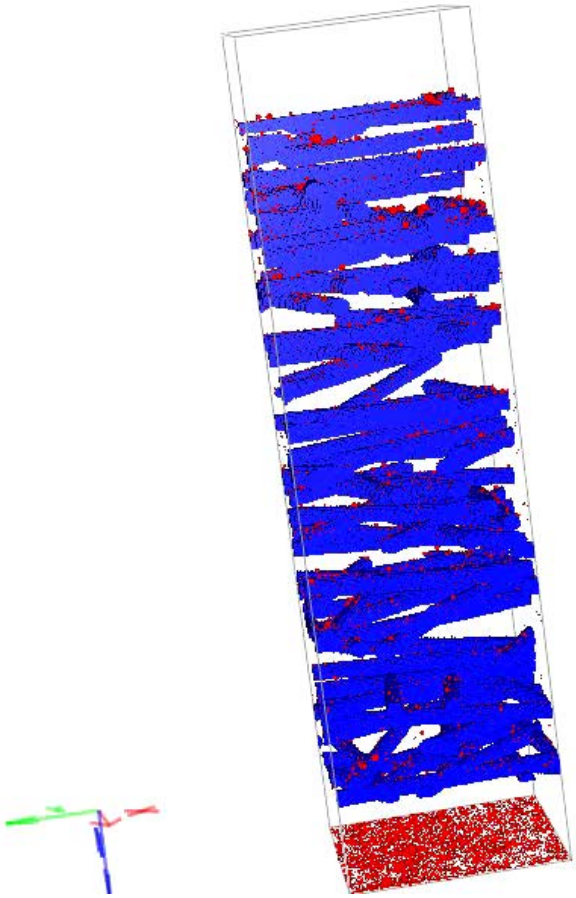
Simulation of Particle Filtration Using

GeoDict

Fraunhofer ITWM

MATH 2 MARKET

Simulation of Particle Filtration Using GeoDict



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Math2Market GmbH,

Kaiserslautern

11th Symposium *Textile Filters*

Sächsisches Textilforschungsinstitut e.V.

March 6th & 7th 2012, Chemnitz

MATH 2 MARKET

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What about Math2Market & Fraunhofer ITWM / SMS?

Math2Market GmbH is a spin-off that markets and further develops the GeoDict software

M2M incorporated 9/2011, the 4 core team members phase from SMS to M2M in 2012.

Andreas Wiegmann, PhD, until June 30th, 2012 is

- Chief Executive Officer at Math2Market GmbH (50% -> 100%)
- Deputy head of department SMS at Fraunhofer ITWM (50% -> 0%)

M2M provides

- licenses,
- software support,
- consulting regarding modelling,
- simulation-based engineering services ,
- commercial-strength software engineering &
- close ties to Fraunhofer ITWM when mathematical research is required

Computer Aided Filter Media Engineering

GEO DICT

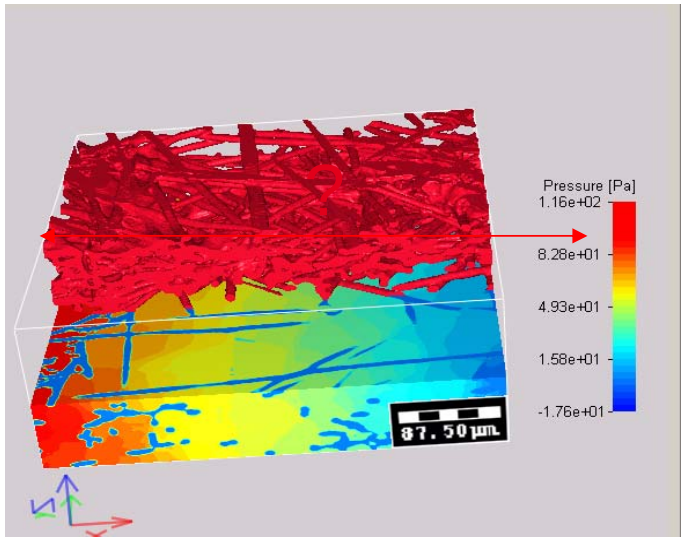
Lab

Filter Media

measure

Properties

manufacture next material



Properties include:

- pore size distribution
- pressure drop
- separation curve
- filter efficiency
- filter capacity
- filter cake formation

