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A micro-macroscopic modelling of particle retention on porous media and its impact on flow behaviour

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DHCAE Tools GmbH, Germany

Simulation solutions based on Open-source solver technology

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User Support Training:

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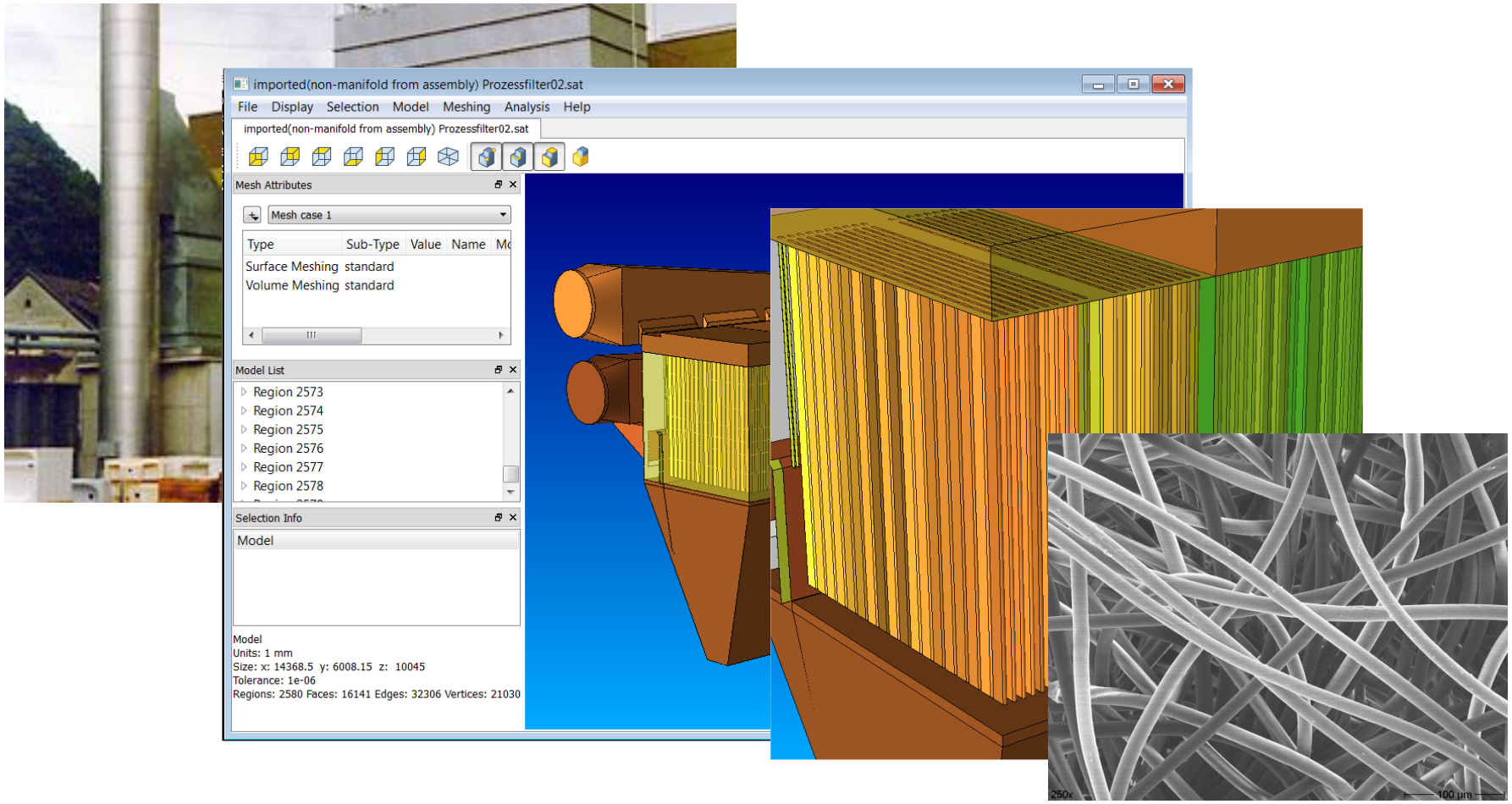


Overall model for retaining particles in fibers

DHCAE Tools

Microscopic discrete model on single fiber structures

Experiment: filter testing facility

Separation - resistance increase

Macroscopic approach: Filter plant

Parcel concept: Hit counter on filter patch + Micromodel

- Local resistance increase
- Local separation
- Reaction on continuous phase

Microscopic Modelling

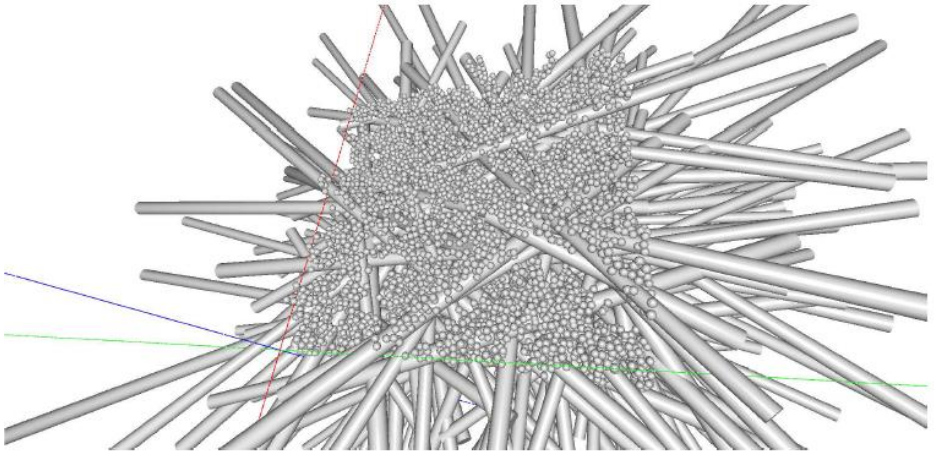
(almost conducted by IWT Bremen)

