SIMULATION OF SOILING IN AN ARTIFICIAL DUSTING DEVICE

COMSOL CONFERENCE 2018 LAUSANNE

Fraunhofer-Institute for Solar Energy Systems ISE

Elisabeth Klimm, Summer Kochersperger, K-A Weiß

Fraunhofer Institute for Solar Energy Systems ISE

COMSOL Coference
Lausanne, 23.10.2018

www.ise.fraunhofer.de

GUS Gesellschaft für Umweltsimulation e.V.

Fraunhofer ISE

Group Service Life Analysis

Fraunhofer ISE

Outdoor Performance

- Outdoor facilities with **diff. climates**
  - Moderate
  - Alpine
  - Arid
  - Maritime
- High-resolution climate monitoring and recording
- Load mapping

Accelerated Testing

- Based on data from outdoor exposure
- Development of procedures
- **Simulation of** degradation mechanisms in **accelerated aging** tests

Analytics

- Identification of degradation indicators
  - Materials
  - Components
- Development of non-destructive test methods
- Efficient, flexible test procedures

Service Life Analysis

- Investigation of
  - **Quality** and
  - **Durability**

of PV-modules, solar thermal collectors and components

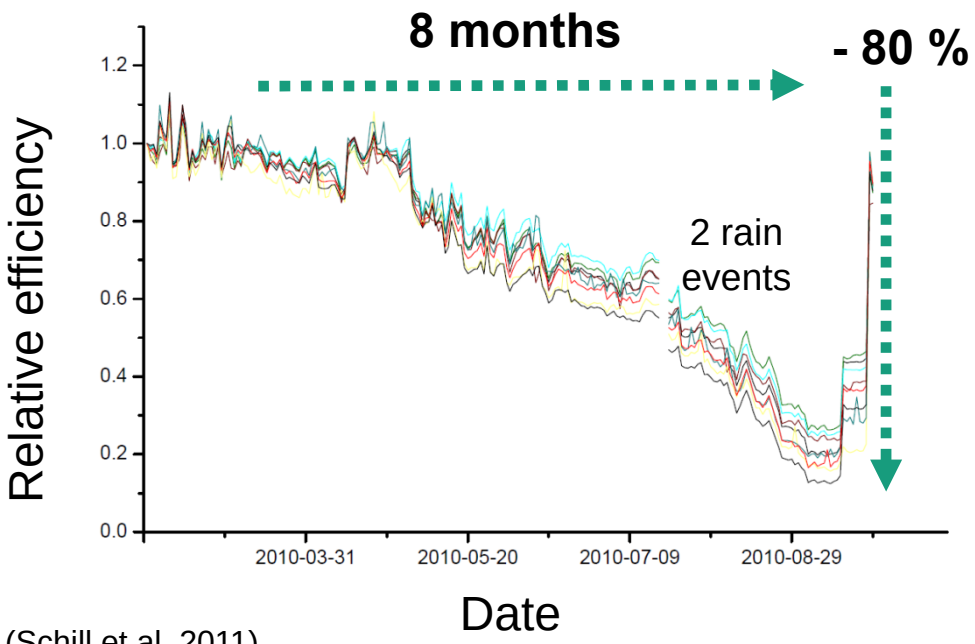
- **Durability testing**
- Standardization

GUS Gesellschaft für Umweltsimulation e.V.

Fraunhofer ISE

Soiling of PV modules

Example of soiling on Gran Canaria, Spain



(Schill et al. 2011)

Testmodules from Fraunhofer ISE

ITC test site – Instituto tecnologico de Canarias
SEDE De POZO IZQUIERDO, Gran Canaria, Spain

Influcences: local weathering, surfaces, degradation, particle physics and chemistry, …

→ **Multi-physics issue**

GUS Gesellschaft für Umweltsimulation e.V.

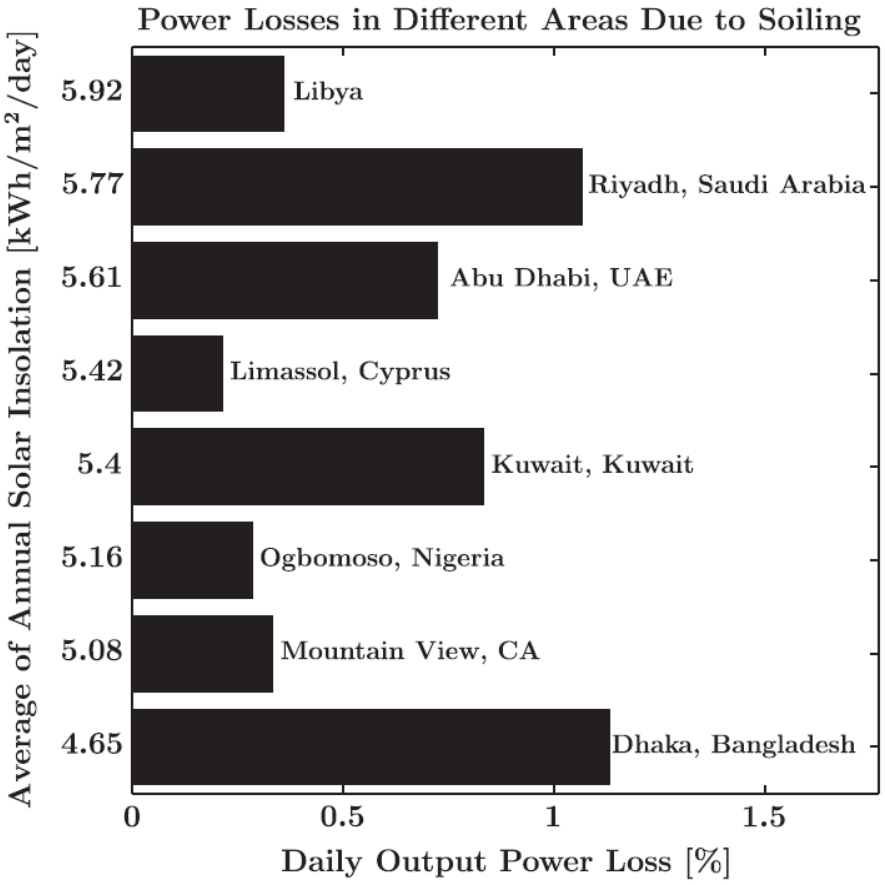
Fraunhofer ISE

Local dependency of soiling in deserts

FEM: A tool to improve the understanding

- Use Numerical Simulation to
  - enhance experimental times
  - choose suitable locations and constitution of solar energy power plants

  in terms of **soiling mitigation**



Sayyah et al. (2014) *Energy yield loss caused by dust deposition on photovoltaic panels*