Computer

Model

generate

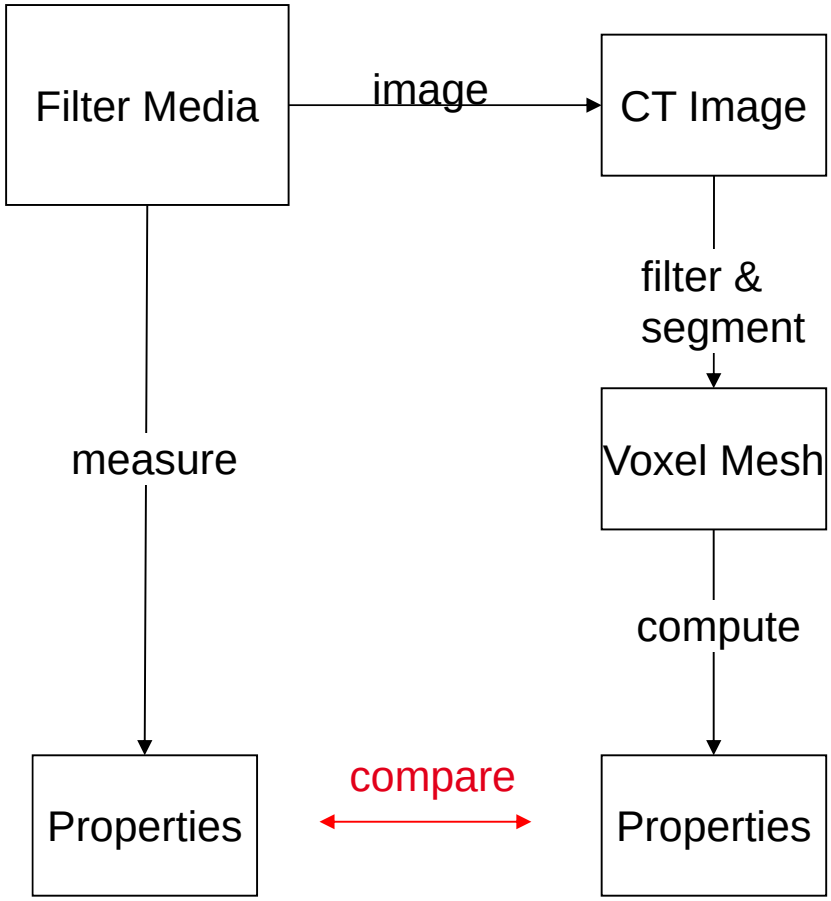
Voxel Mesh

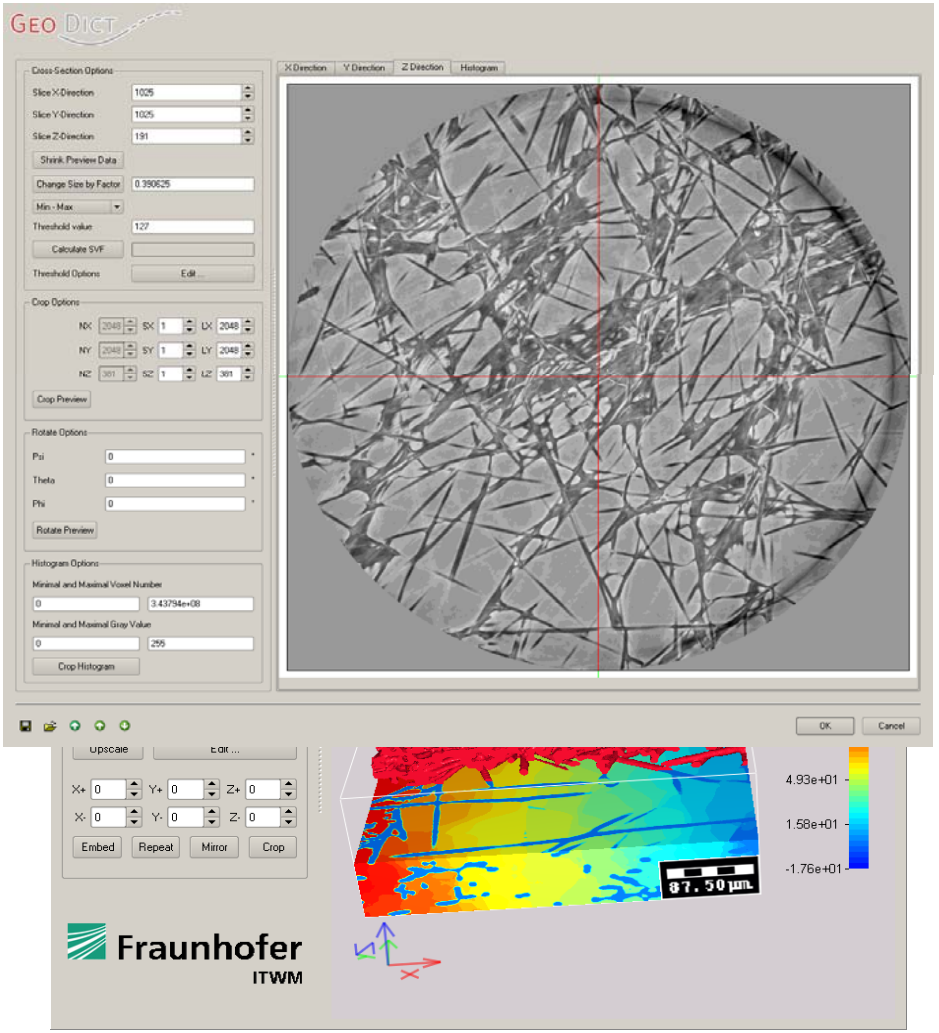
compute

Properties

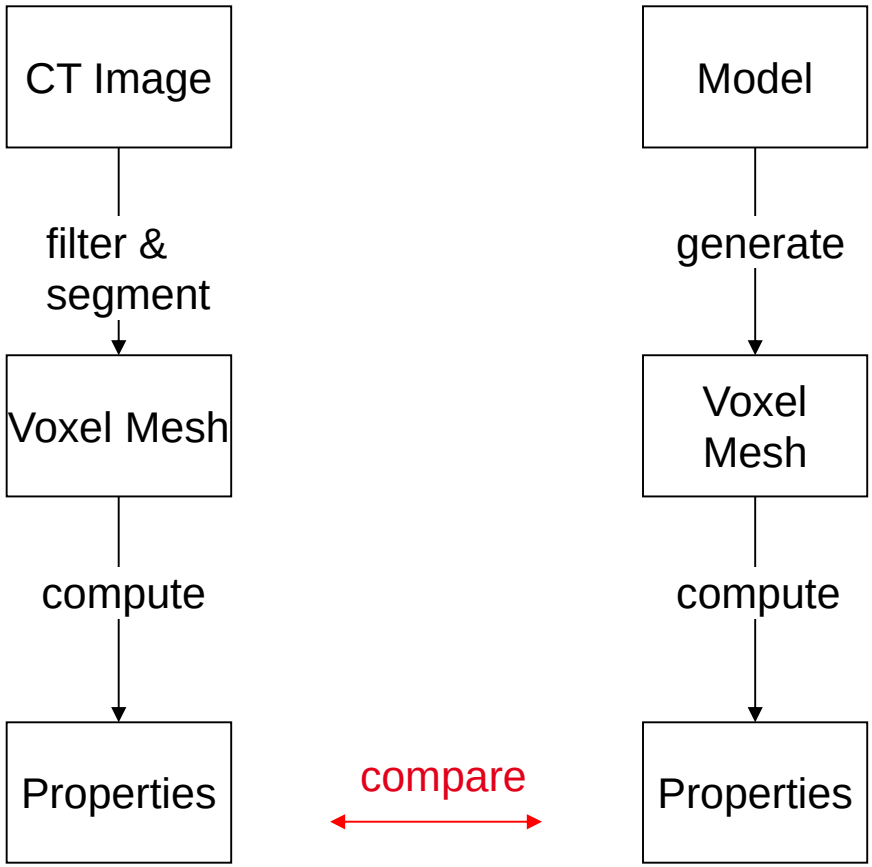
try next set of parameters

Validation - Step 1: Property Computations