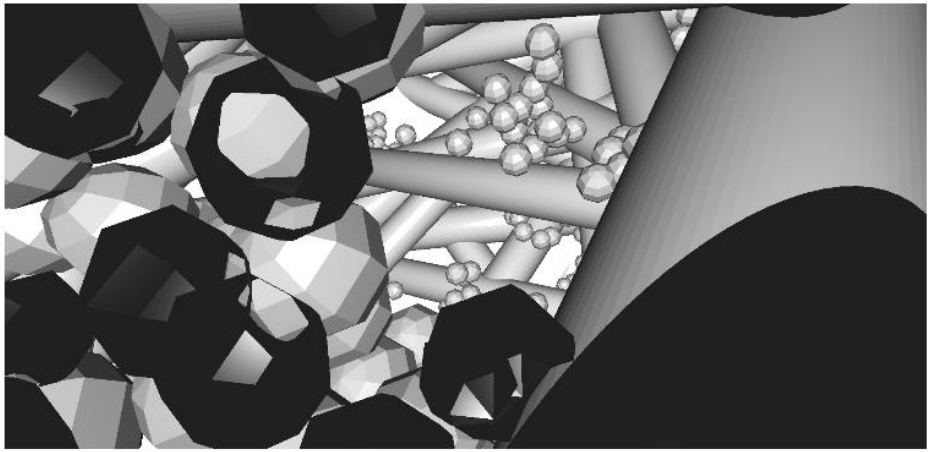
Continuous flow

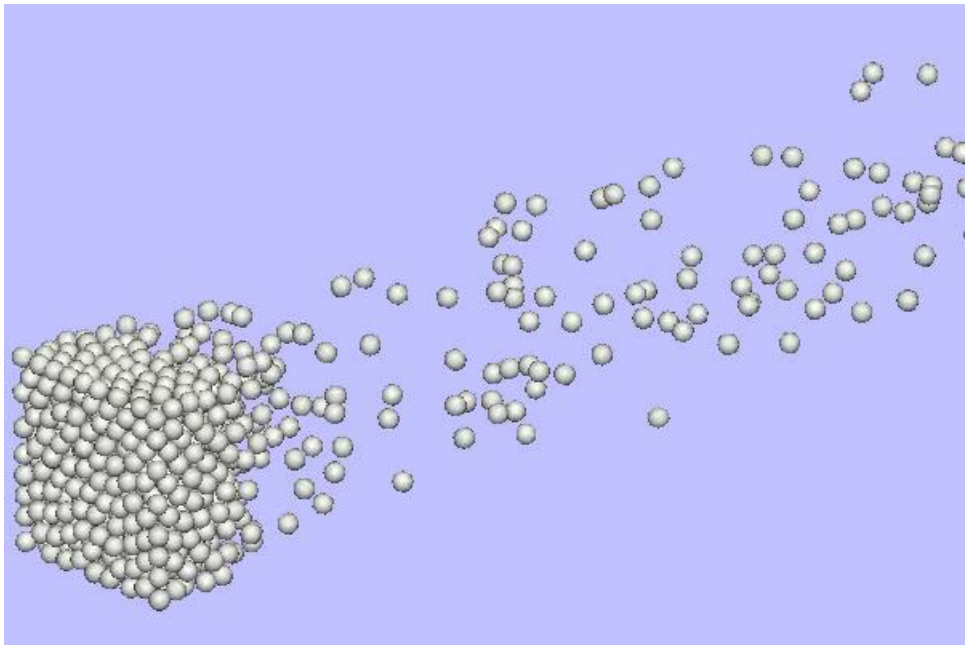
Particle flow

Settling

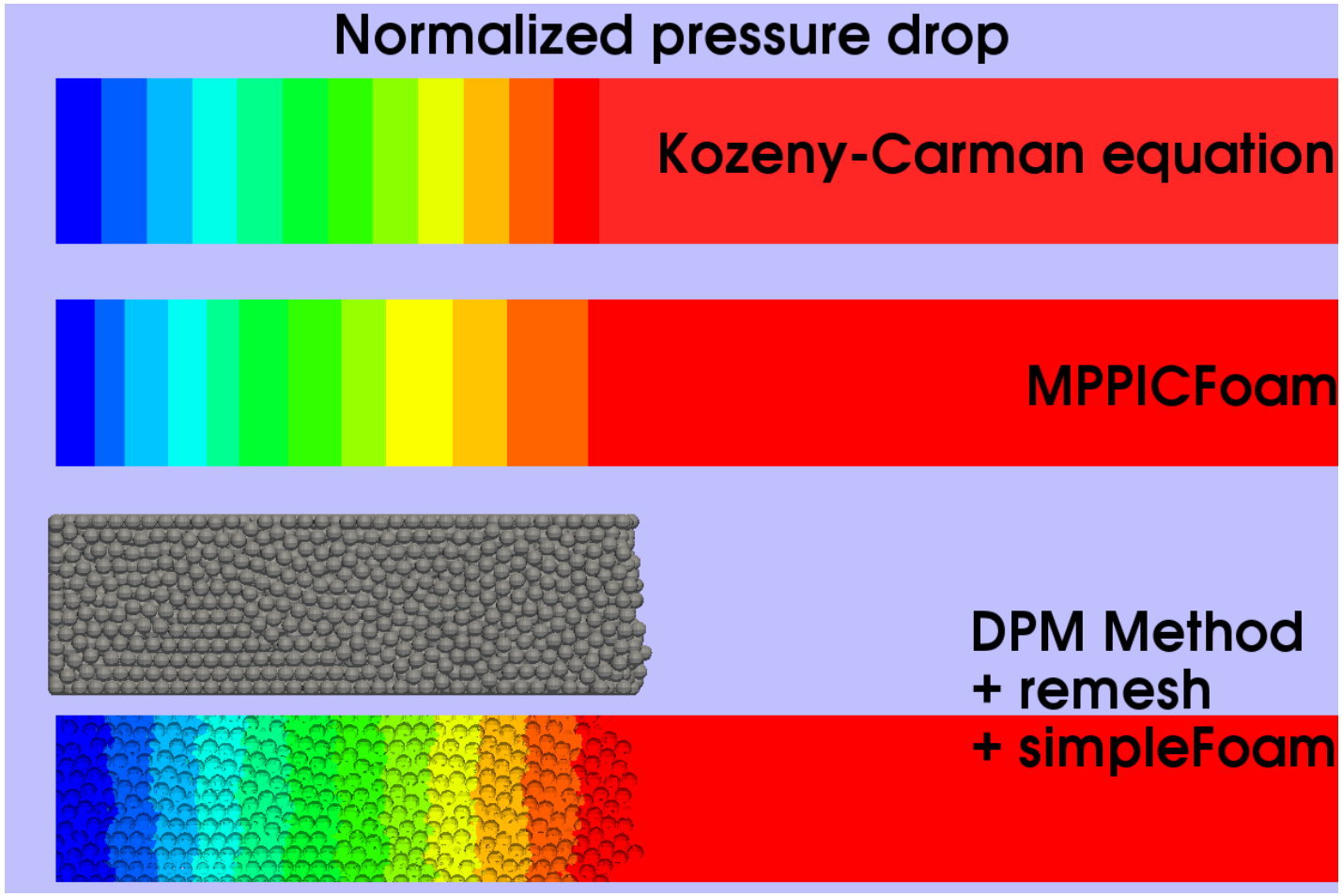
Remeshing



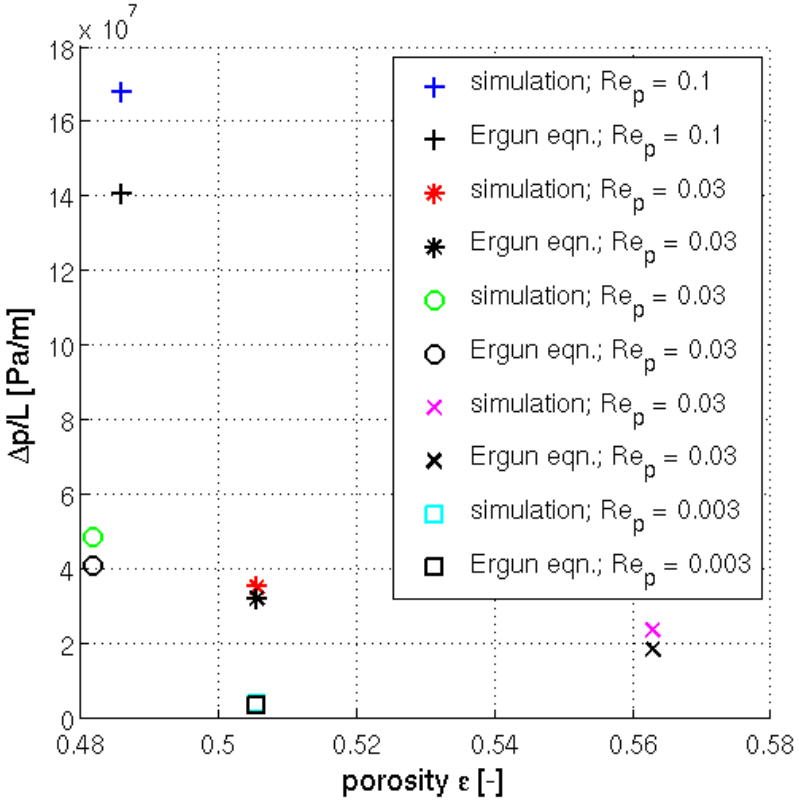


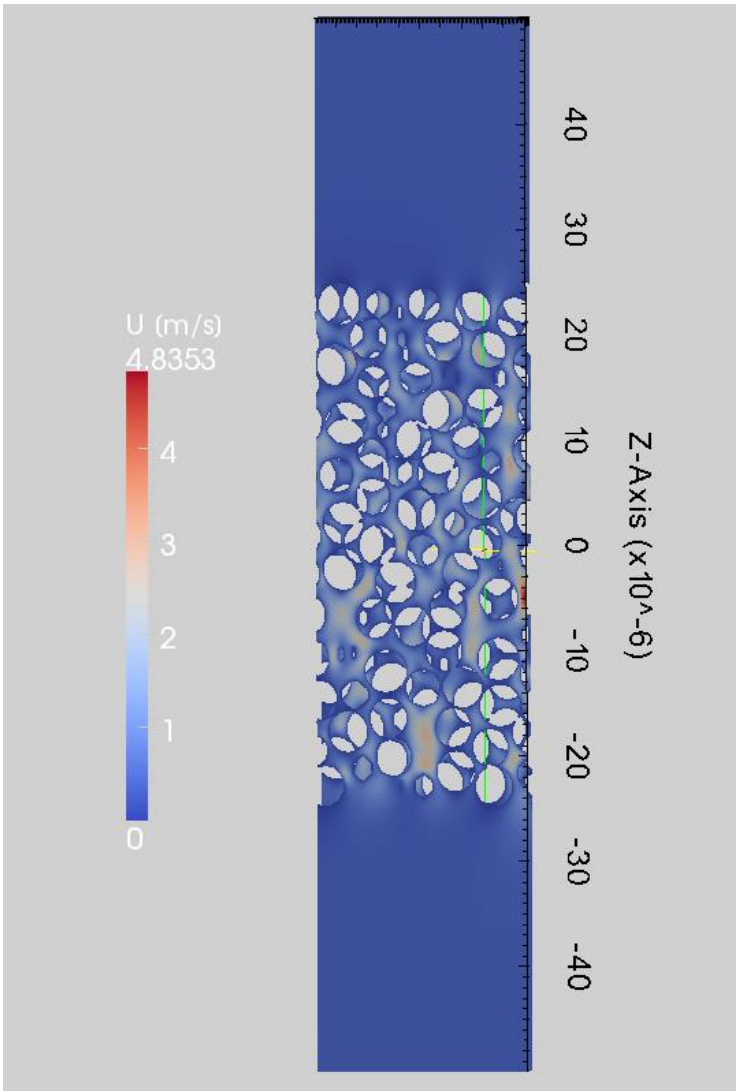


Comparison model approaches



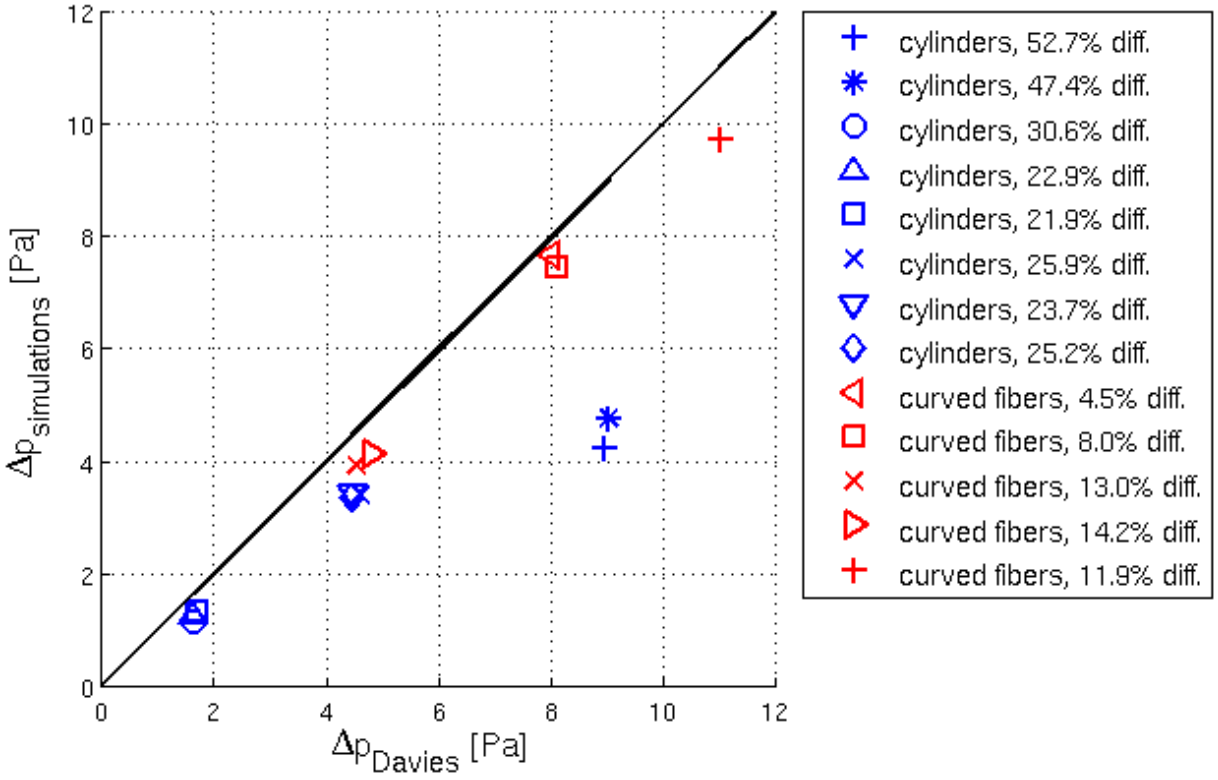