FEM Simulation Approach

Going indoor - for better control of boundary conditions

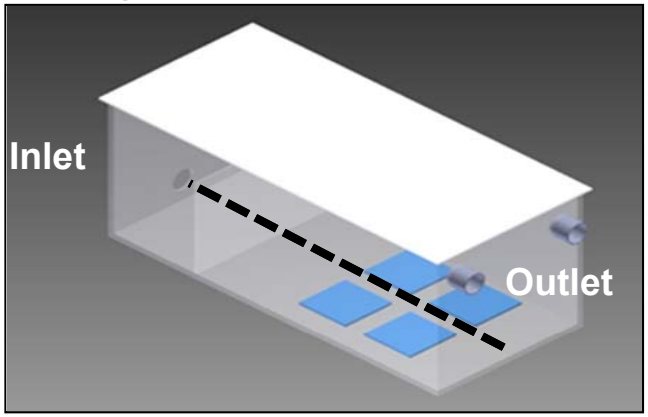
- Reproducible conditions and actual set- up, fast to verify, fast to learn, ..
- FEM Model:
  - Geometry of actual artificial soiling device
  - Conservation of momentum

    inlet velocity = outlet velocity
  - “Wind” speeds chosen to match desert wind, set to ~ 5 m/s and kept stable during test and simulation

Pressure [bar]	Inlet Velocity [m/s]	Outlet Velocity [m/s]
1.5 bar	5.7	5.5

Indoor test set-up for homogen-eous soiling

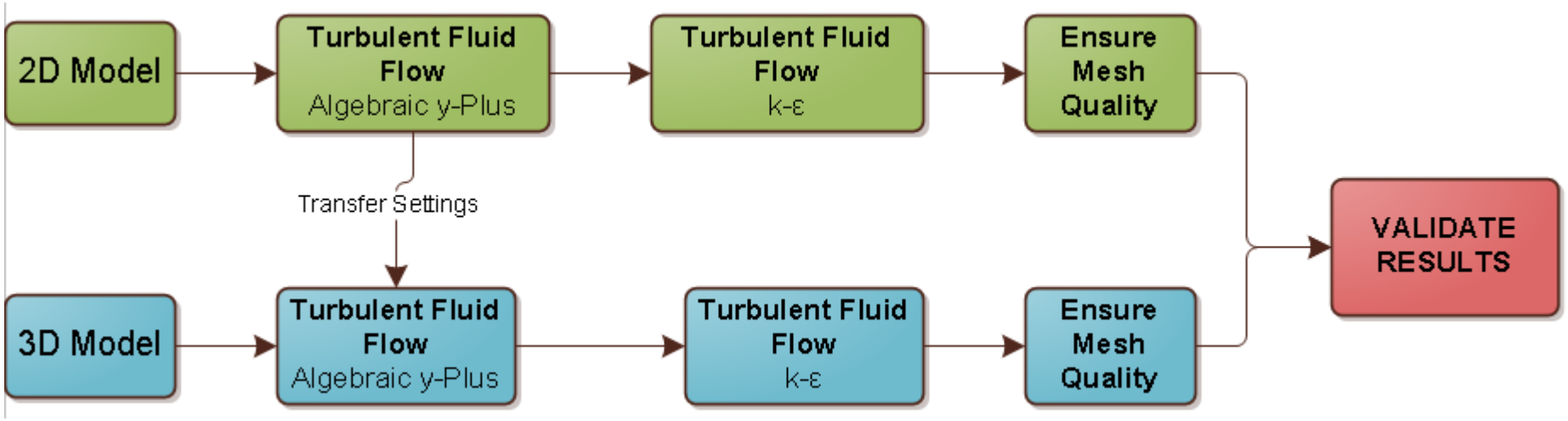
CAD rendering of the artificial dusting device



FEM Simulation Approach

Simulation of the Lab Test

Comsol 5.3



Characterizing the System
Physics and Turbulent Fluid Flow

Knudsen Number $Kn = 1.7 * 10^{-6}$

Kn < 0.01 and continuous flow (Navier-Stokes is valid)

Mach Number

Velocity [m/s]	Mach Number
1	$2.9 * 10^{-3}$
5	0.015
10	0.029

Compression can be ignored (M < 0.3)

Reynolds Number

υ inlet (m/s)	Re	Flow Regime
1	$2.7 * 10^3$	Transition
5	$13.5 * 10^3$	Turbulent
10	$27.1 * 10^3$	Turbulent

Turbulent Fluid Flow for υ inlet

Characterizing the System
Translation into COMSOL Language

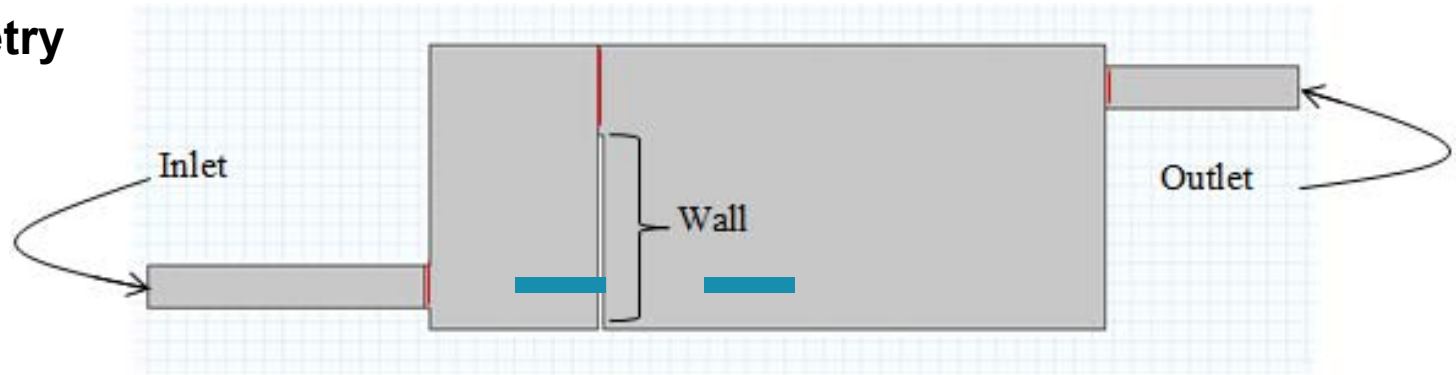
- $k-\varepsilon$ turbulence model
- Wall function used, non-zero velocity for flow assumption for boundary layers
- Inconsistent Stabilization Method used to aid in convergence;

  parameter to minimize diffusion: $\frac{1}{CFLCMP}$

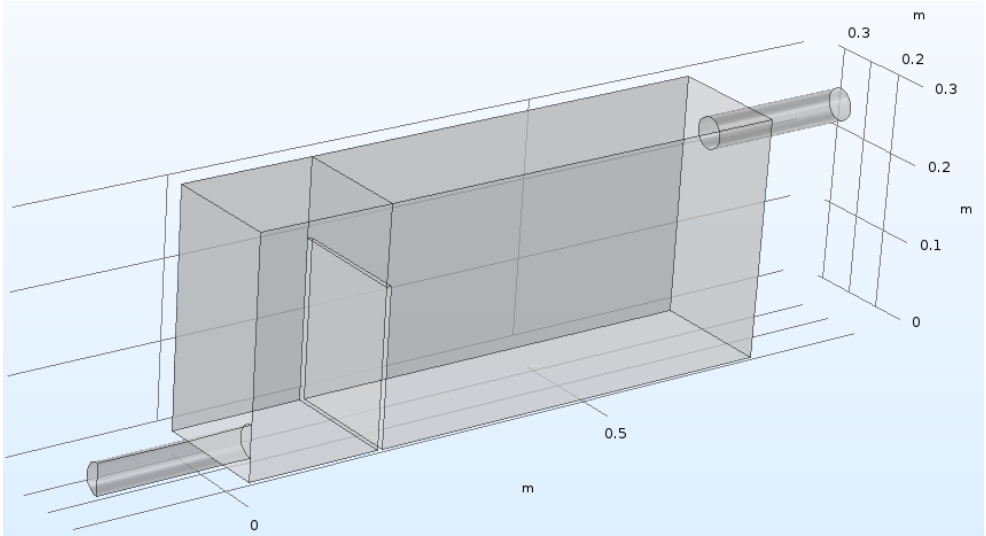
FEM Simulation of artificial soiling device

