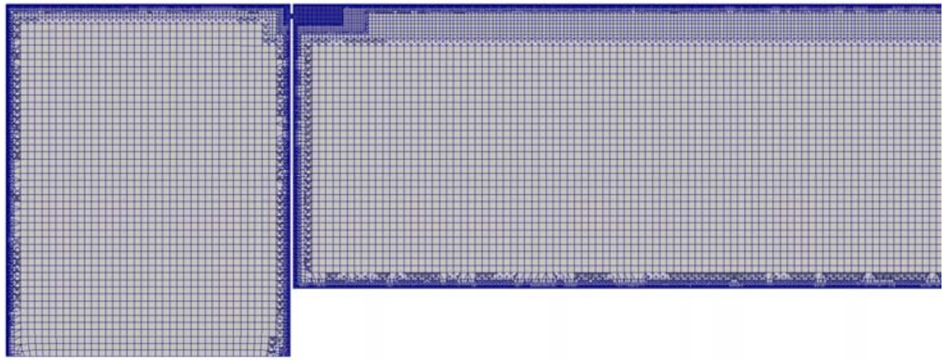
- Particle simulation as a post **processing using time averaged gas flow field**
- Gas turbulence needs to be taken into account in the particle simulation (particle tracks needs to be modulated stochastically)
- Gas turbulence can be divided into two parts:
    1. Modelled (result of turbulence modelling)
    2. Resolved (result of unsteady simulation)
- Traditionally resolved part is not taken into account (but is in this study)
- Only **drag force** and **gravity** (can be easily ignored or given any small value → microgravity) is taken into account

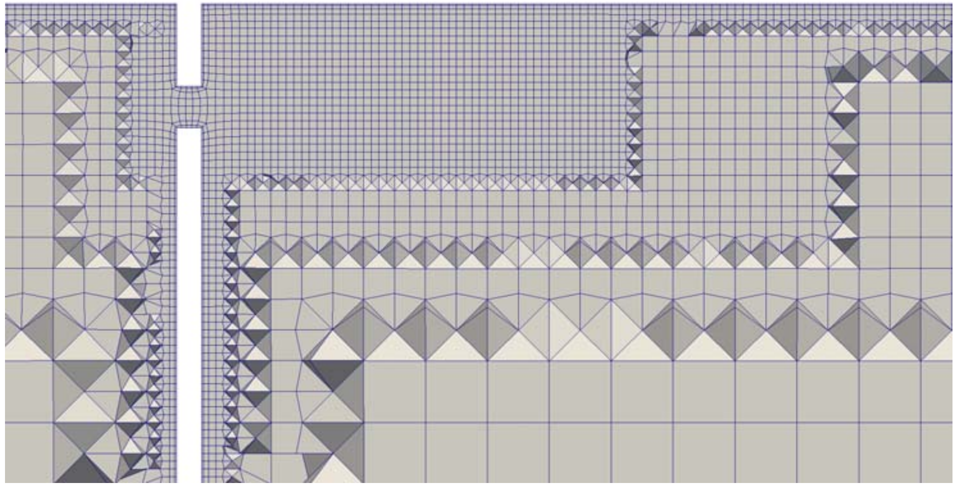
Software

- Salome for pre-processing (www.salome-platform.org)
- cfMesh for grid generation (cfmesh.com)
- OpenFOAM for solution (www.openfoam.org)
- Paraview for post-processing (www.paraview.org)

- Note: all of them are distributed as **open source software**
    - Complete transparency
    - User can implement his/her own models
    - Active community to help