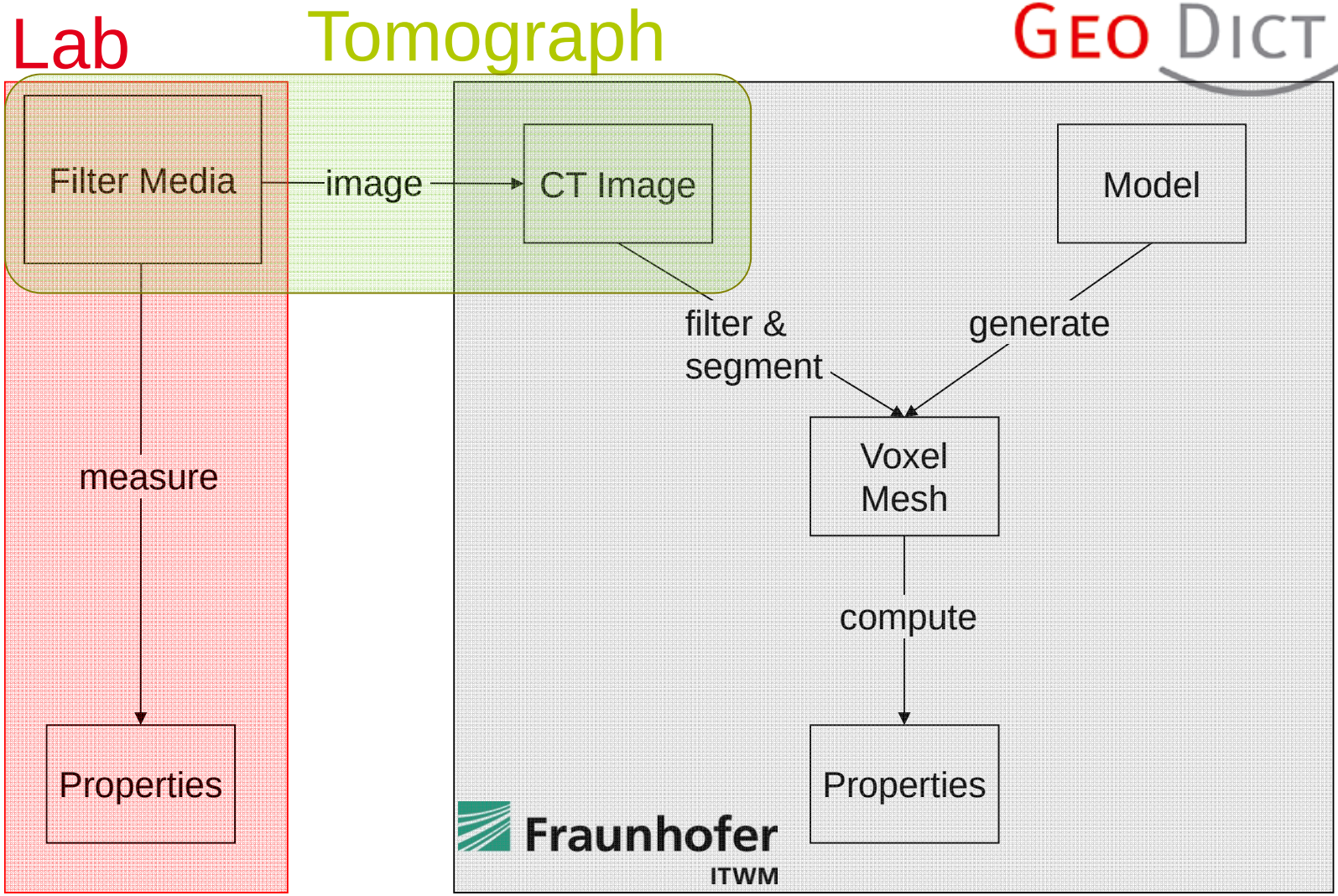




Validation - Step 2: Material Models

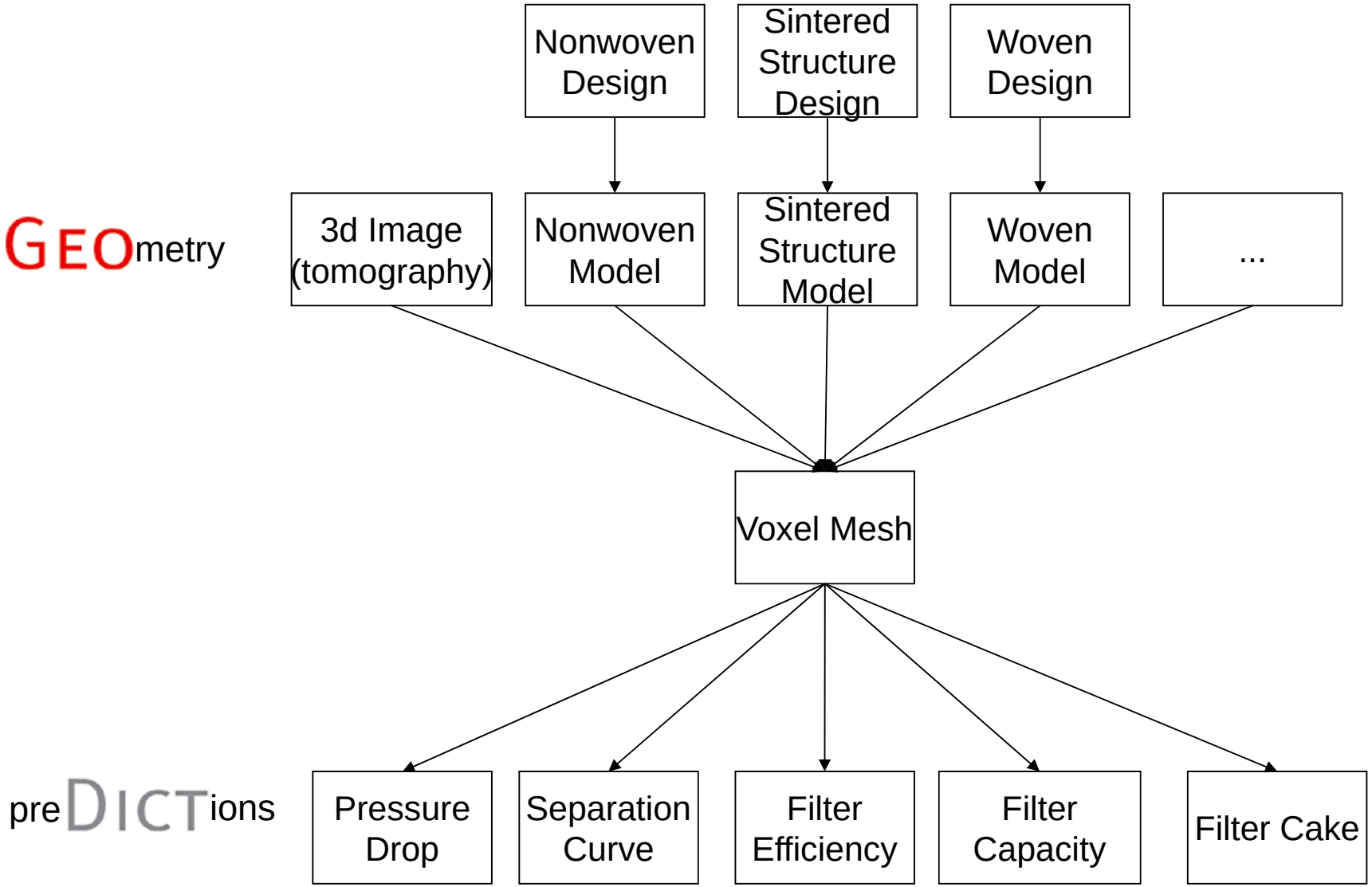


Computer Aided Filter Media Engineering



Computer Aided Filter Media Engineering

GEO DICT