Geometry of Models

2D Geometry



3D Geometry

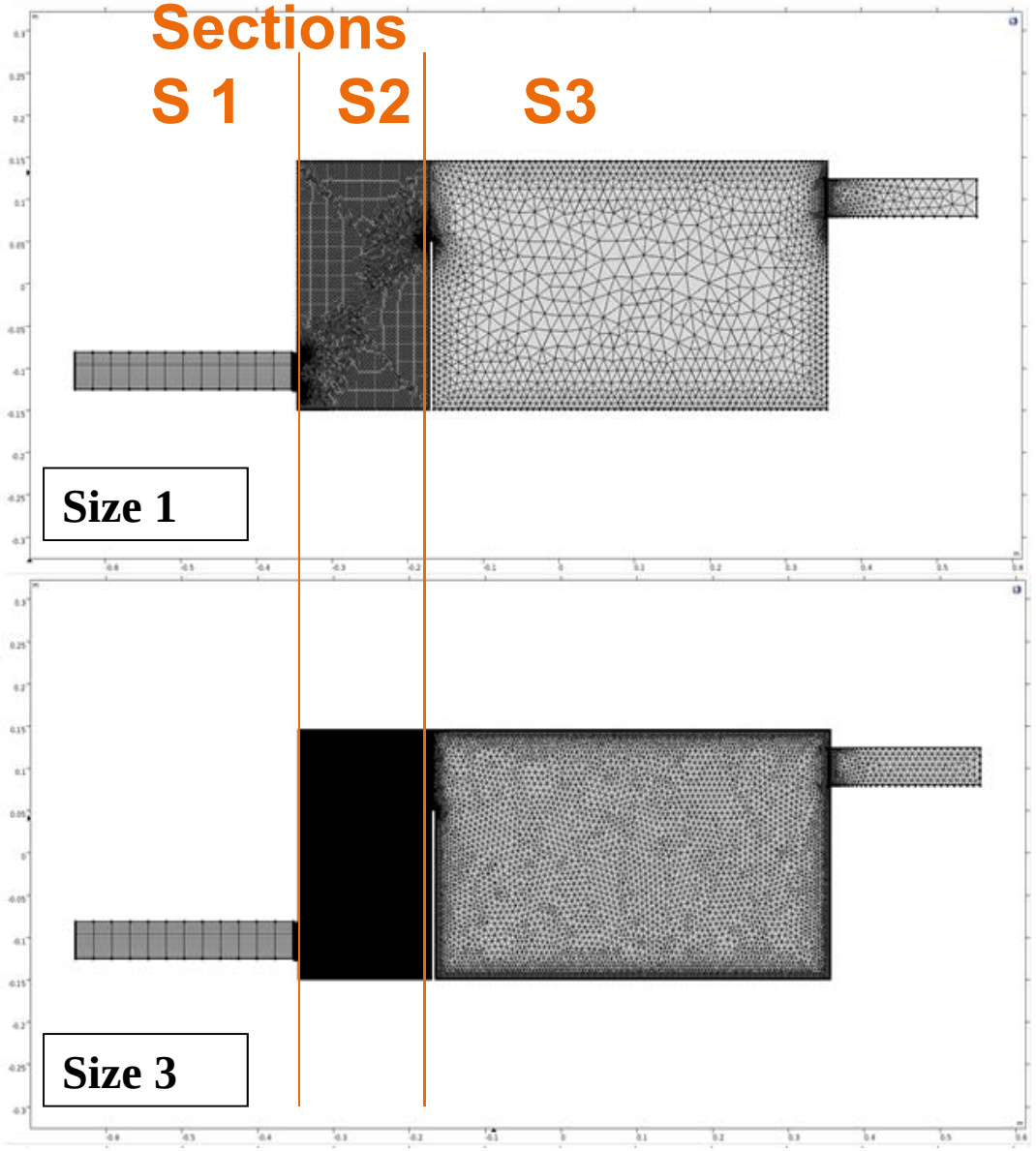


3D-Model cut along the plane of symmetry to simplify the simulation

Scale Size Dimensions

Mesh 2D

- Meshing was completed in sections
- Comparison of Scale Size Functions
  - 1
  - 3
  - 6