Flow through close-packing of spheres

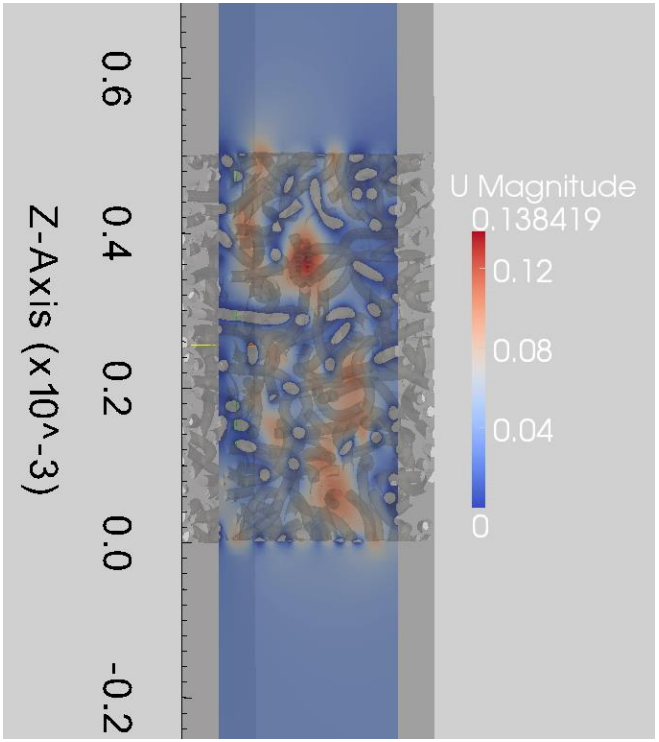




particle diameter	4 µm
porosities	48.2 … 56.3 %
approaching velocities	0.01 … 0.36 m/s

Flow through fiber packages





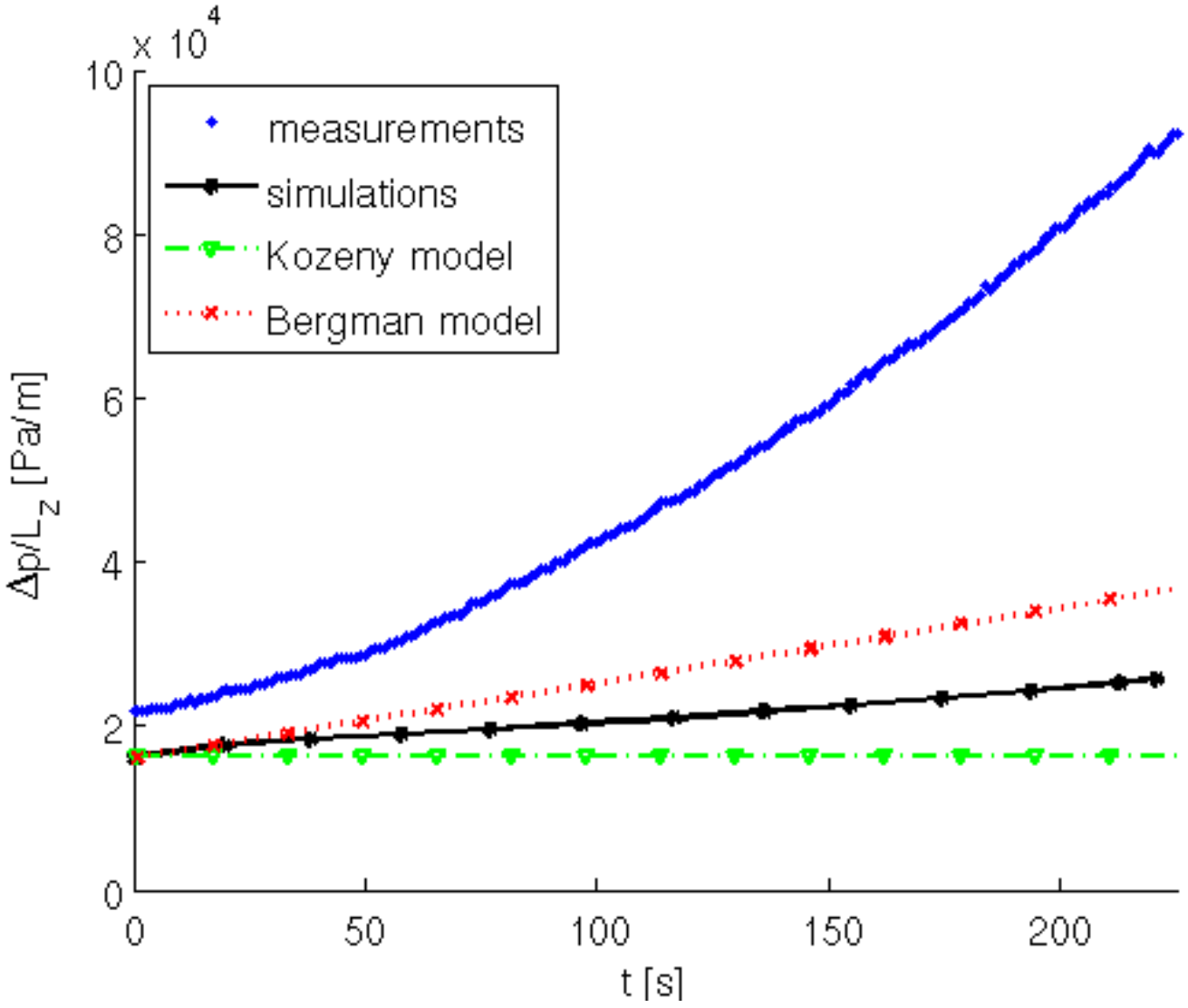
fiber diameters	15 … 25 µm
volumes	0.0315 … 0.25 mm³
velocity	0.0333 m/s