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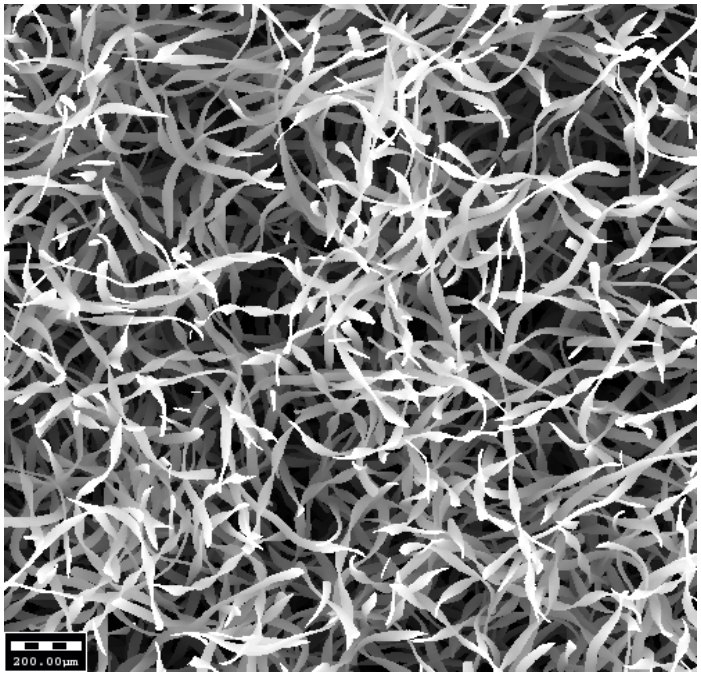
Andreas Wiegmann

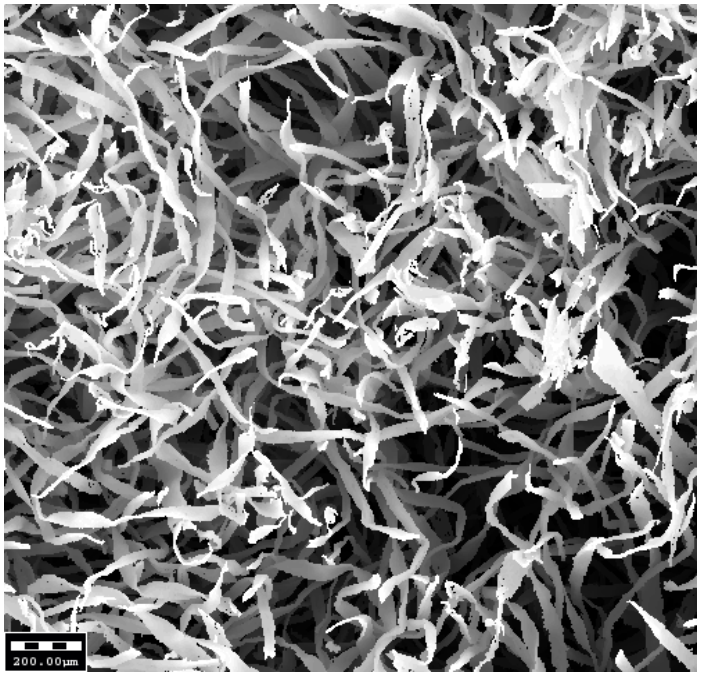
Filtersymposium, Chemnitz

March 7th, 2012

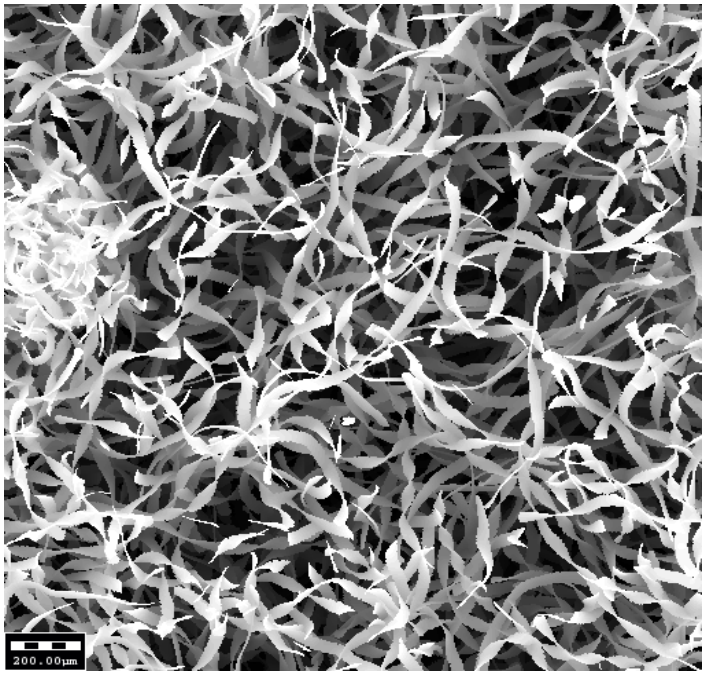
Modell of a nonwoven



homogeneous



tomogram



inhomogeneous

GeoDict‘s four representation languages of (textile) filter media

- **Design**:
  Fiber orientation, porosity / base weight, fiber diameter / dtex,
  fiber cross-section, fiber curvature etc.