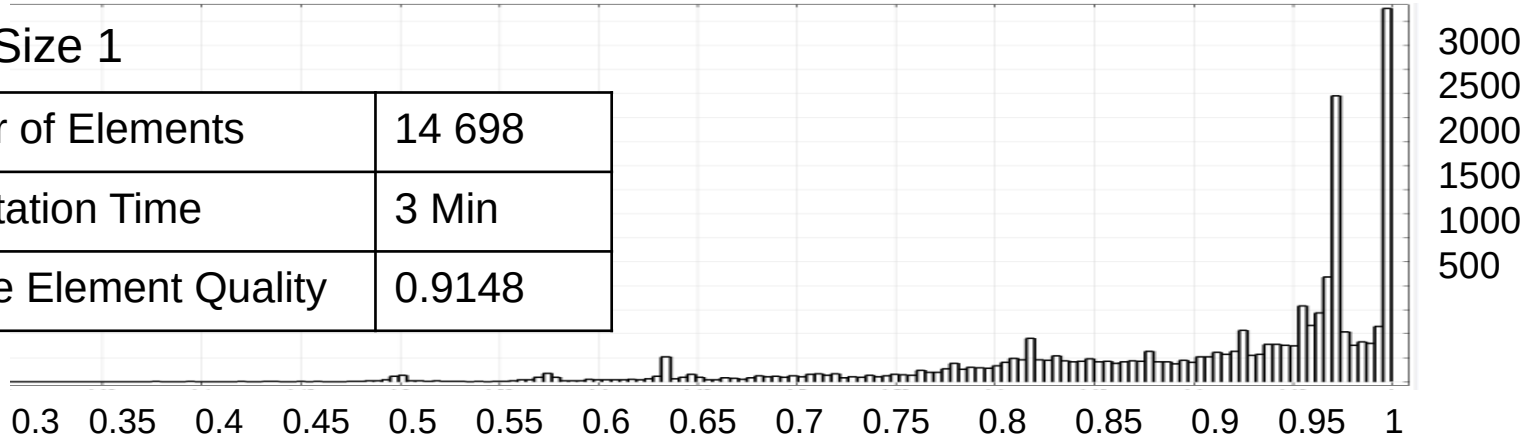
Statistics

Mesh 2D: Comparison of Skewness in Sizes 1 and 3

Histogram of Number of Elements vs. Element Quality

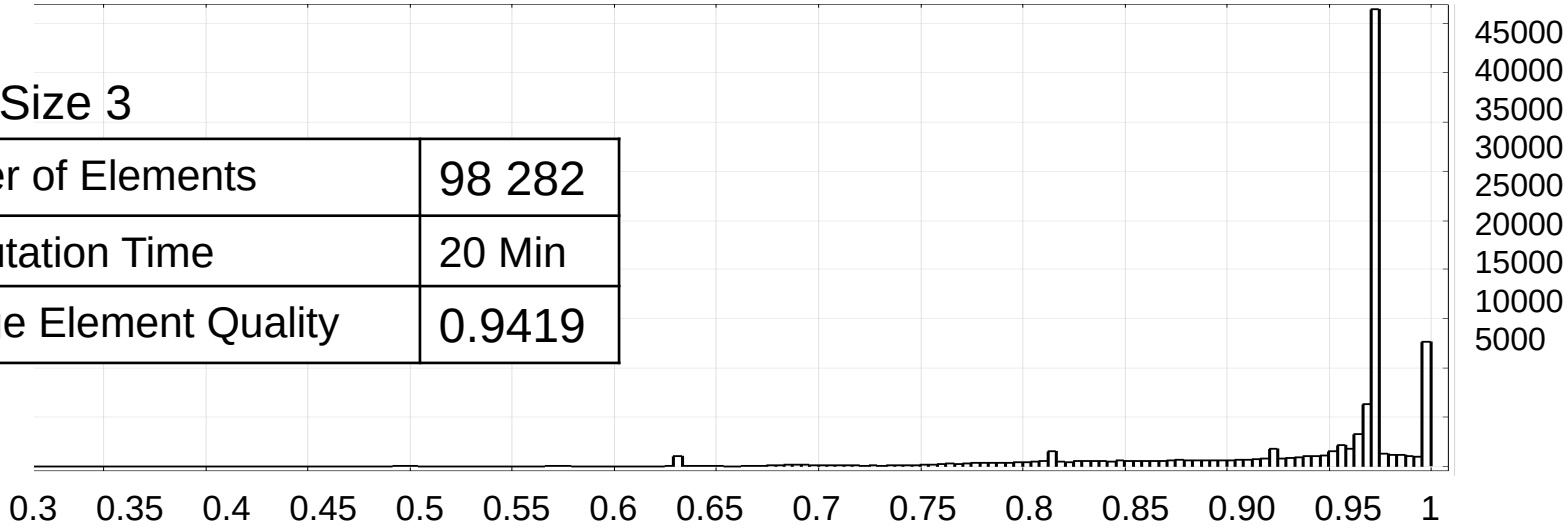
Mesh Size 1

Number of Elements	14 698
Computation Time	3 Min
Average Element Quality	0.9148



Mesh Size 3

Number of Elements	98 282
Computation Time	20 Min
Average Element Quality	0.9419

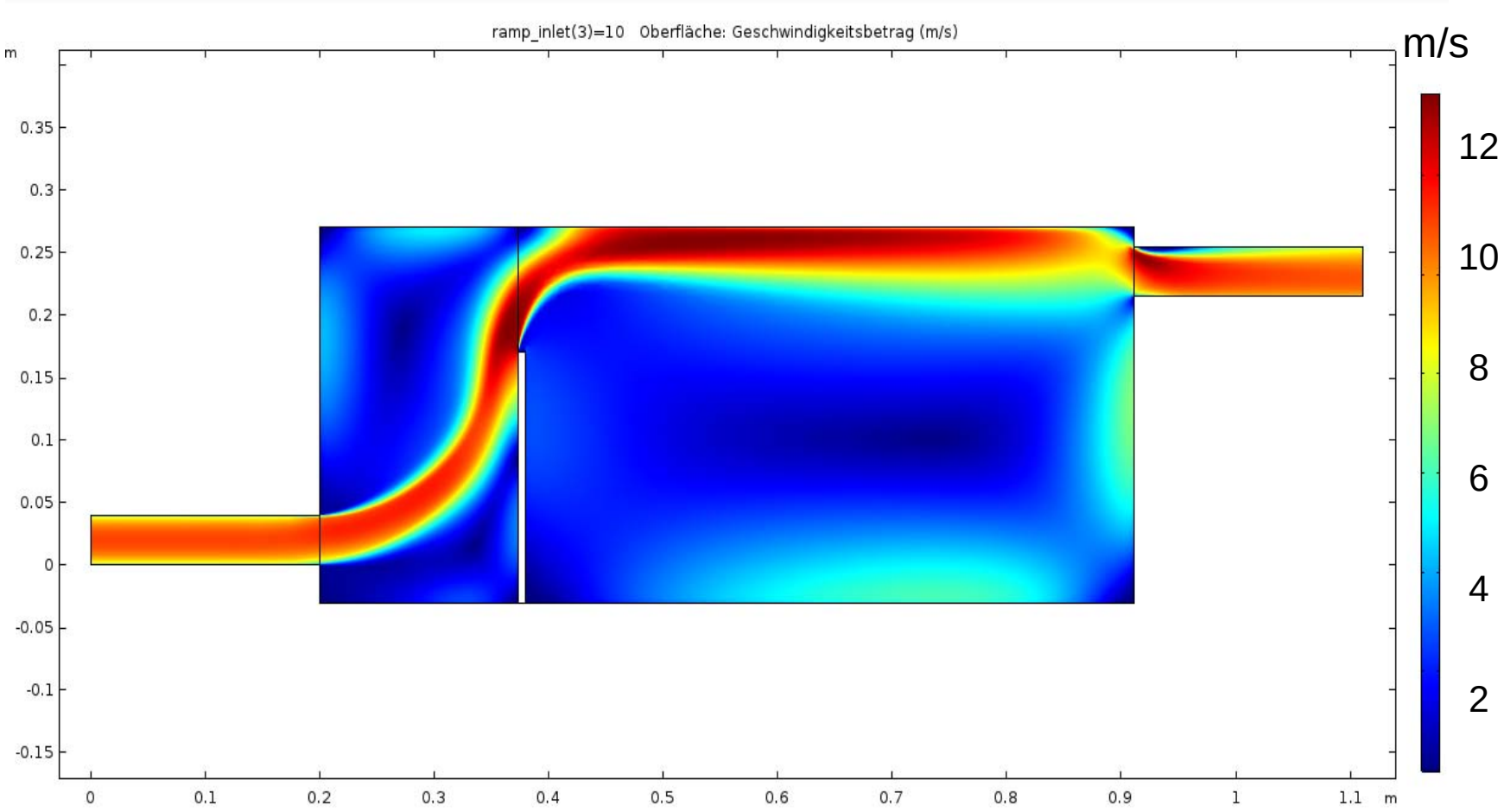


Computer: Intel i7 processor-6700 CPU with 8GB RAM

Fraunhofer ISE

FEM Simulation