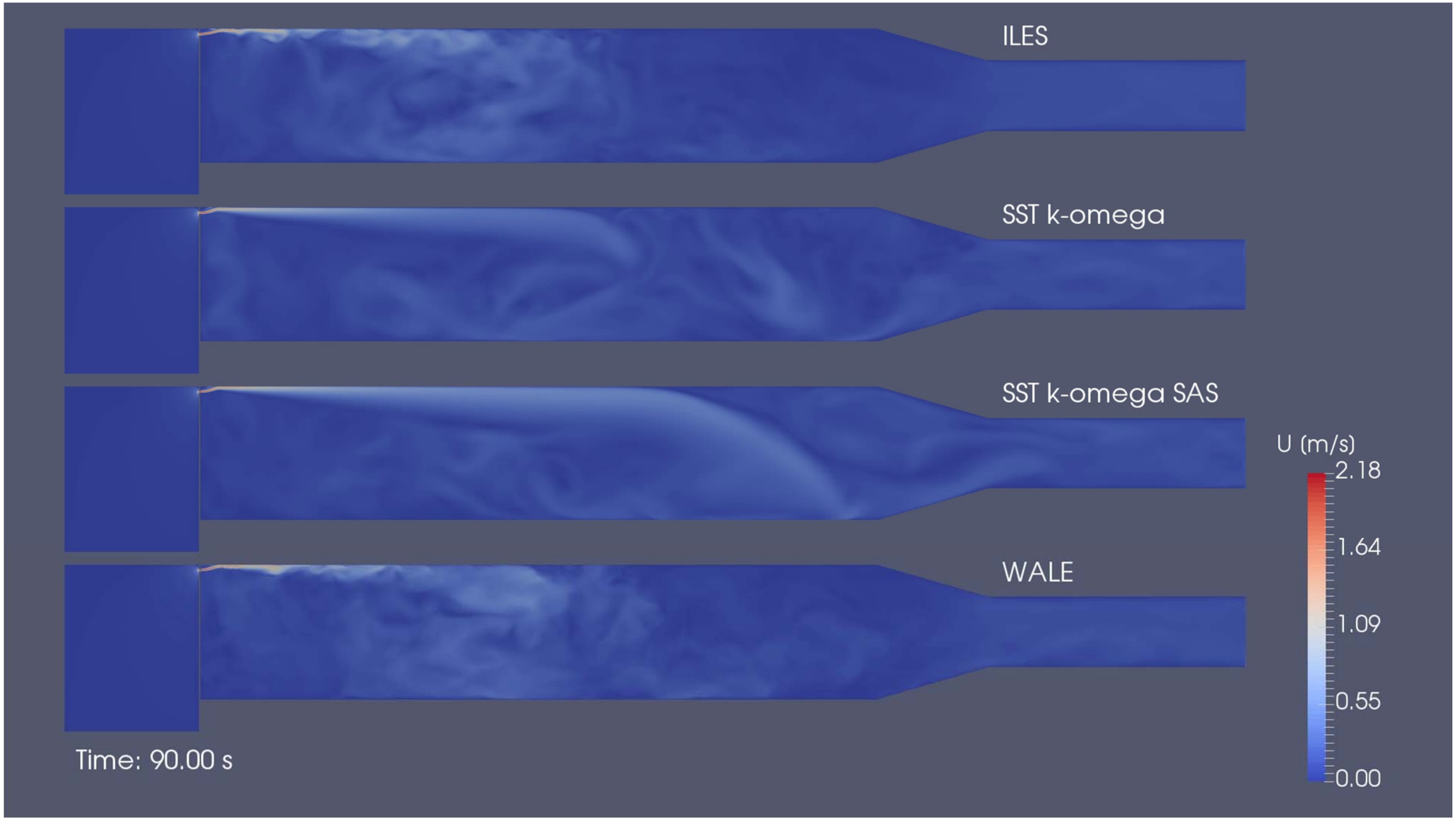
Computational grids



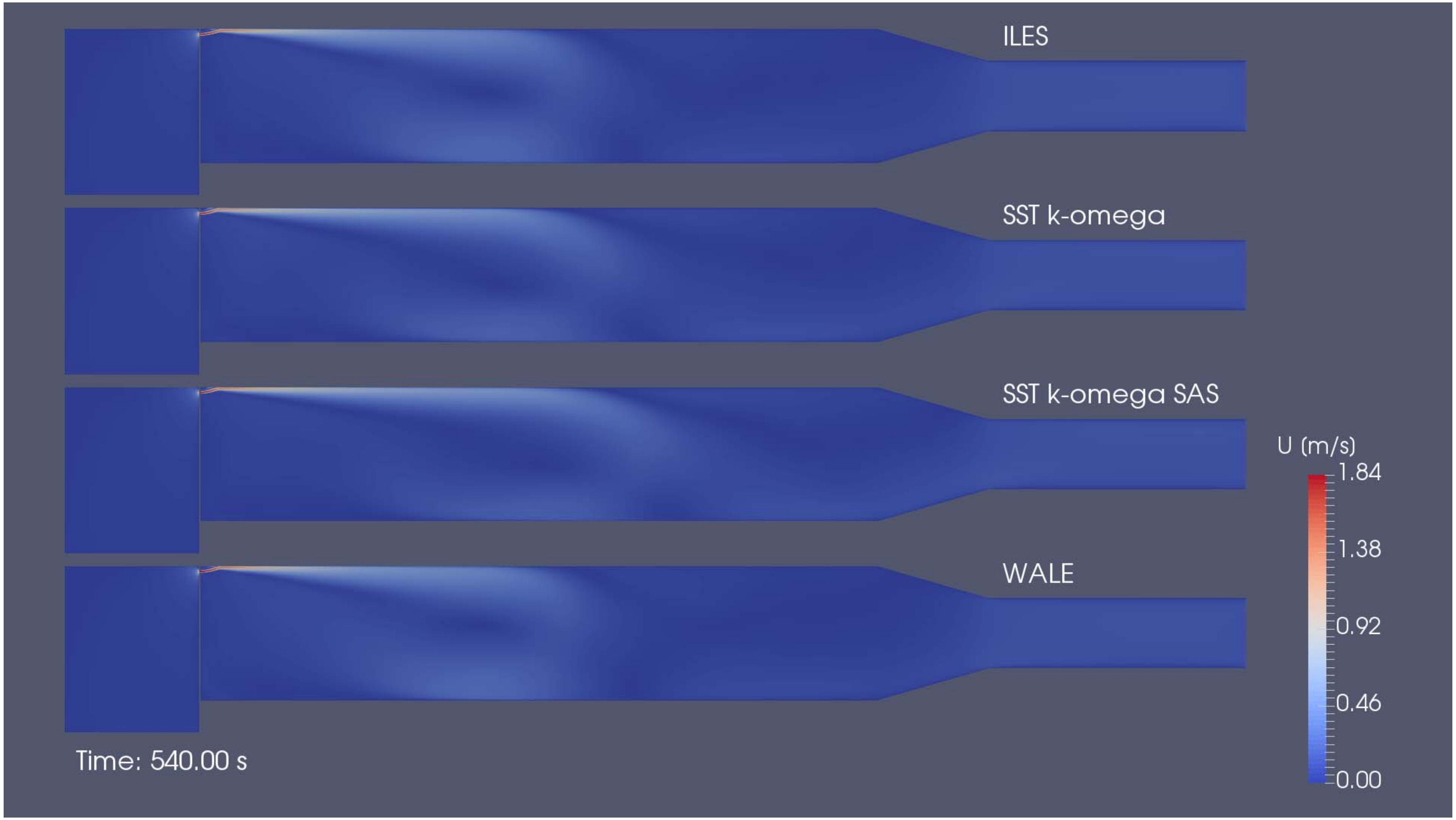


- Three different grids are used:
  - Coarsest: ~0.6 million cells
  - Coarse: ~6.8 million cells
  - Normal: ~14.5 million cells
- Computational time with the finest (normal) grid:
  - In the gas flow simulation one to two **months** with **160** CPU cores.
  - In the particle simulation one to two **days** with **1** CPU core.