- **Objects**:
  ns (number of segments),
  Point(1), Point(2), …, Point(ns), diameter

- **Image**:
  nx, ny, nz, (numbers of voxels in the three directions),
  dx, dy, dz, (lengths of voxels in the three directions),
  c(1,1,1), c(1,1,2), c(1,1,3), … c(nx, ny, nz)

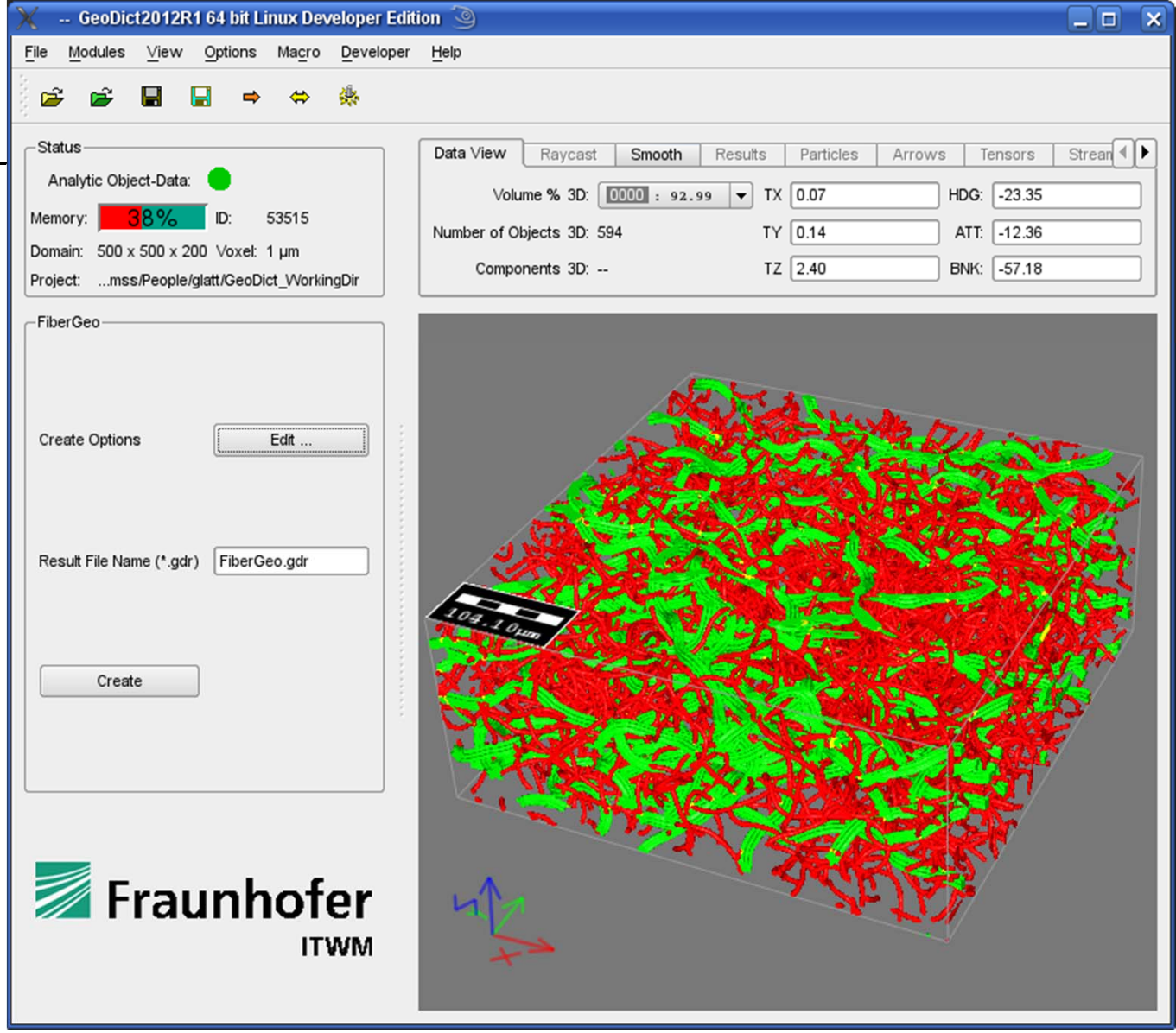
- **Surface**:
  nt (number of triangles),
  P(1,1),P(1,2),P(1,3),P(2,1),P(2,2),P(2,3),P(3,1),P(3,2),P(3,3),…,P(nt,1),P(nt,2),P(nt,3)