Results 2D: Surface velocities (υ_{inlet} =10 m/s), Mesh Size 3

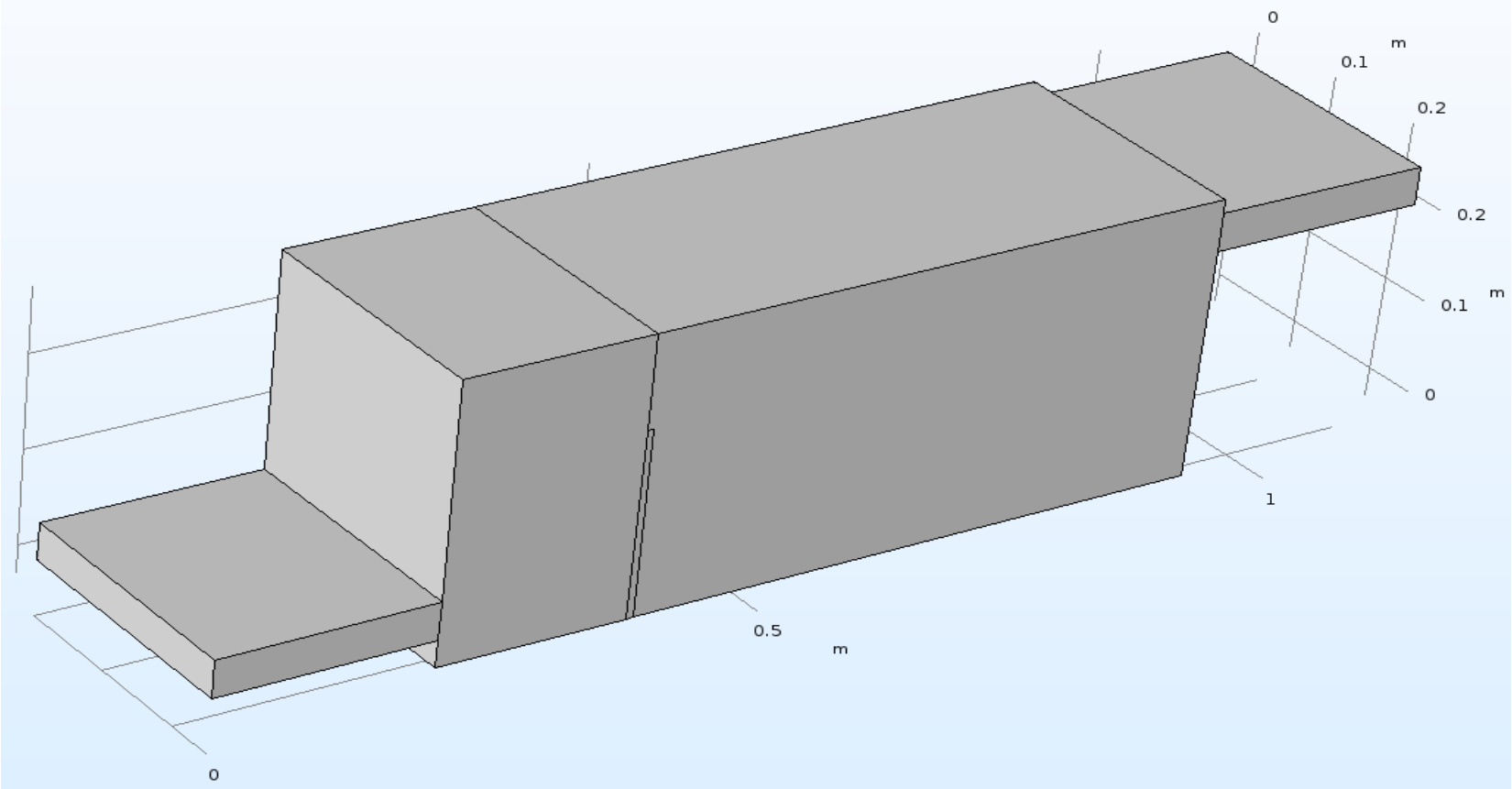


GUS Gesellschaft für Umweltsimulation e.V.

Fraunhofer ISE

FEM Simulation

Results 2D: 2D Geometry interpretation



- Physics transfered to 3D Model, which will allow for correct round inlet and outlets to be studied.

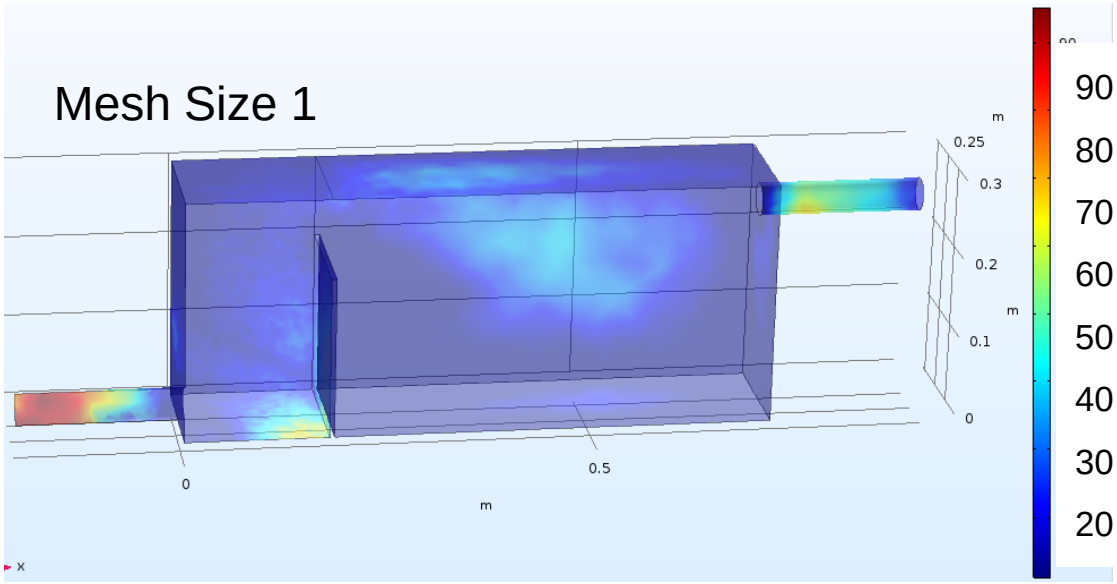
FEM Simulation

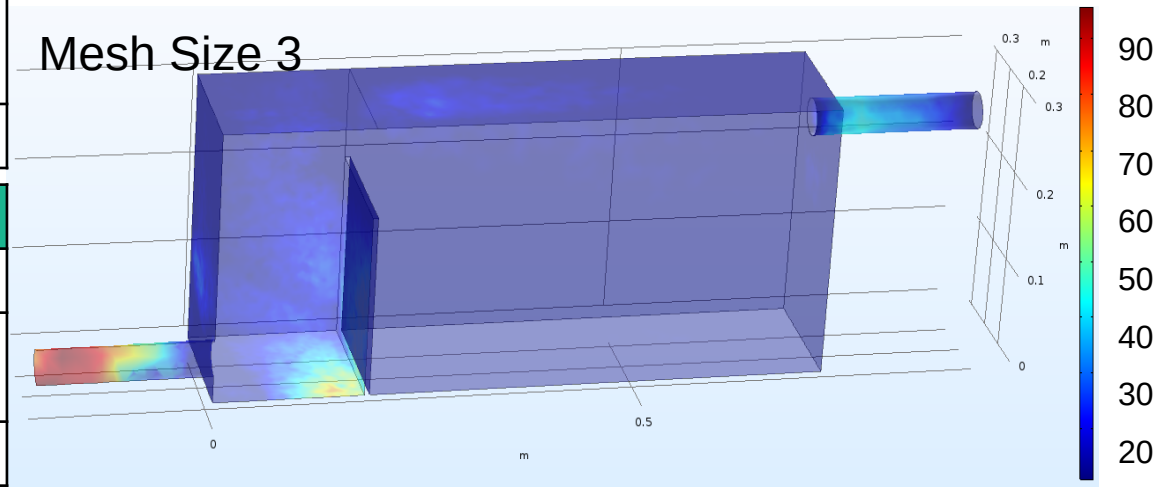
Mesh 3D

- Resolution and Quality of different mesh sizes analyzed
- Size 3 sufficient and selected