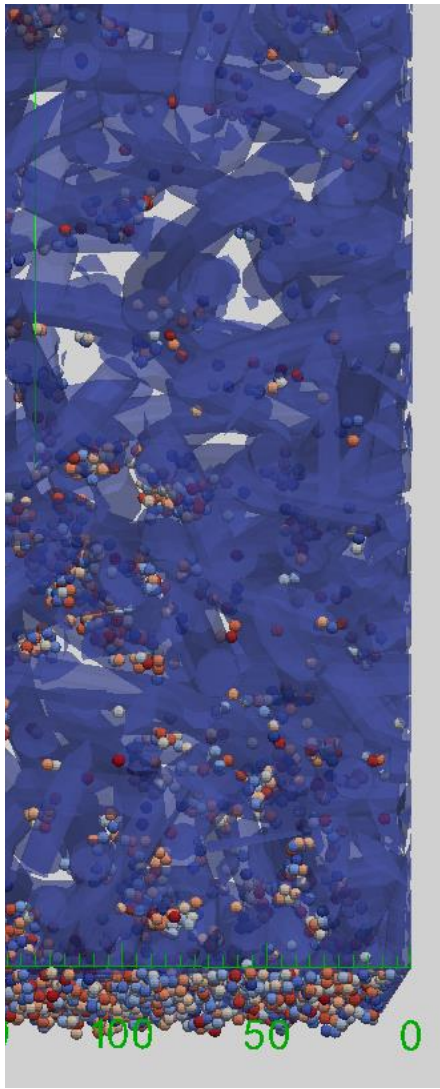
Further models included and tested:

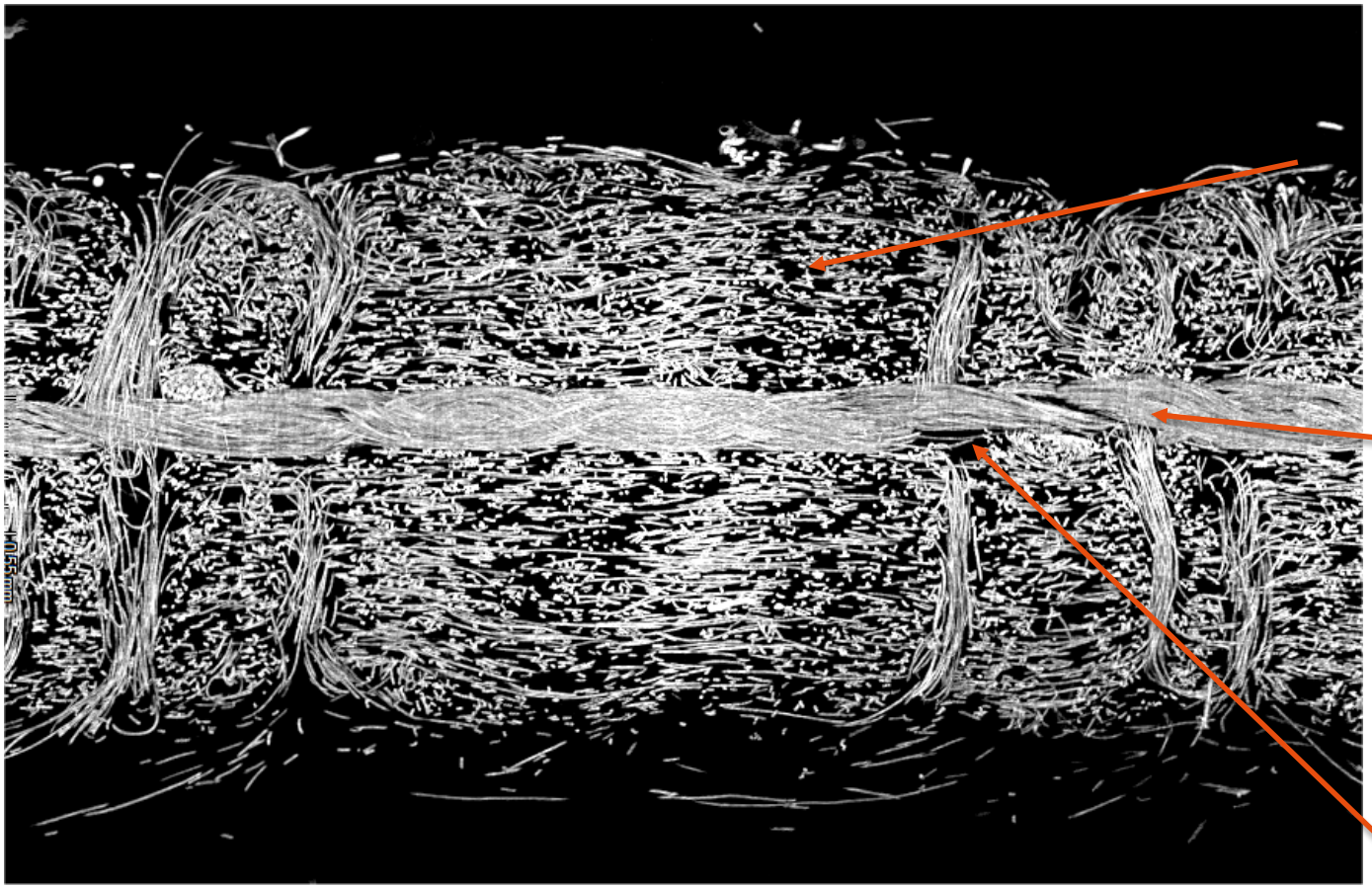
- Impact models
- Particle-particle collision models
- Sticking of single particle at fibers depending on the adhesion energy

Particle penetration in fiber structure

- Expected decay with depths observed







$\Delta p \sim \varepsilon^{4,5}$

Δp may differ by a factor of 10 or more depending on flow path even for a constant mean porosity

Conclusion micro modelling:

Agreement is found for

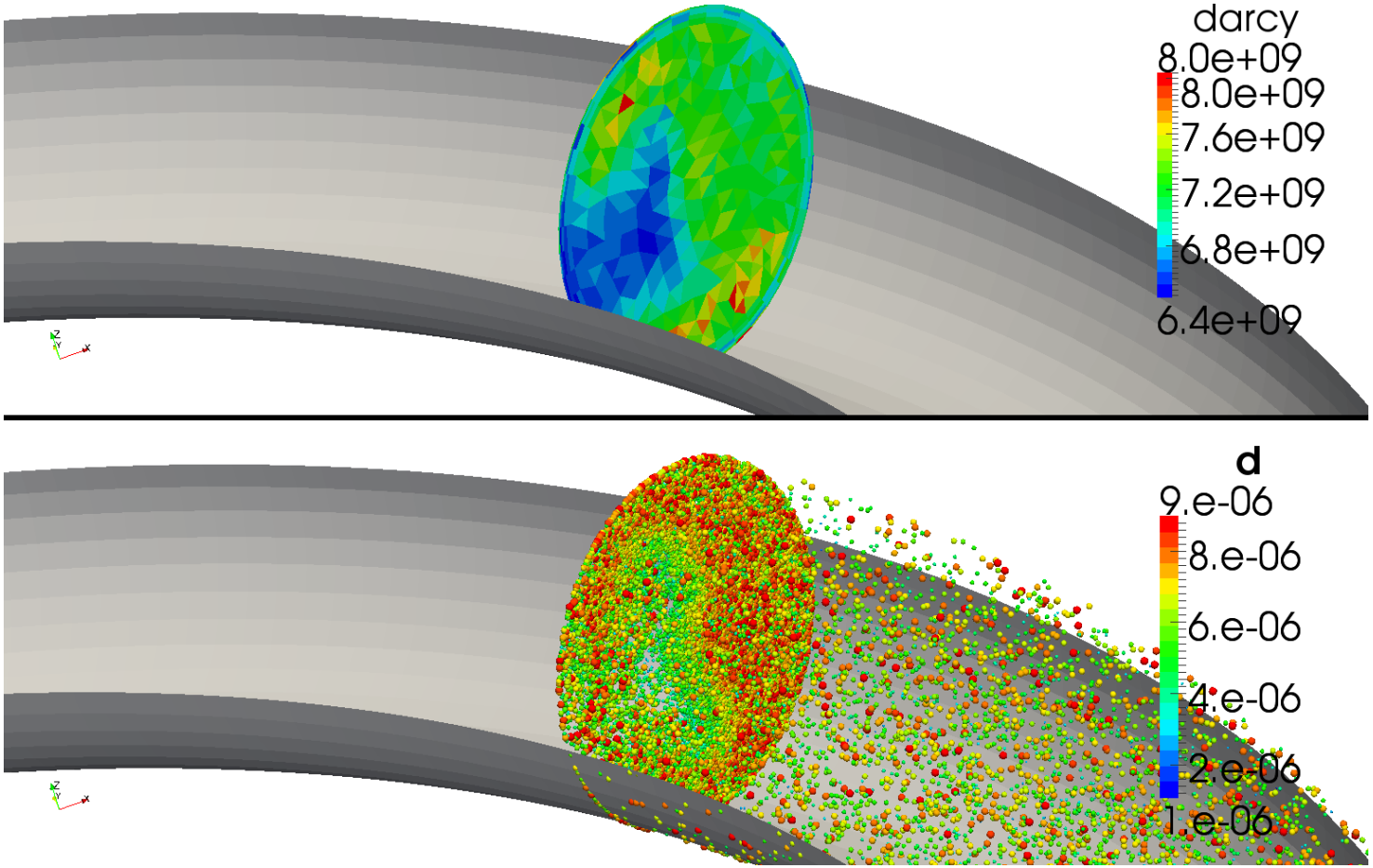
- pure particle agglomeration (filter cake)
- flow through idealized fiber structure