Virtual paper: cellulose fibers & fines

paper.gmc

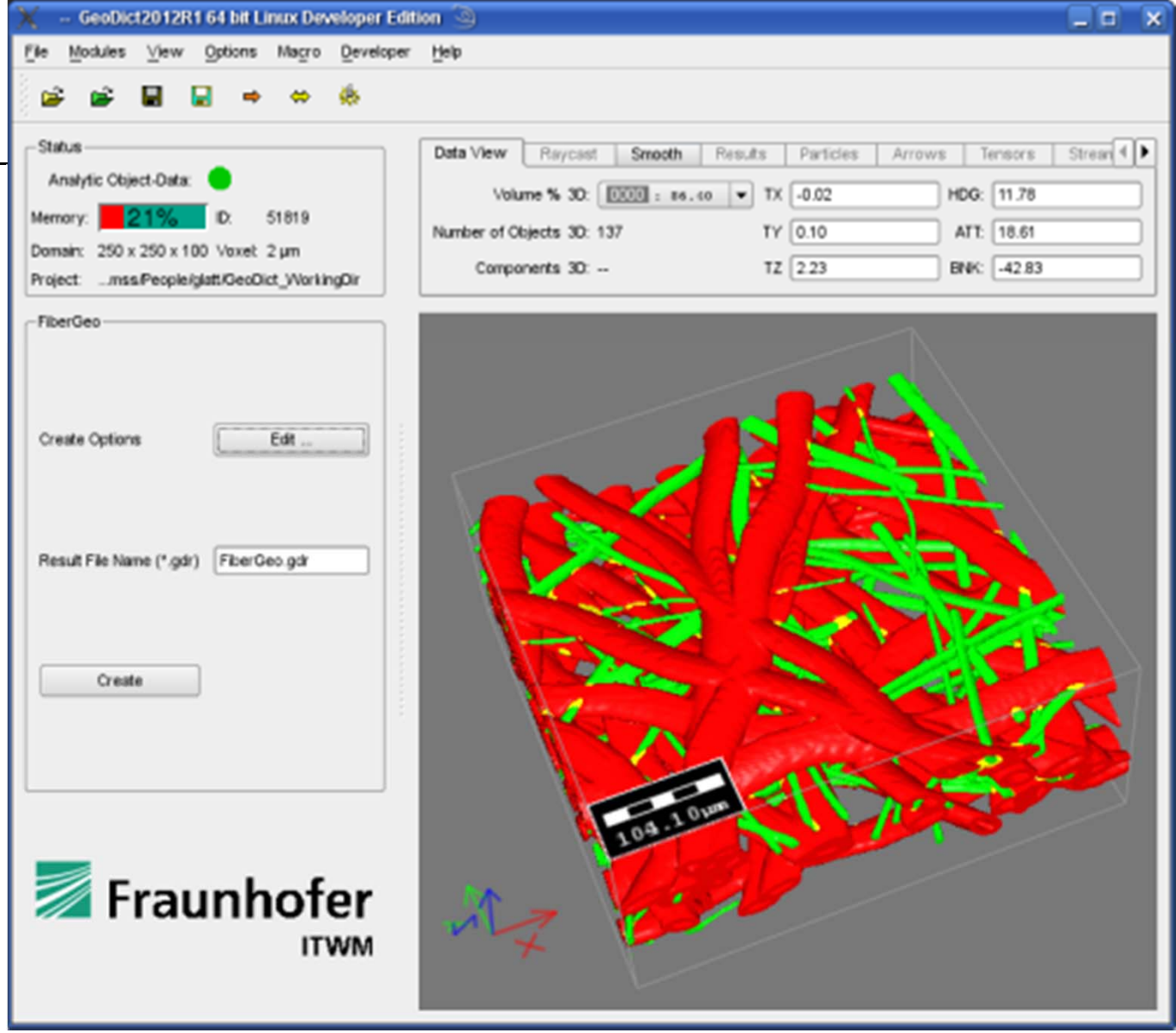
paper.gad

paper.leS



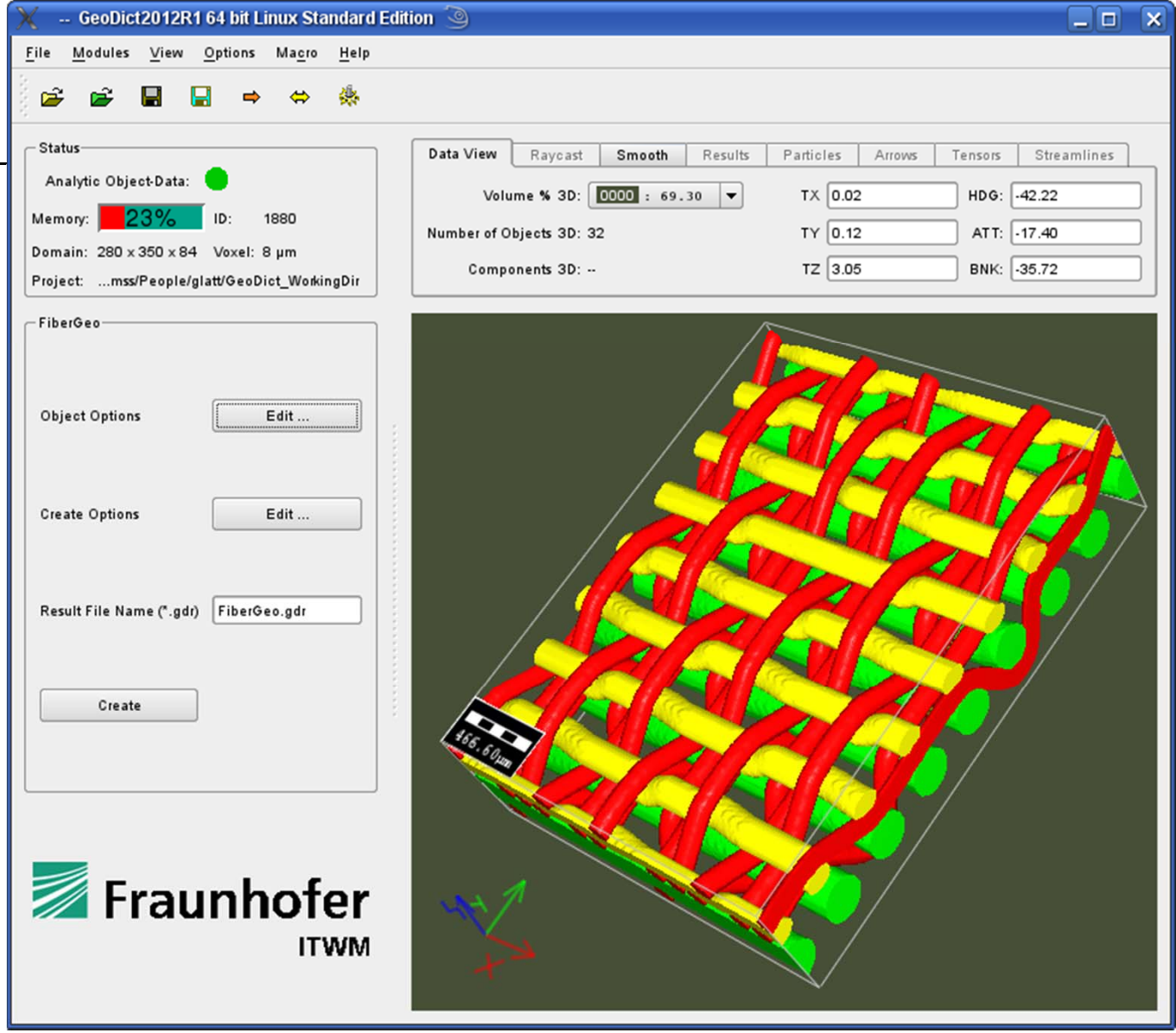