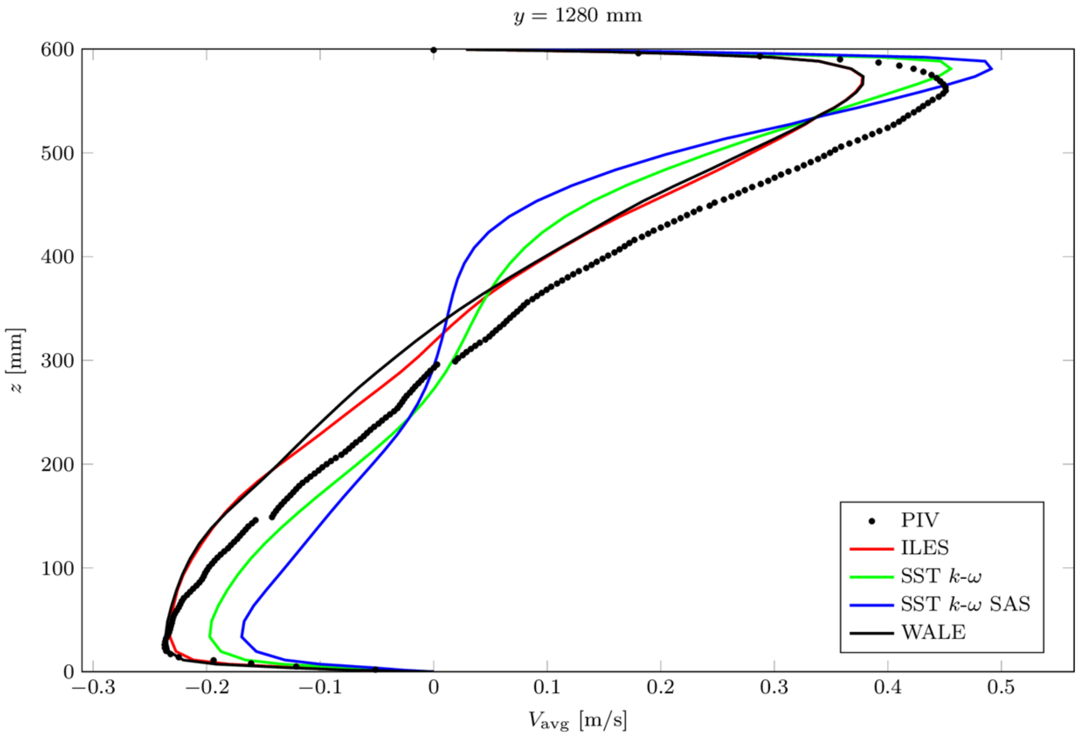
Turbulence modelling approach comparison – time dependent nature of the flow