Real complex needle felt can not be modelled accurately yet due to

- highly inhomogeneous porosity distribution in cross section
- highly nonlinear behaviour of pressure loss f (porosity)

Macroscopic Modelling
(conducted by DHCAE Tools)

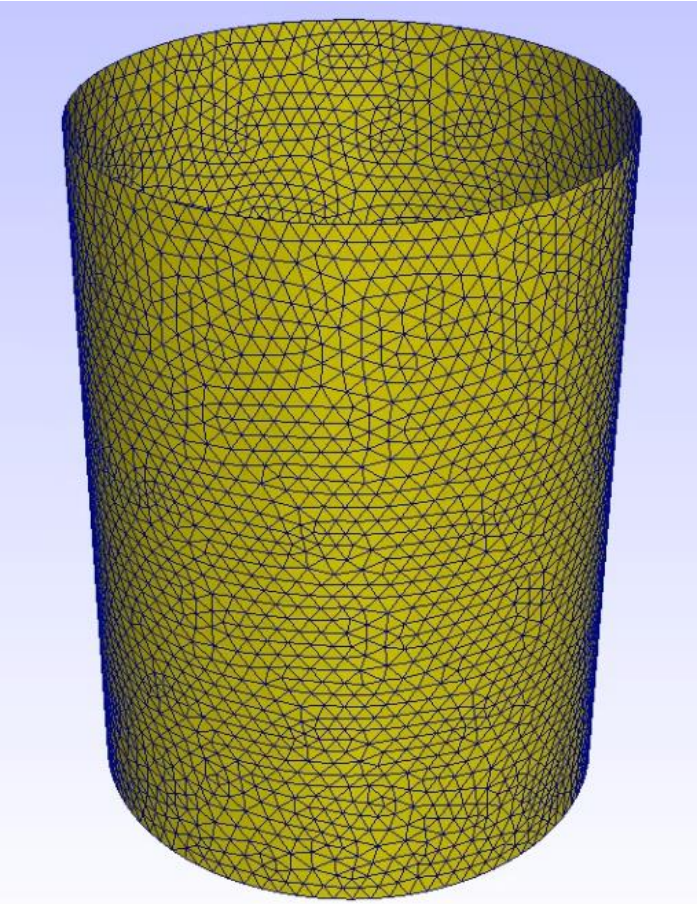
Filter patch



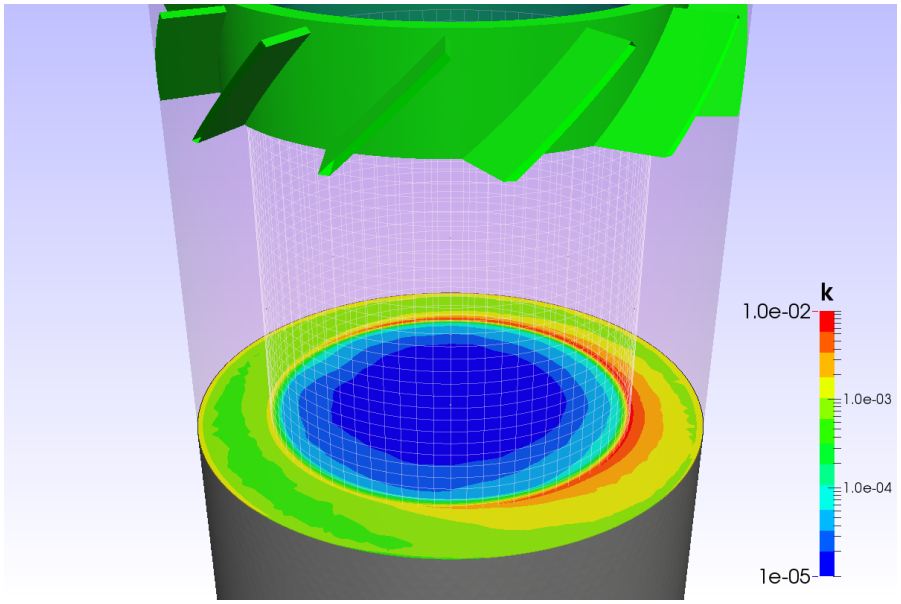
Filter approach

Saves in each face:

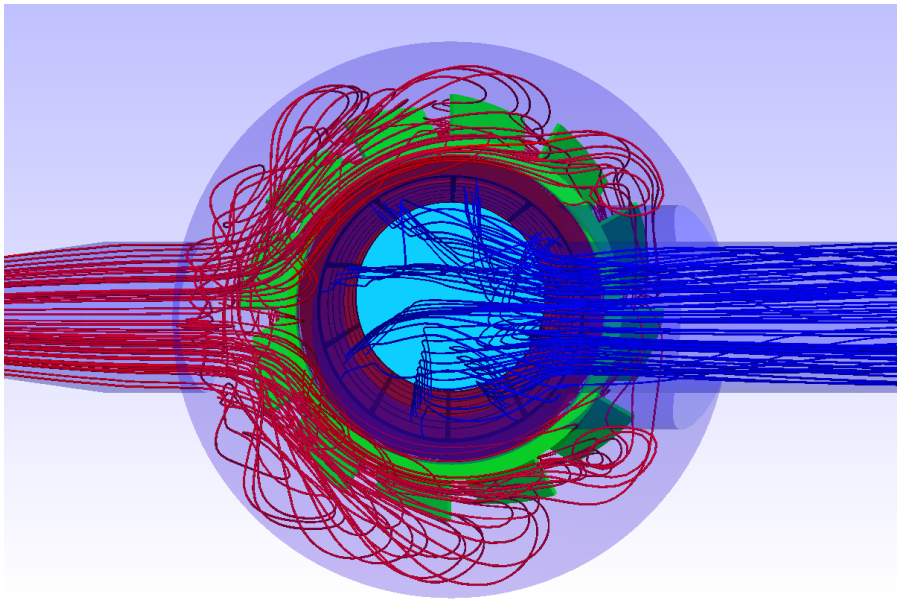
- Local particle load (e.g. mass per m^2)
- Particle hits
- Darcy & Forchheimer start values:
  - Resistance of unloaded filter
  - Time dependent resistance value for cleaned filter
- Variable Darcy & Forchheimer values depending on filter load:
  - mass
  - particle size
  - load period
  - compressible or incompressible filter cake