Statistic	Mesh 1
Elements	1 244 645
Ave Element Quality	0.6946
Comp. Time	8,5 h

Statistic	Mesh 3
Elements	2 509 493
Ave Element Quality	0.6842
Comp. Time	19 h

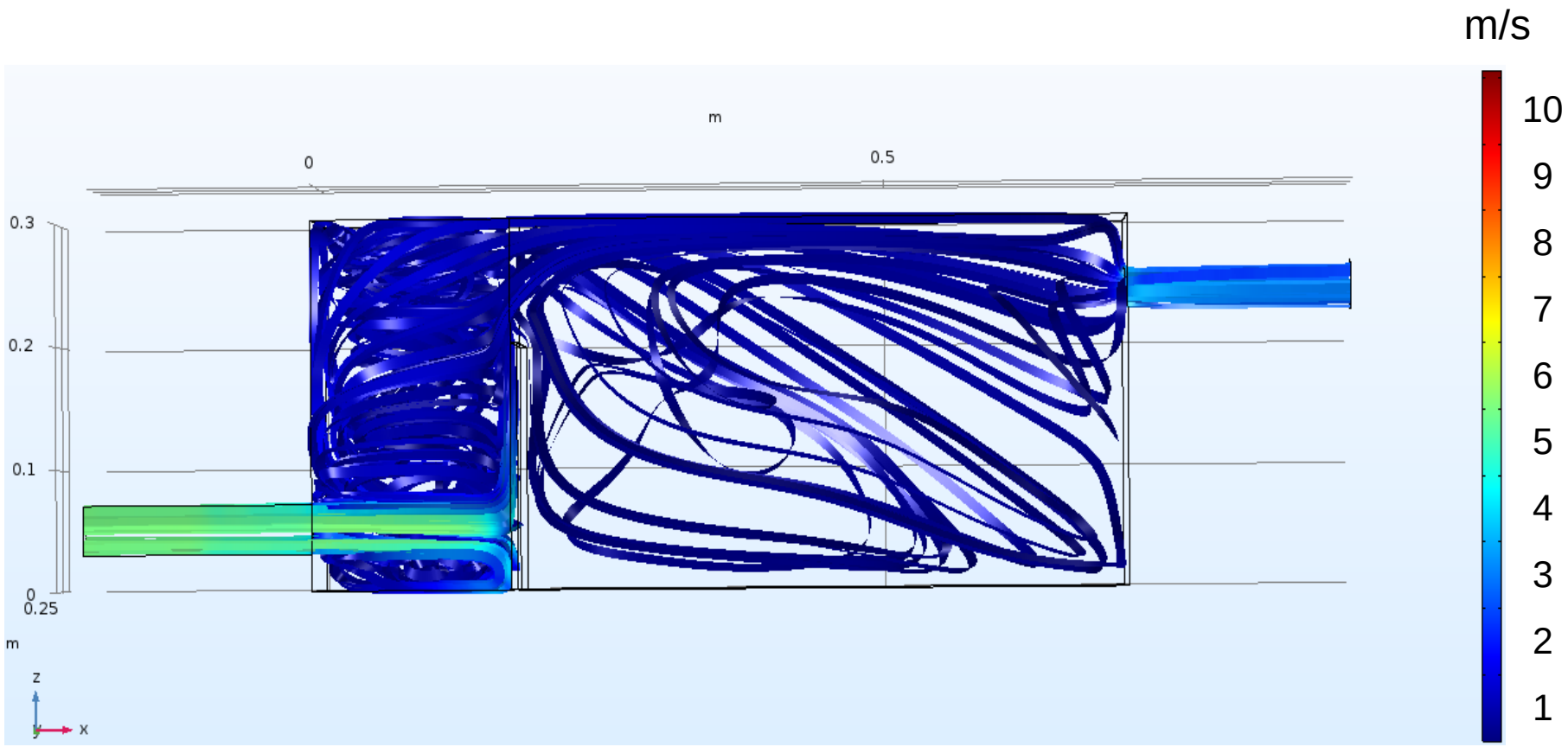




GUS Gesellschaft für Umweltsimulation e.V.
Fraunhofer ISE

FEM Simulation

Results 3D: Stream line velocities, Mesh size 3

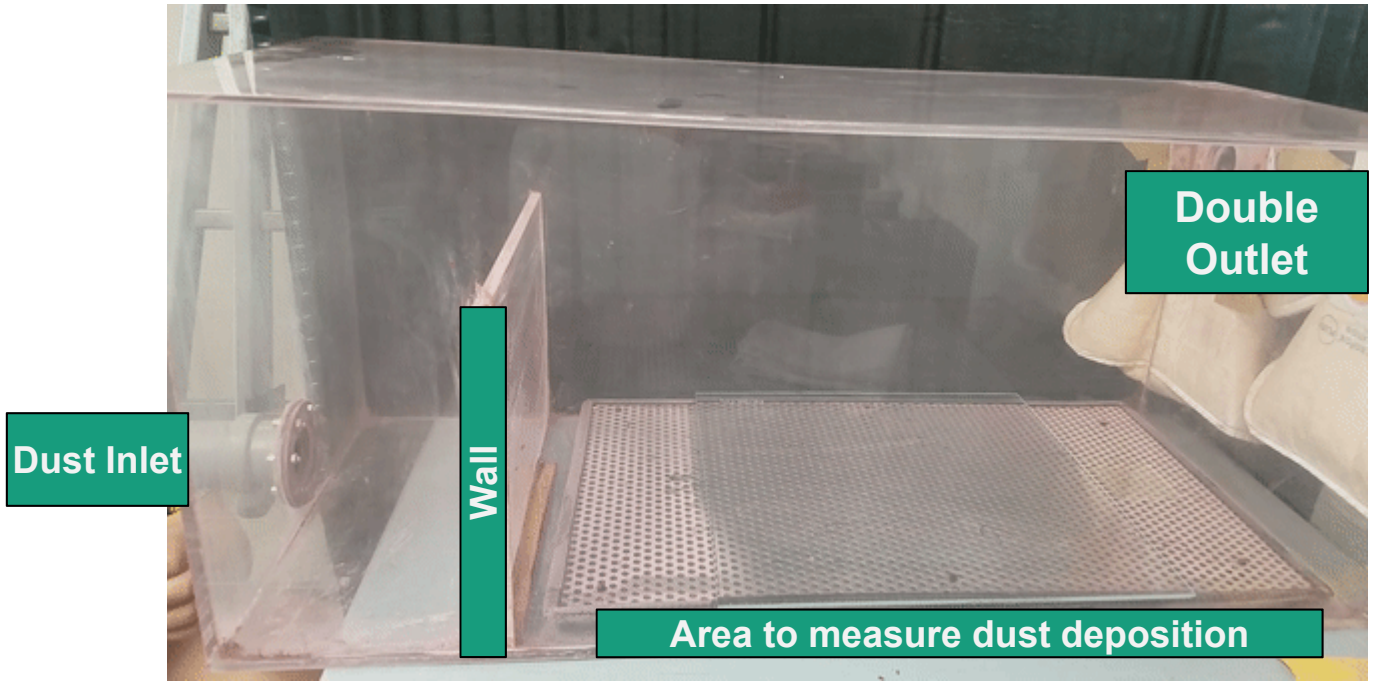


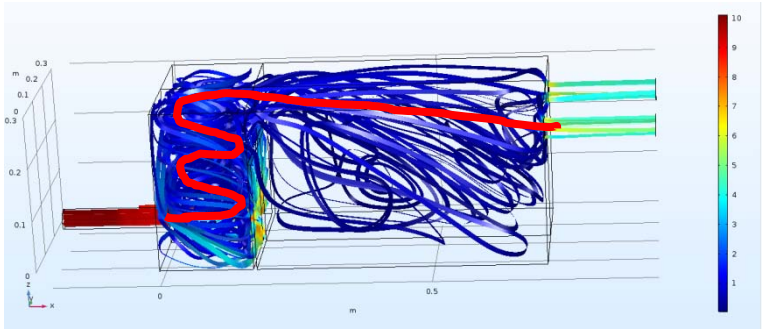
GUS Gesellschaft für Umweltsimulation e.V.

Fraunhofer ISE