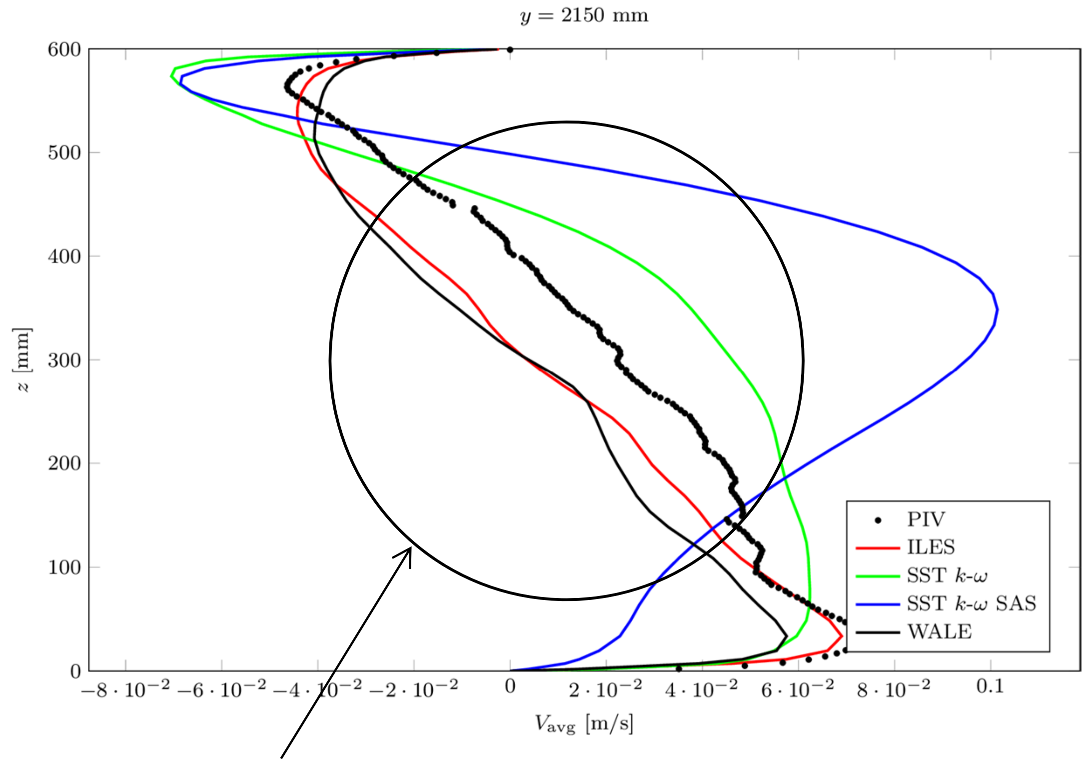


Turbulence modelling approach comparison – time-averaged flow field



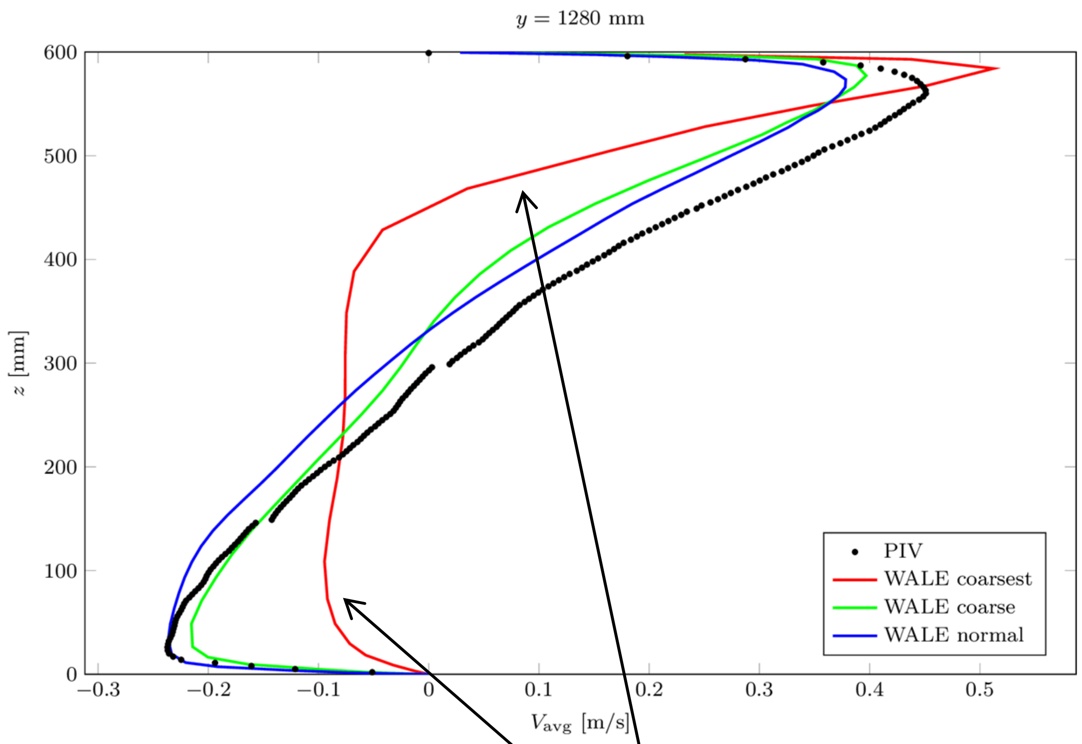
Turbulence modelling approach comparison – time-averaged flow field in the symmetry plane