Additional effects in filters



Damping of turbulence



Flow redirection for higher resistance

Iterative coupling approach

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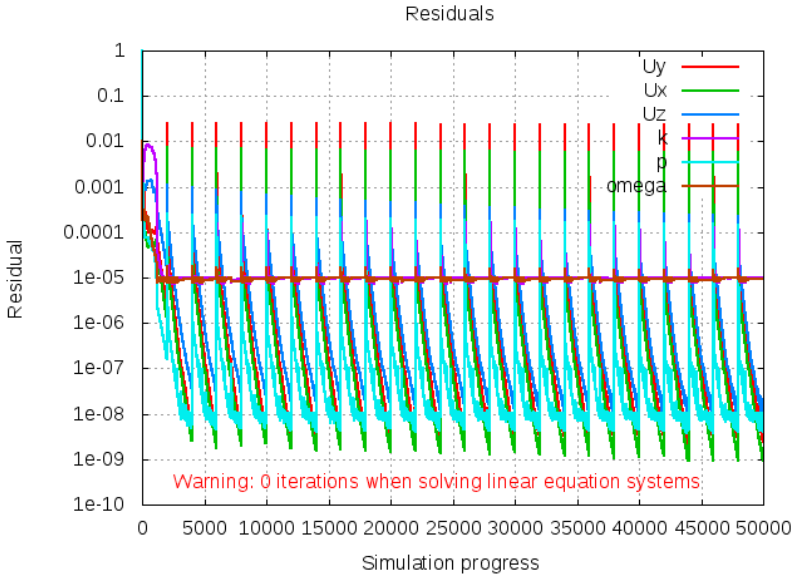
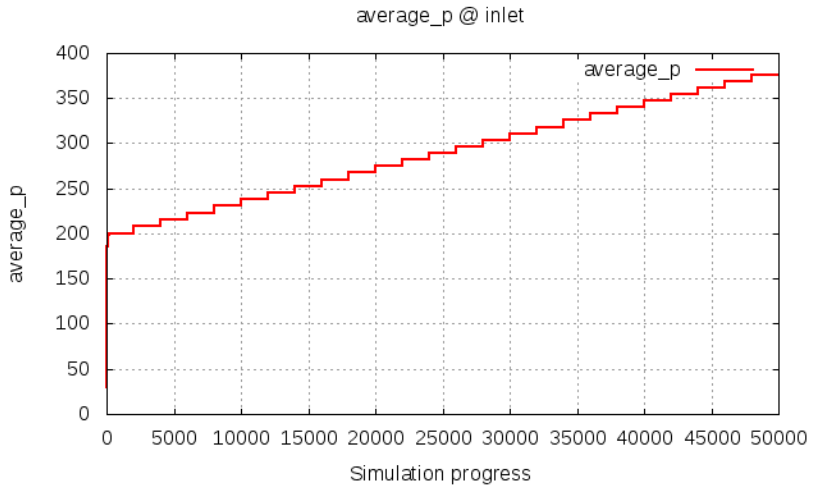
Steady state simulation of continuous flow field

Particle transport with LTS

Resistance update

Cleaning: New filter start value





OpenFOAM® extensions / adaptations

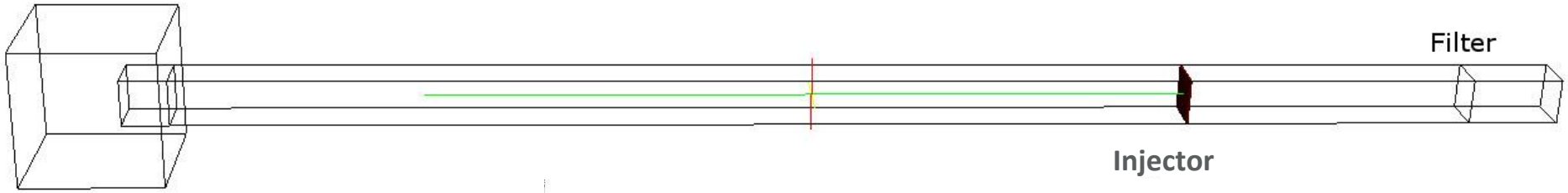
Filter patch:

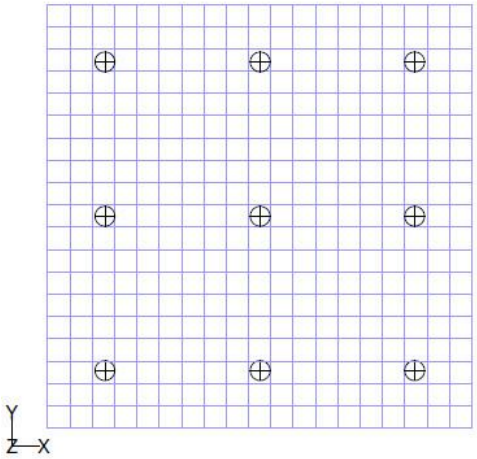
- Generation of filter patch based on porousBaffle functionality
- Locale resistance
- Different resistance characteristic
- Particle sizes passing the patch

Overall iteration process

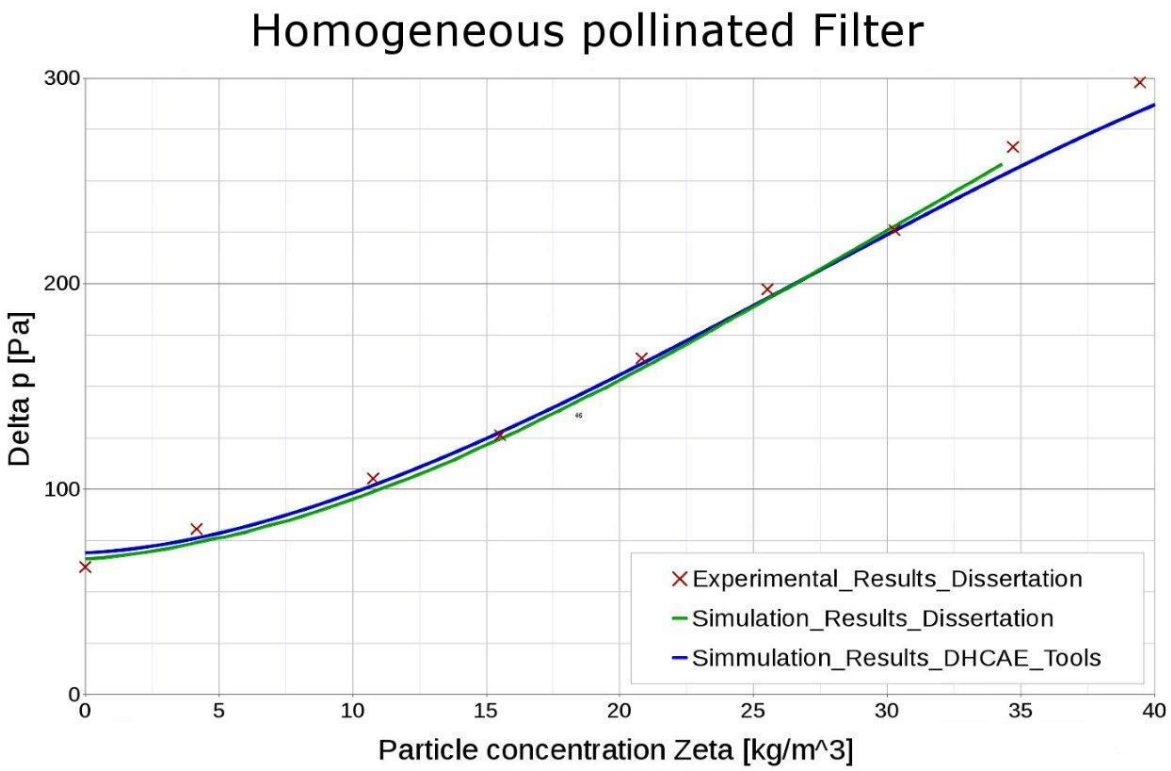
- Filter stabilization (under relaxation factors)
- Turbulence damping at filter
- Flow redirection in case of stronger resistance
- Iterative coupling with continuous flow
- Improved parallel performance for LTS particle tracking