FEM Simulation

Validation (υ_{inlet} = 5 m/s)



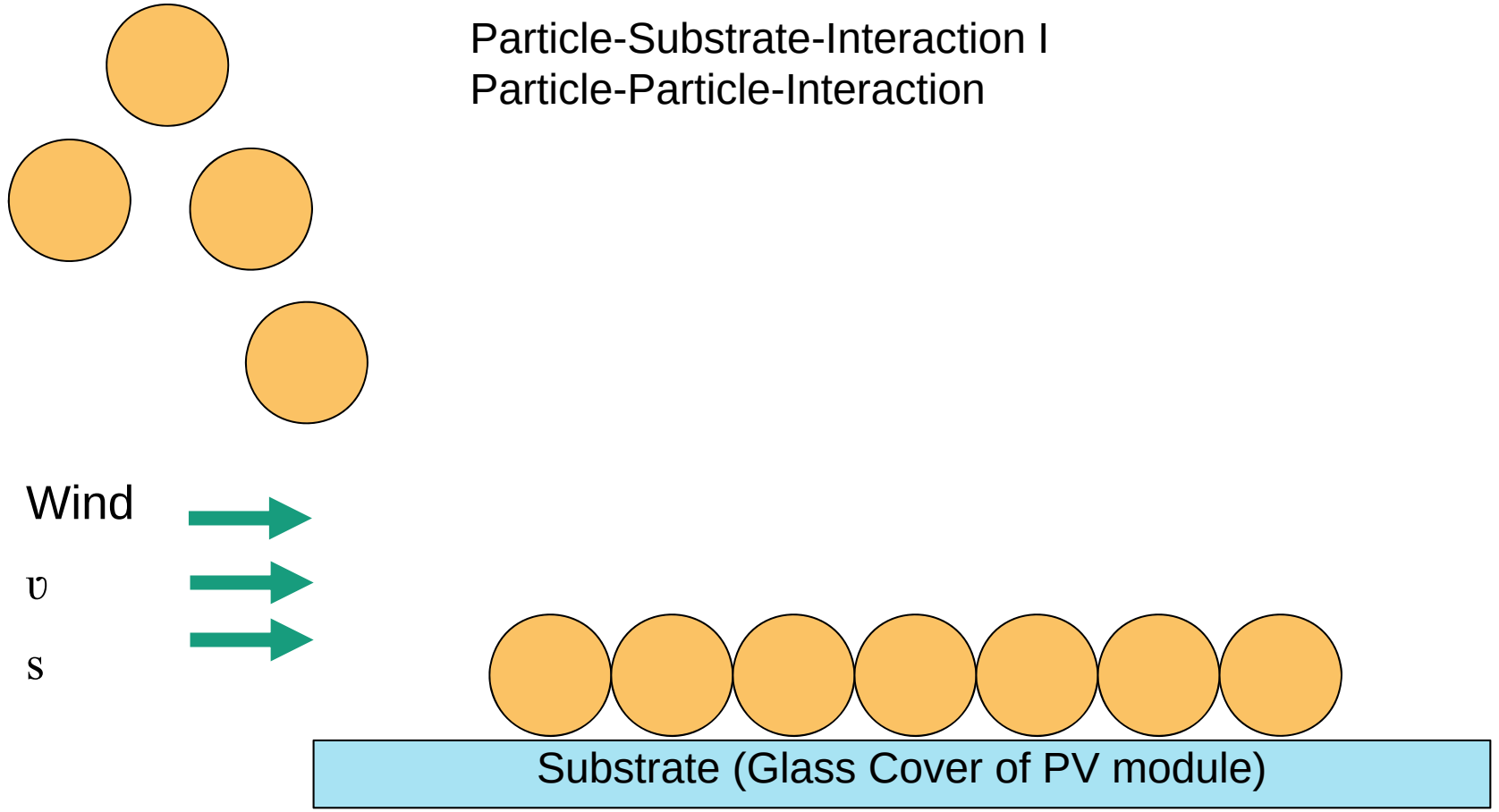


Summary
Numerical Soiling Simulation

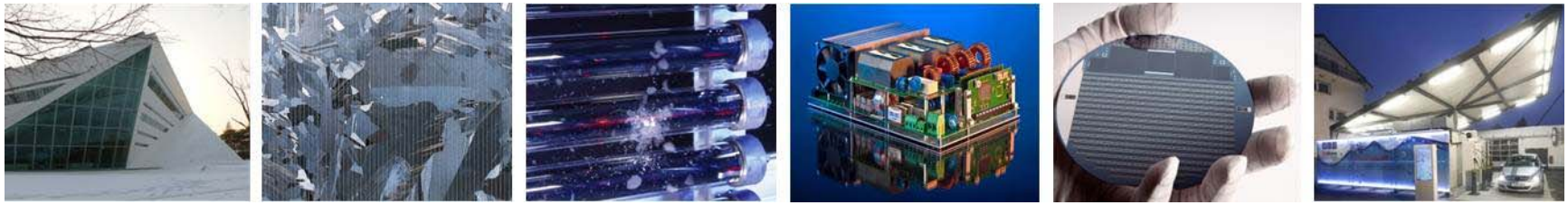
- Successfull CFD simulation of laboratory soiling tests with COMSOL 5.3a
- 2D model is not sufficient enough to capture results
  - 3D model necessary for accurate results
- 6 h computation time for 3D model
- Mesh Scale Size Geometries functions (Size 3) can successfully aid in obtaining better results