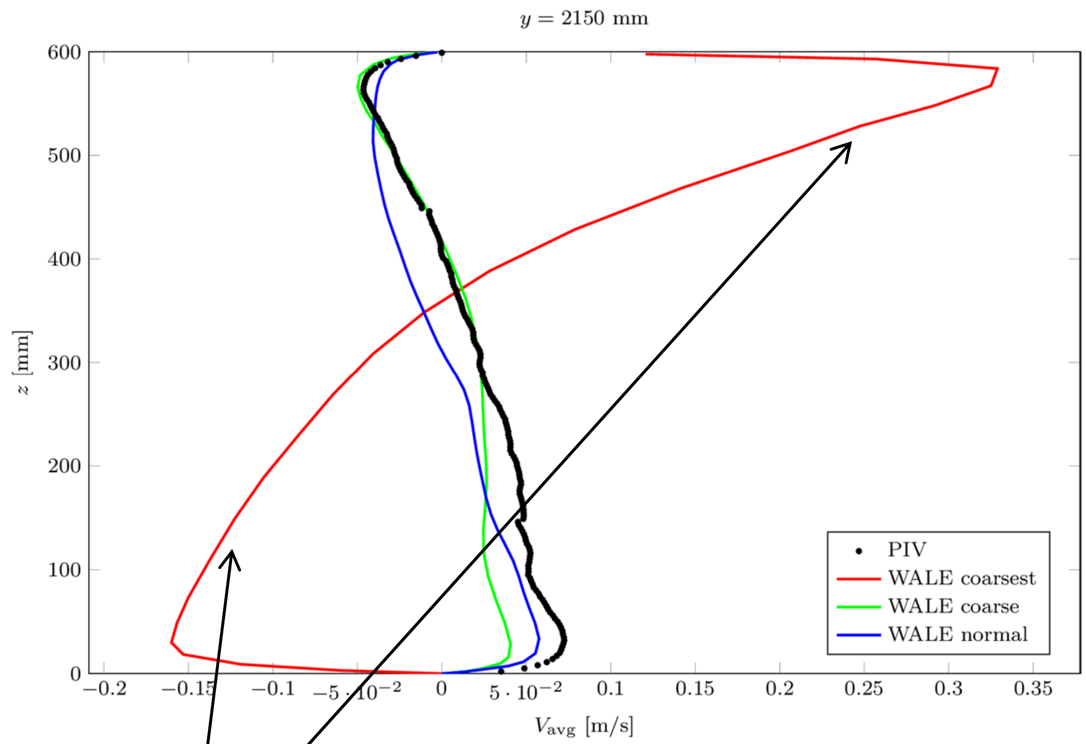




ILES or WALE
should be used

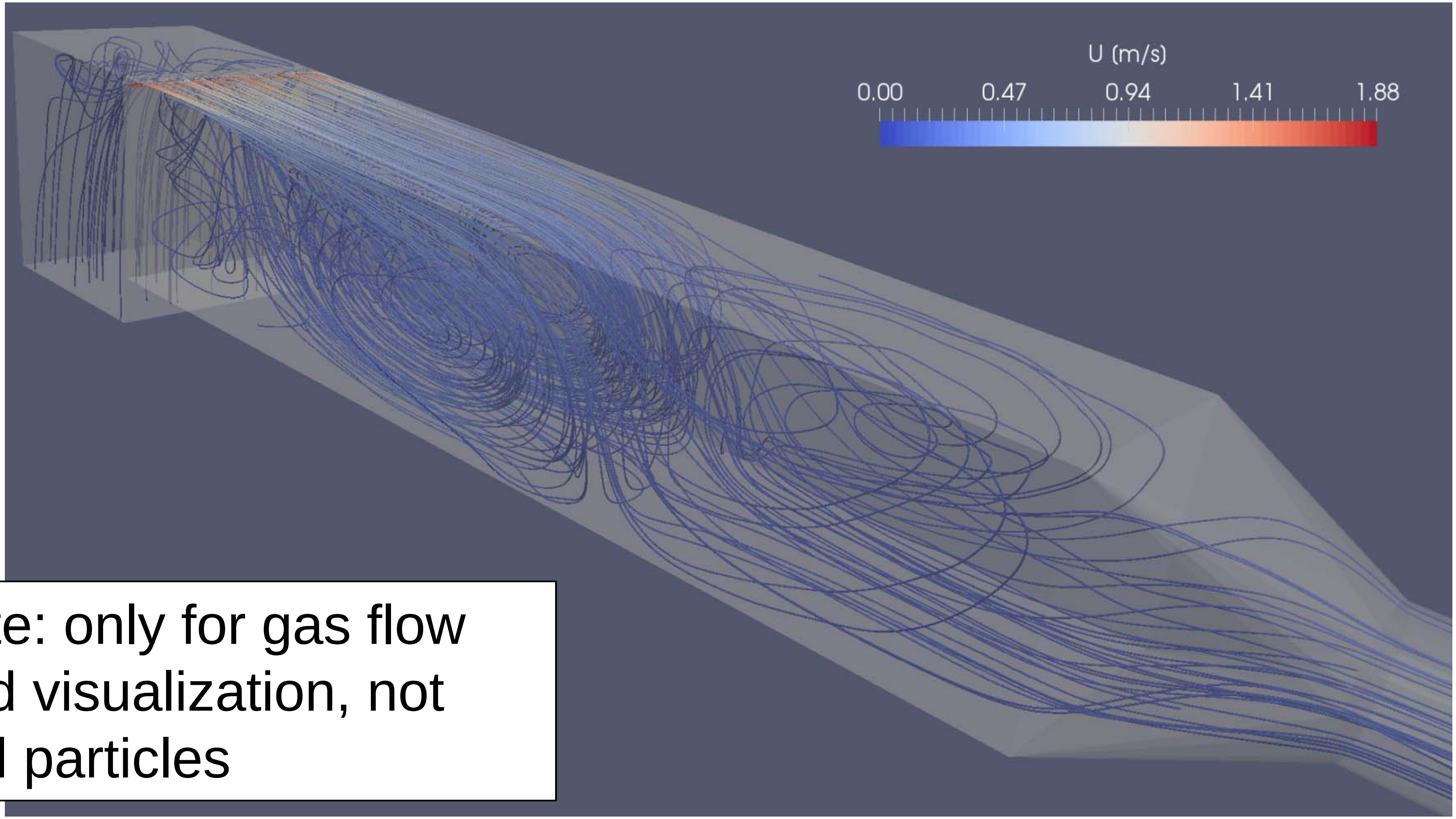
Grid independency test – time-averaged flow field in the symmetry plane using WALE





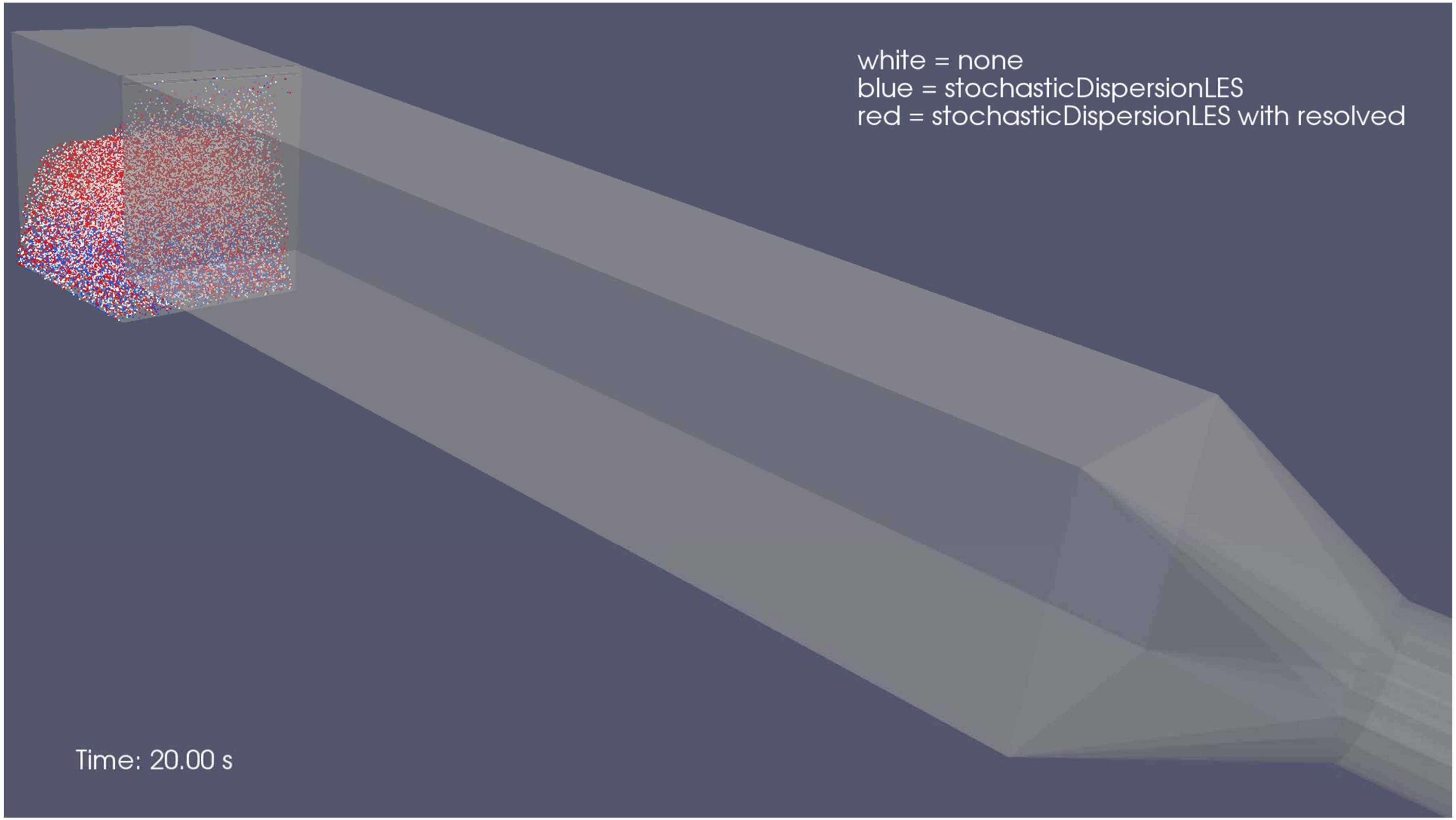
The coarsest grid is too coarse, the normal grid produces almost grid independent results