Validation

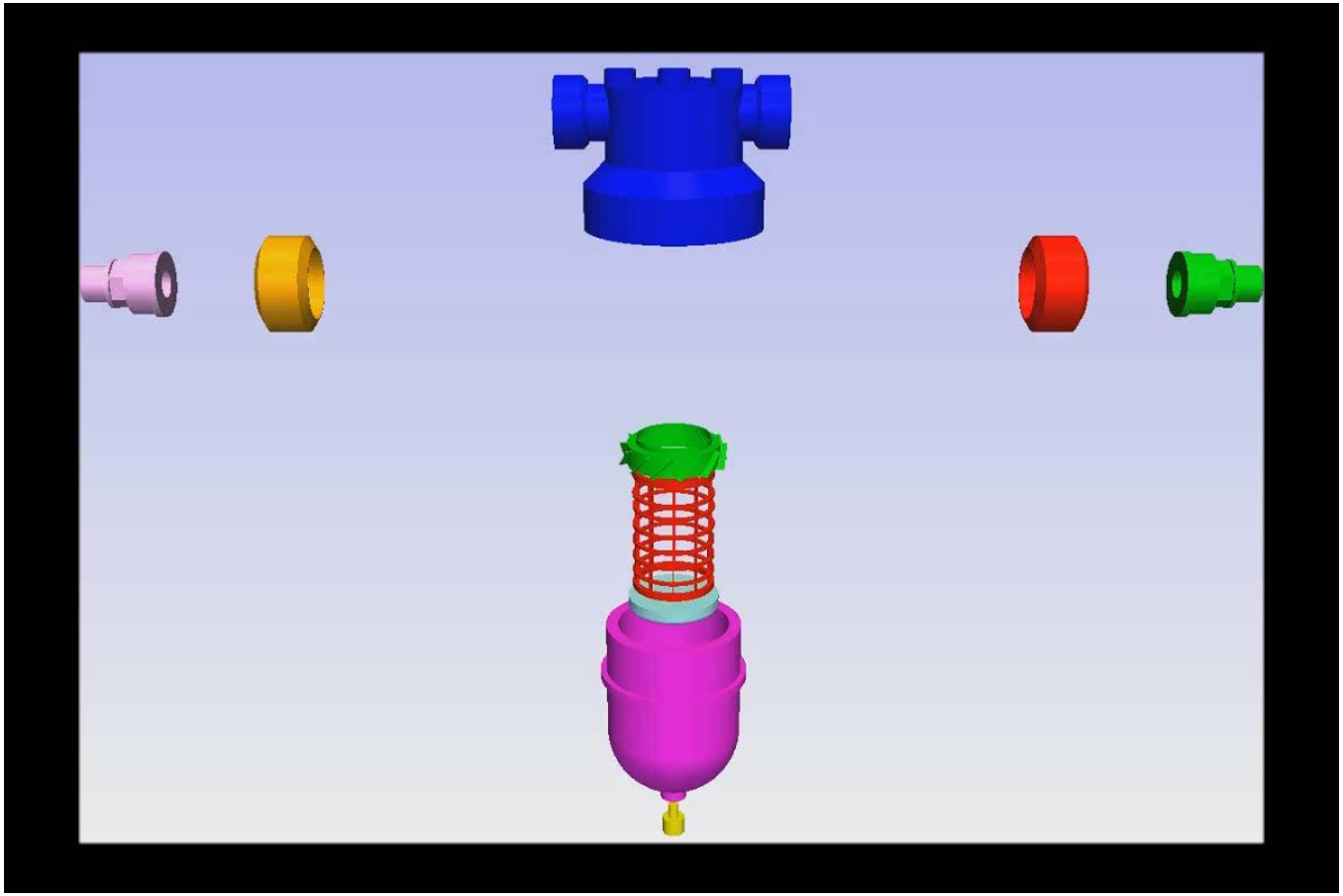




Numerische Modellierung des zeitlichen Verhaltens von Strömungen in der Umgebung von Tiefenfiltern, Michele Cagna



Filter animation



Real filter plant

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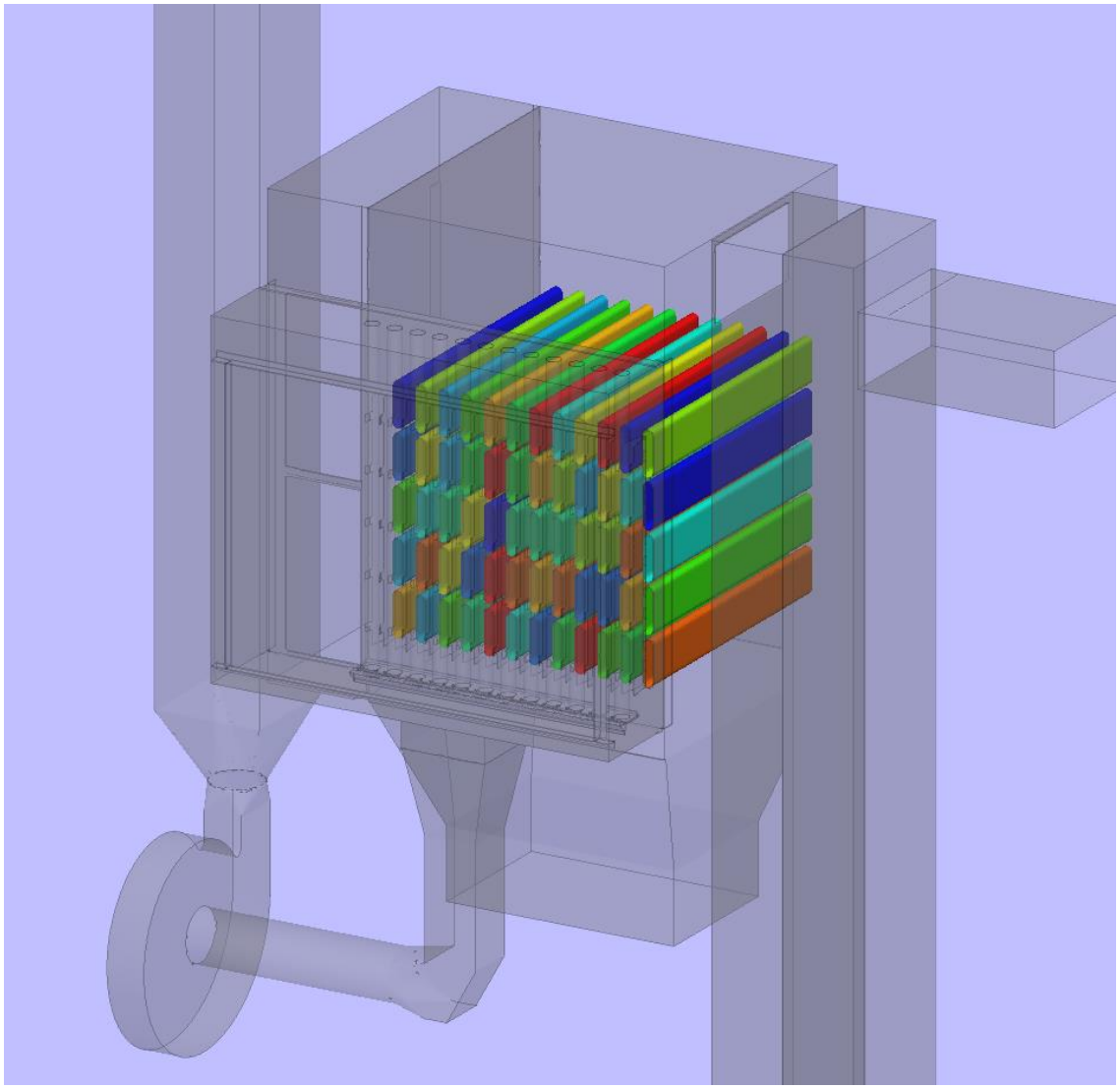
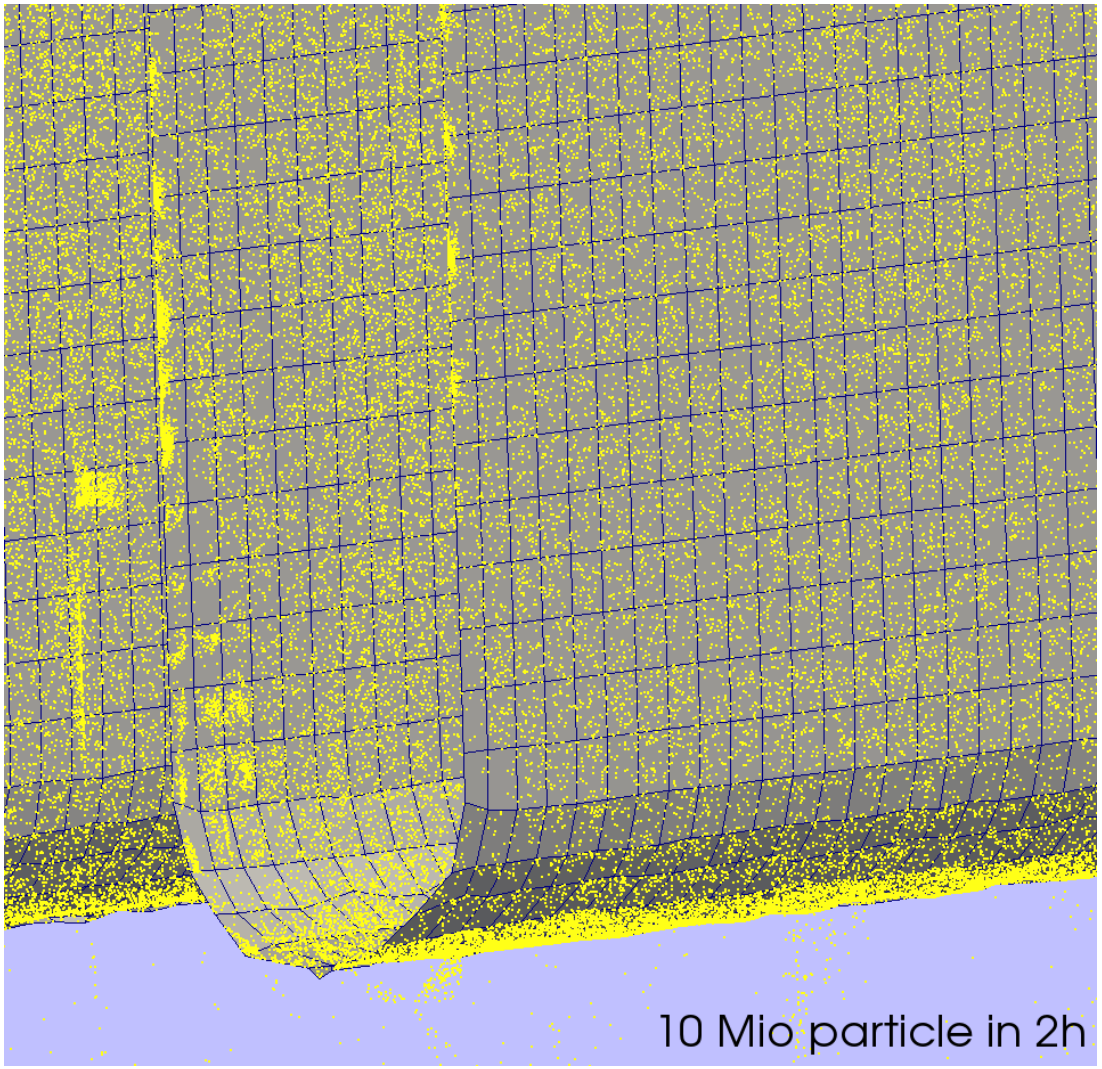
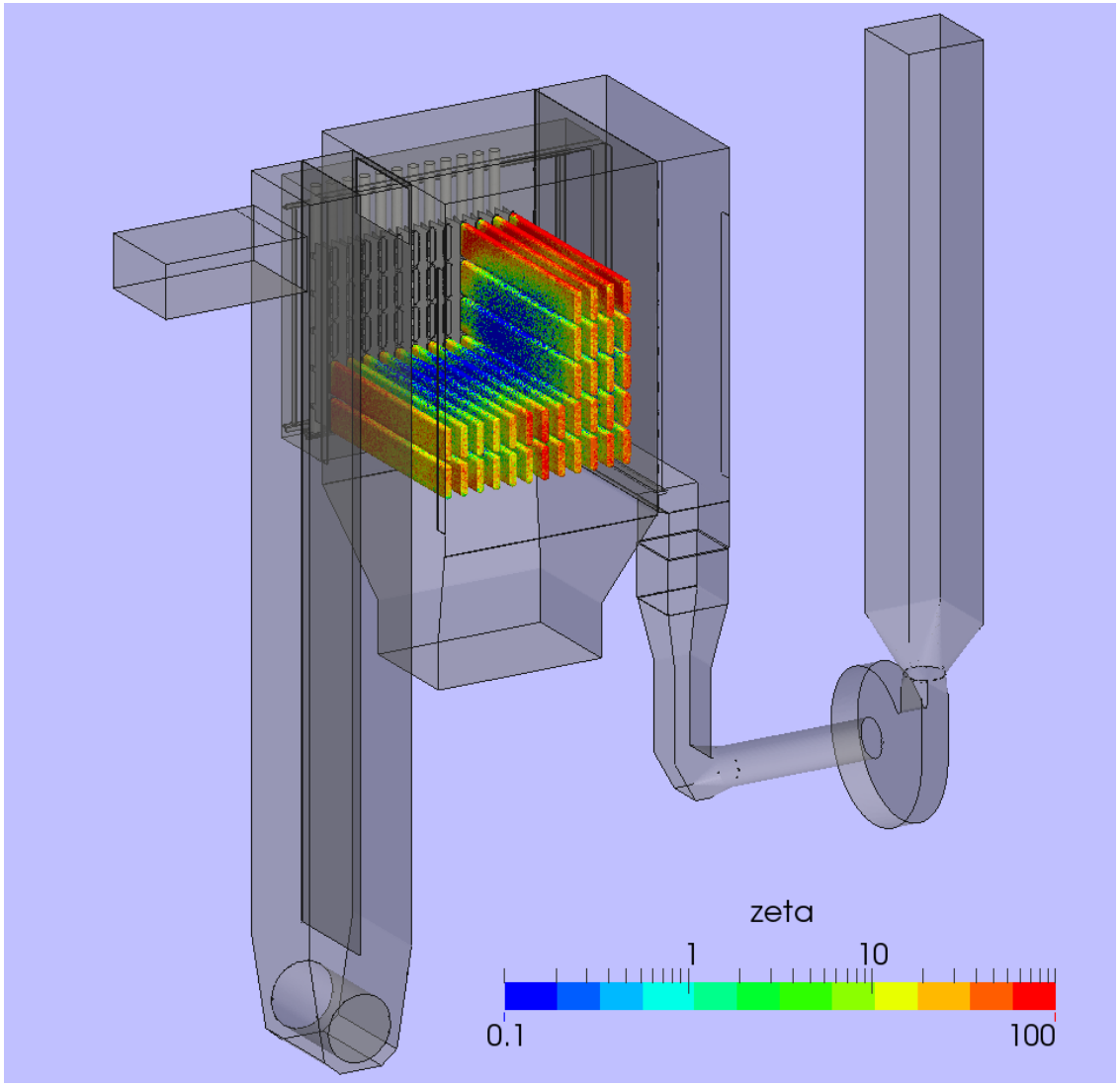