Outlook

Environmental dependent multi-physics simulation



Thanks for your attention



Fraunhofer-Institute for Solar Energy Systems ISE

Elisabeth Klimm

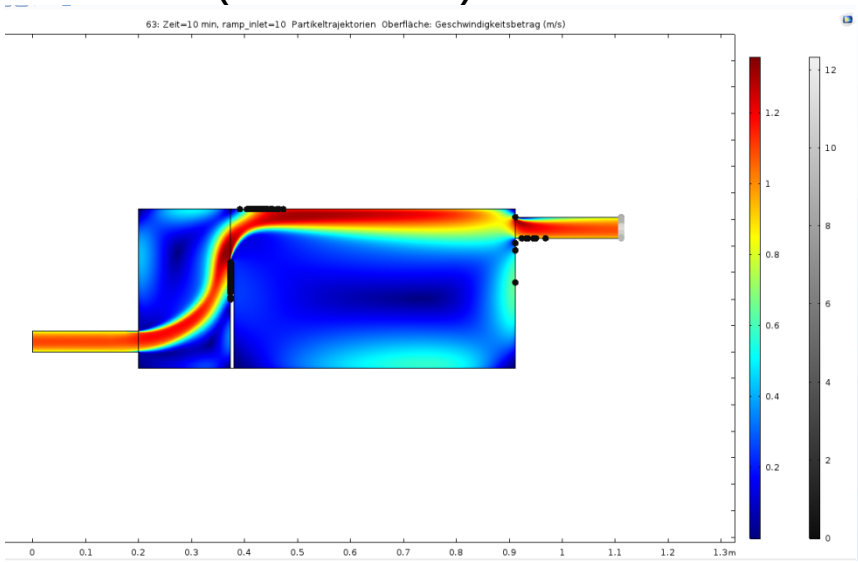
Elisabeth.klimm@ise.fraunhofer.de

www.ise.fraunhofer.de

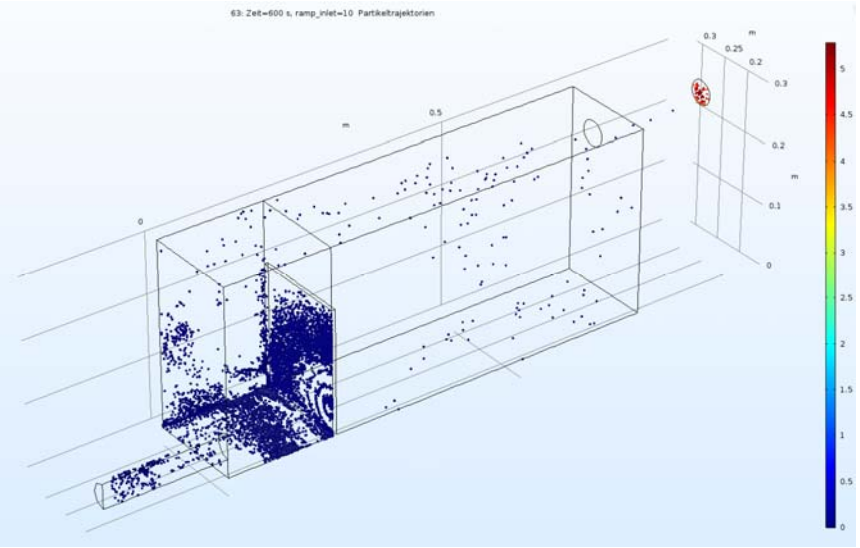
Outlook

Solutions for Particle Trajectories with 1000 particles

2D Mode
(c.t.: 1 hour)



3D Model
(c.t.: 12 hours)

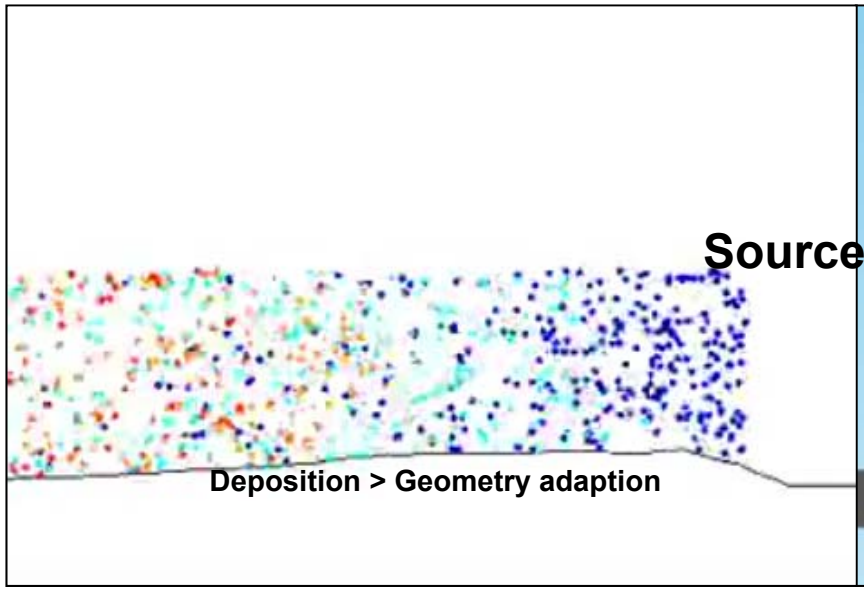


- 2D Results are not sufficient; Results with and without fluid-particle interaction show almost no difference
- 3D Model of particle tracing shows promising first results

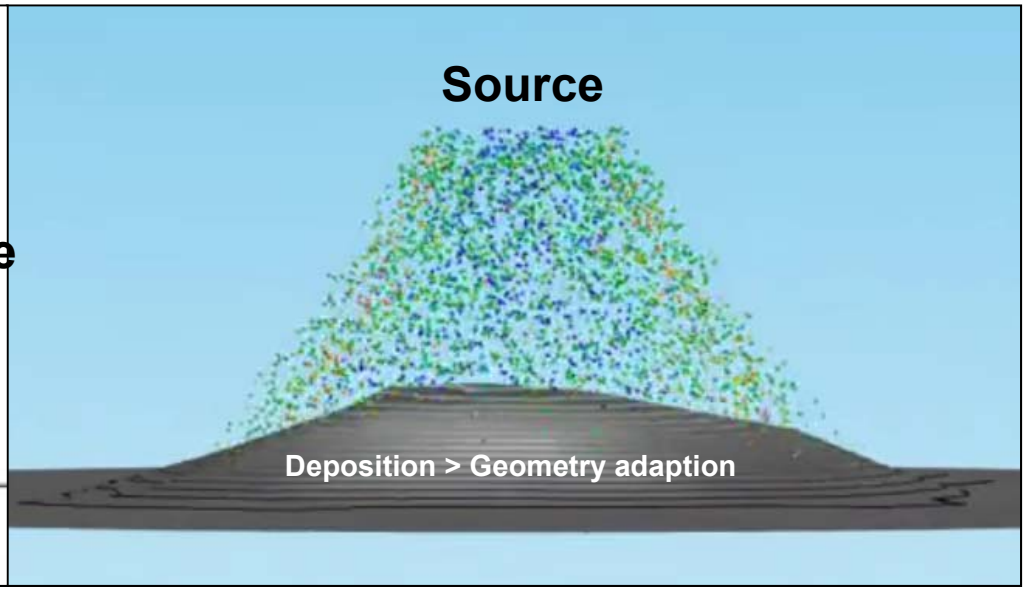
With kind support and technical assistance of COMSOL

Solutions for Particle Deposition
Models from COMSOL

2D Model



3D Model



https://www.youtube.com/watch?v=TgtVcDyUmf4

https://www.youtube.com/watch?v=mCvHQsAkBu0