Streamlines of <u>massless</u> particles using time-averaged flow field and WALE



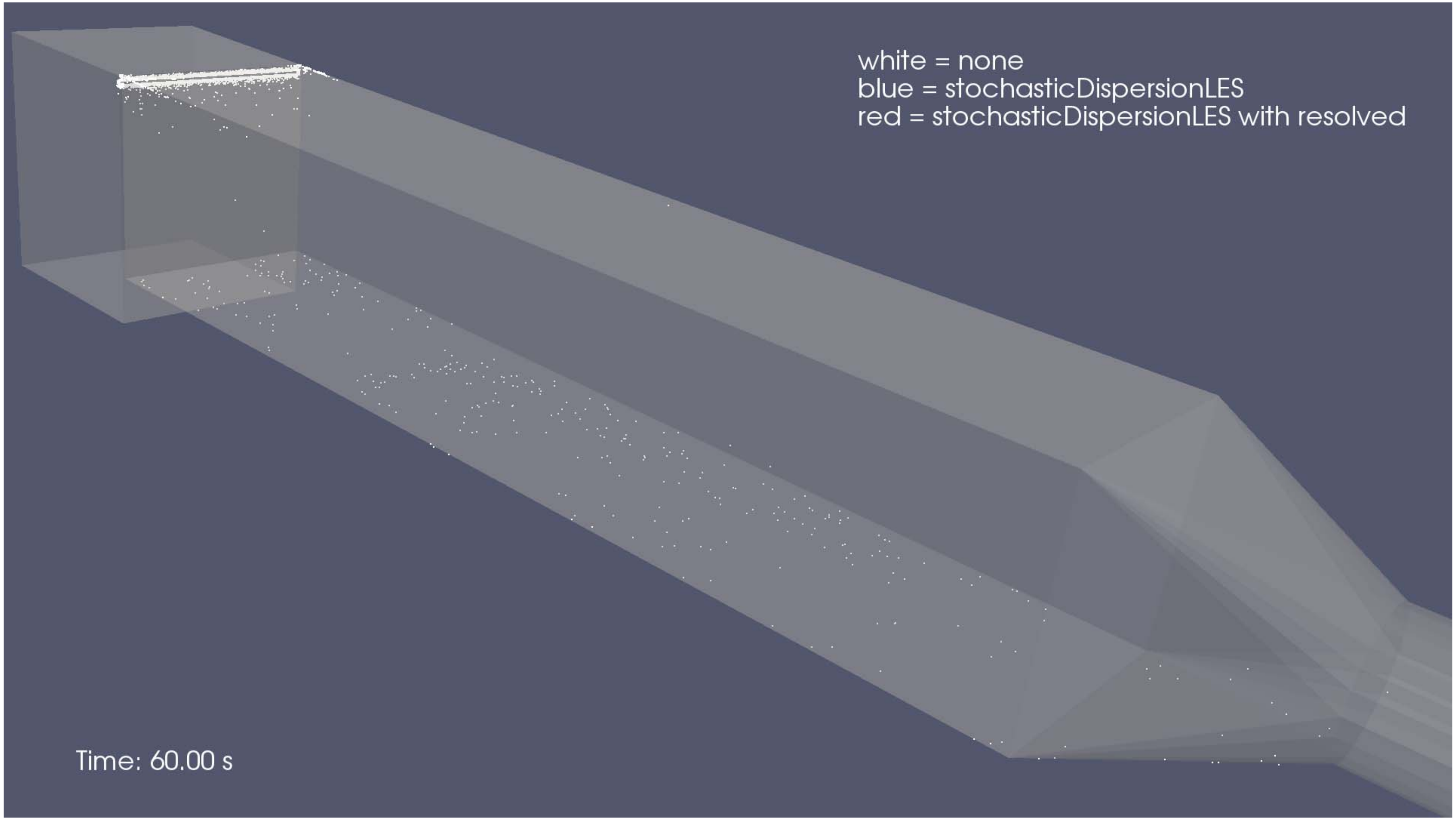
Note: only for gas flow field visualization, not real particles