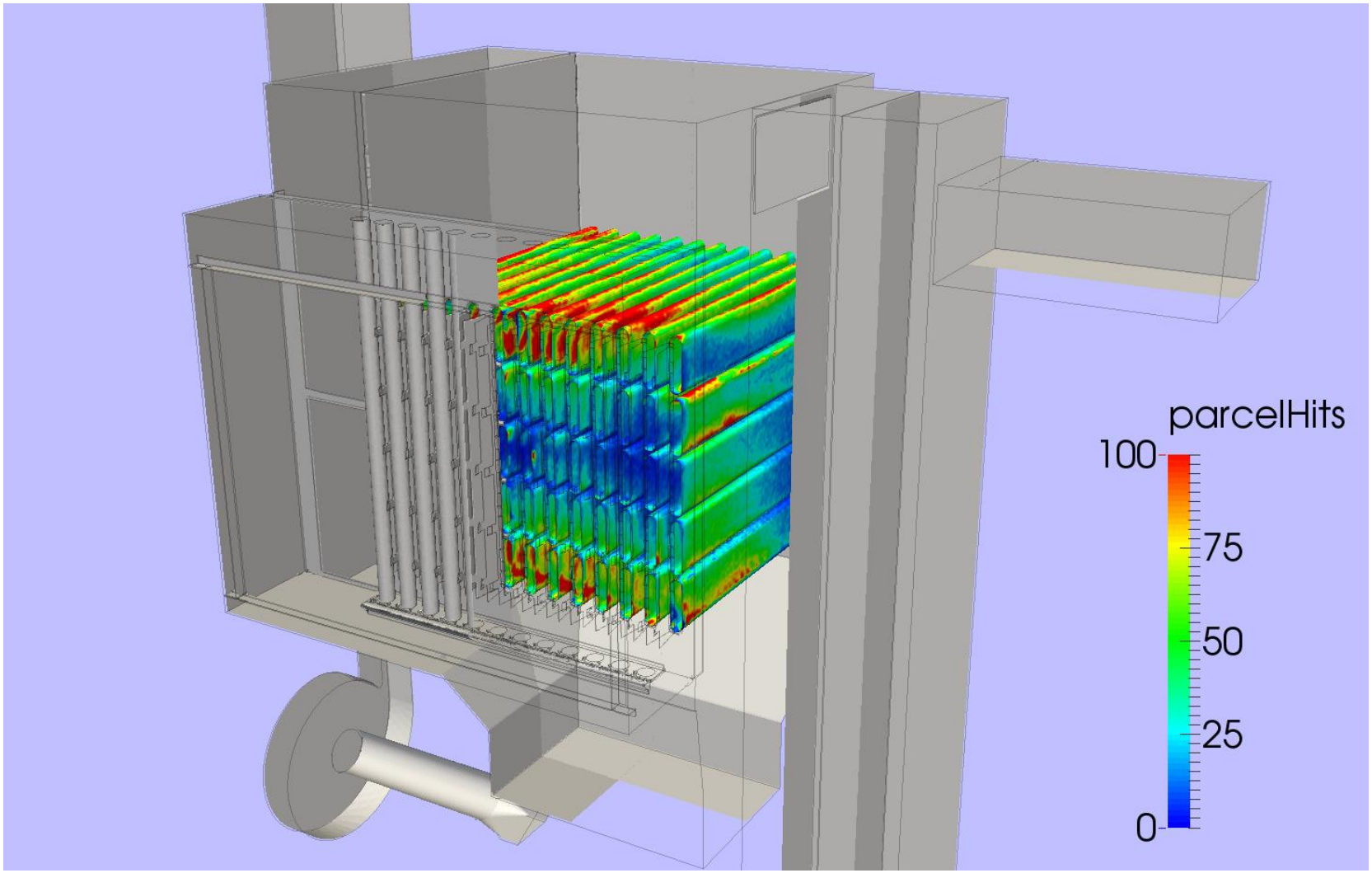


Real filter plant



Real filter plant

DHCAE Tools



Conclusion macroscopic model / outlook

Validation:
Pressure increase validated according literature for filter test rig

Feasibility for real technical plants
Simulation runtime seems acceptable (due to LTS transport)

Final steps:
Real filter plant: Comparison with local flow rate through filters
Filter deformation (deformation caused by local pressure distribution)

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