Particles (d = 1 um, rho = 1000 kg/m3) – comparison of modulation methods

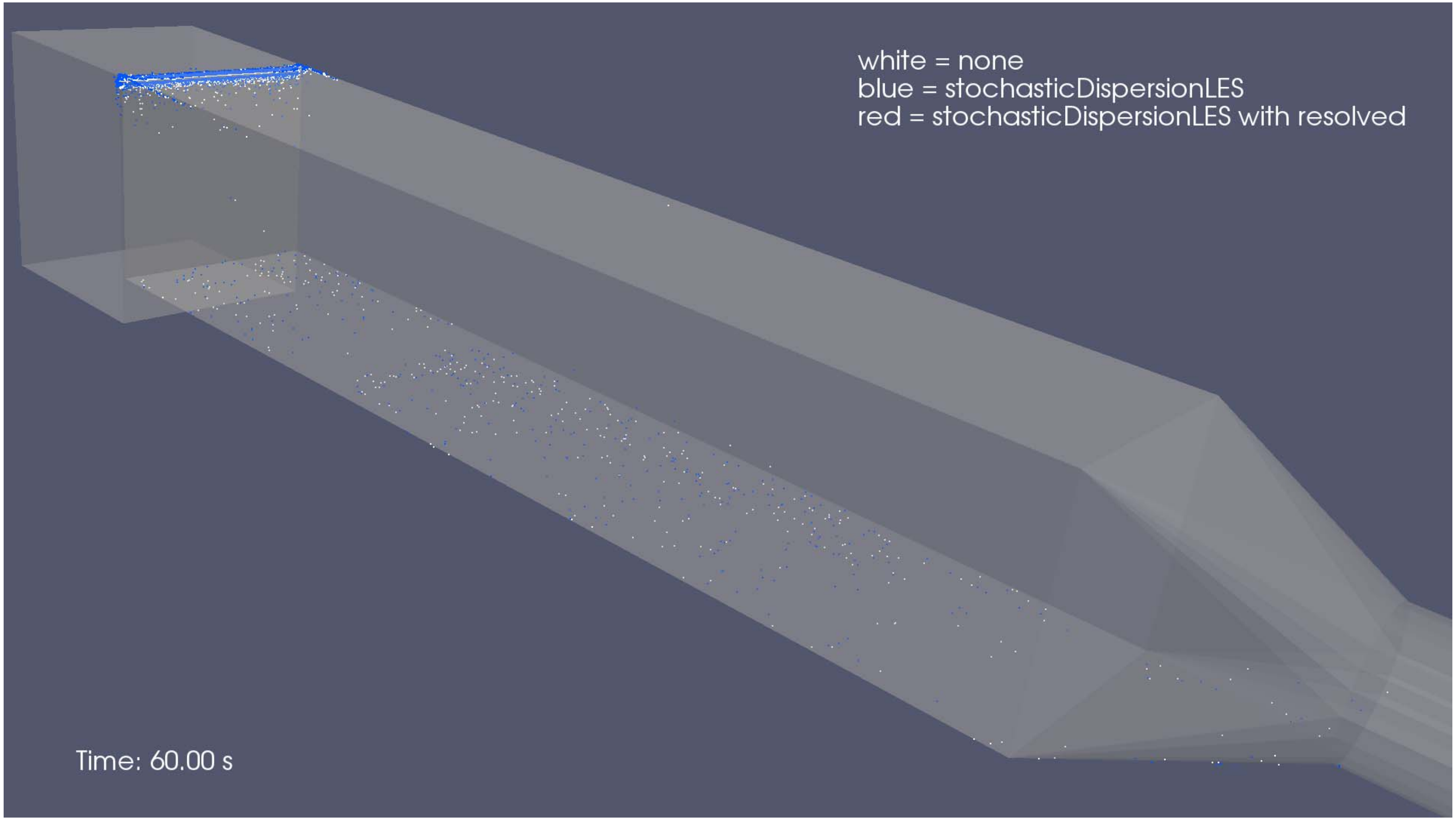


Particles (d = 1 um, rho = 1000 kg/m3) – comparison of modulation methods

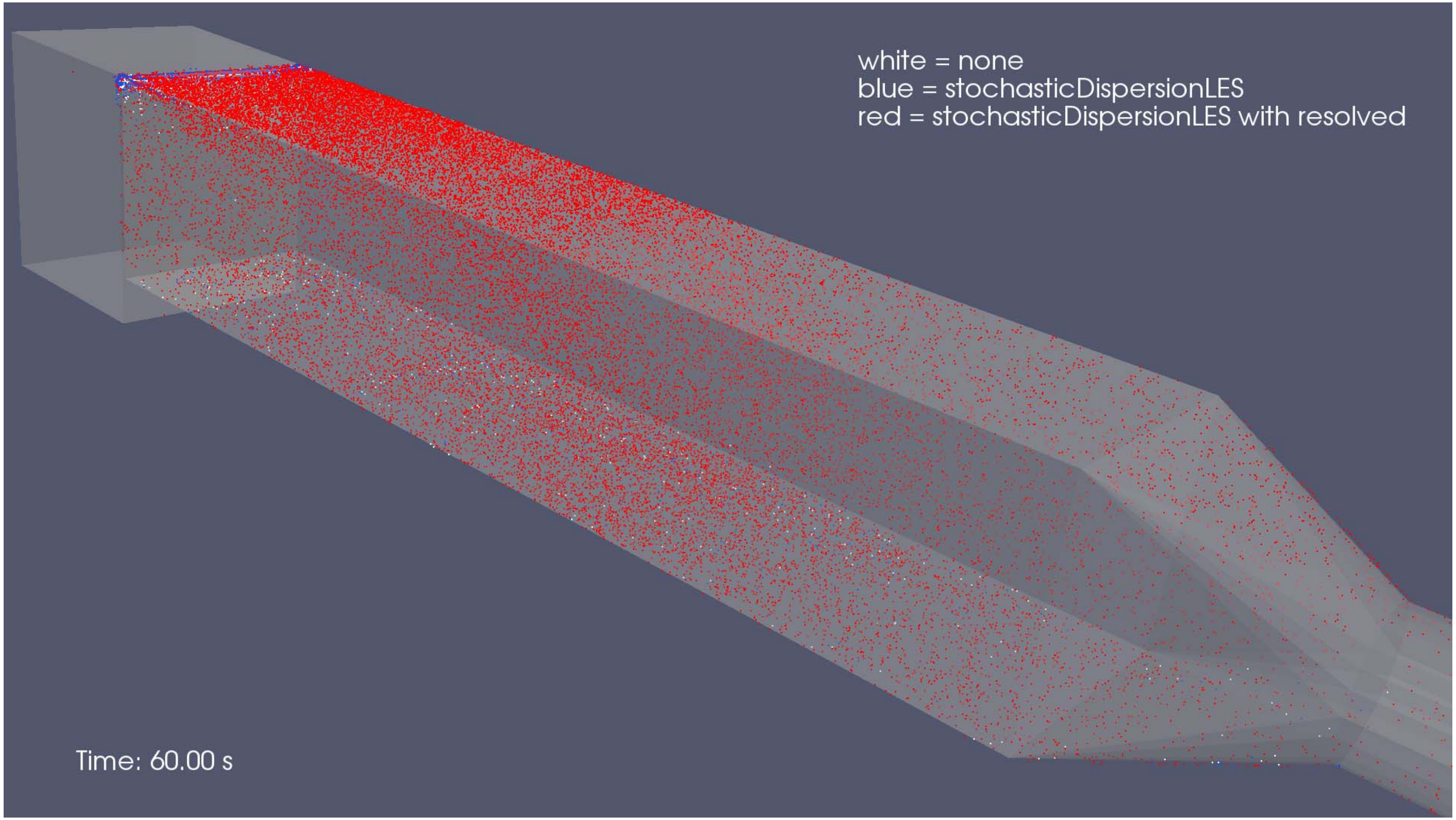
Deposition with different methods



Deposition with different methods



Deposition with different methods



Summary

- Very demanding case because of
  a) unsteady nature of the flow field and
  b) laminar/turbulent nature of the case.
- Only method tailored for the unsteady simulation can be used (like LES)
- Particle modulation due to gas flow field turbulence has to be done correctly

Model validation in Comex Hydrosphere Habitat

Summary

Modelling of air flow field and particle dispersion and deposition can be done in good accuracy in laminar/turbulent flow case, but care and modern modelling methods are needed!

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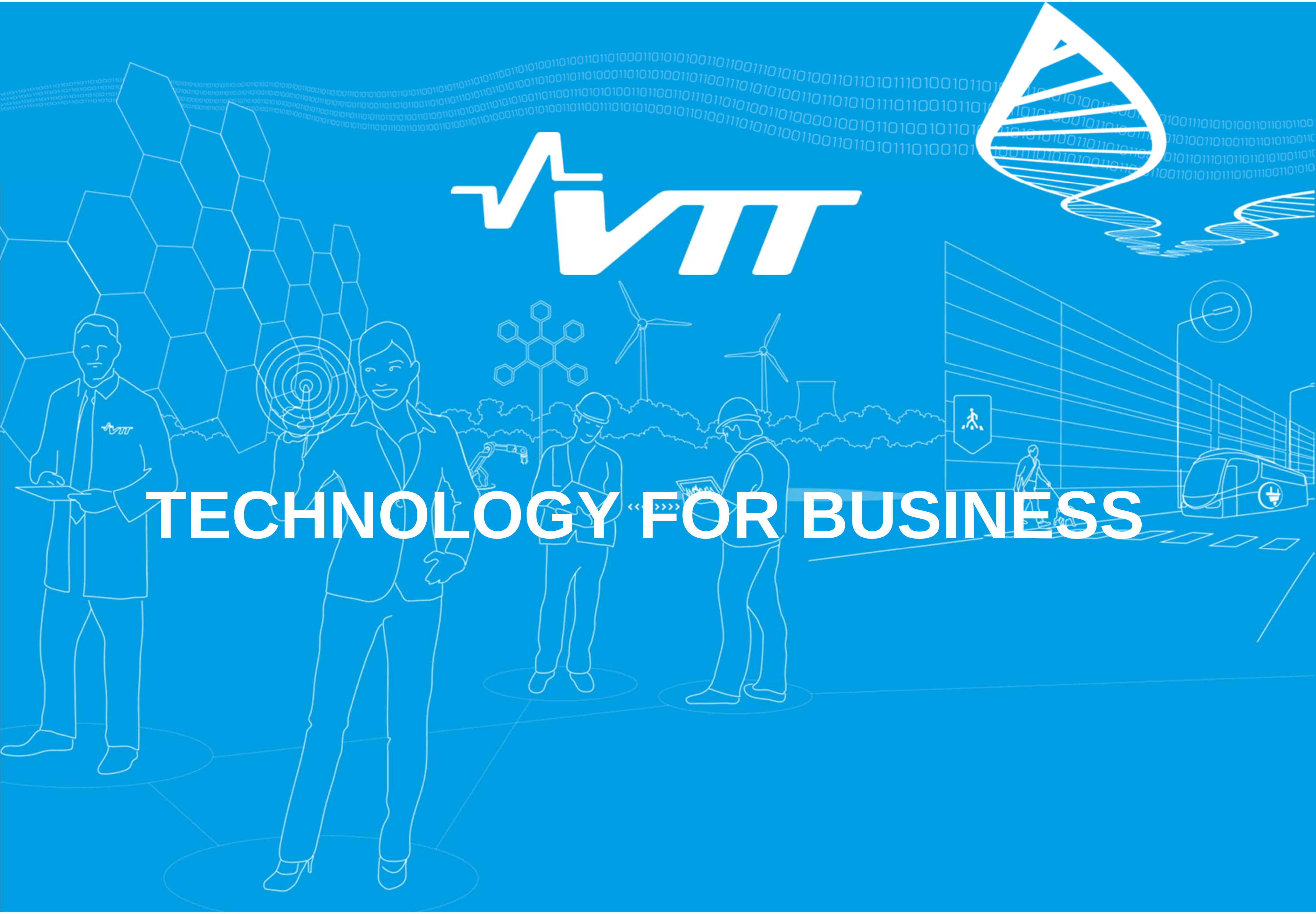
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