Virtual meltblown: curved fibers

meltblown.gmc



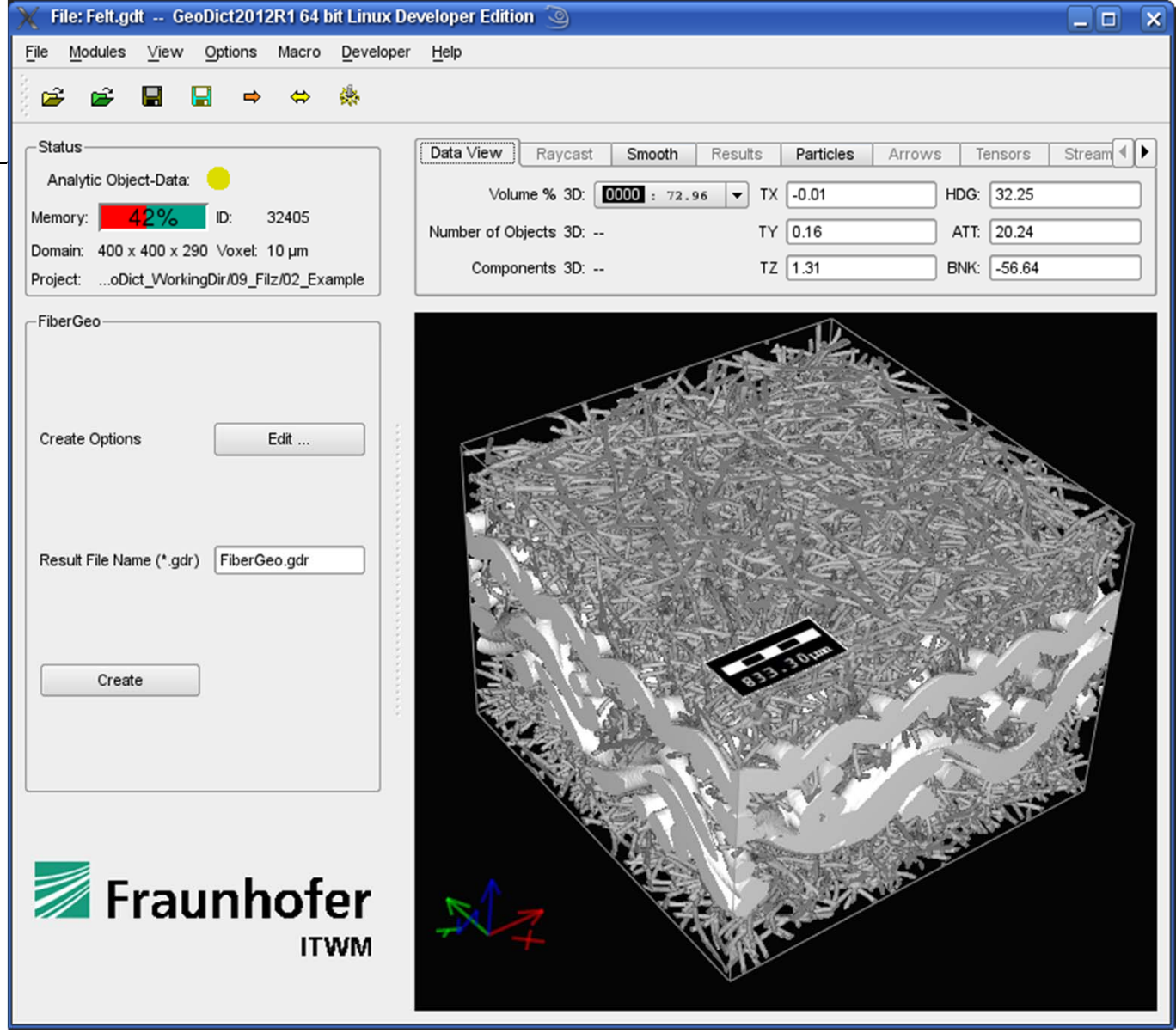
Virtual woven: multiple weft layers

weave.gmc



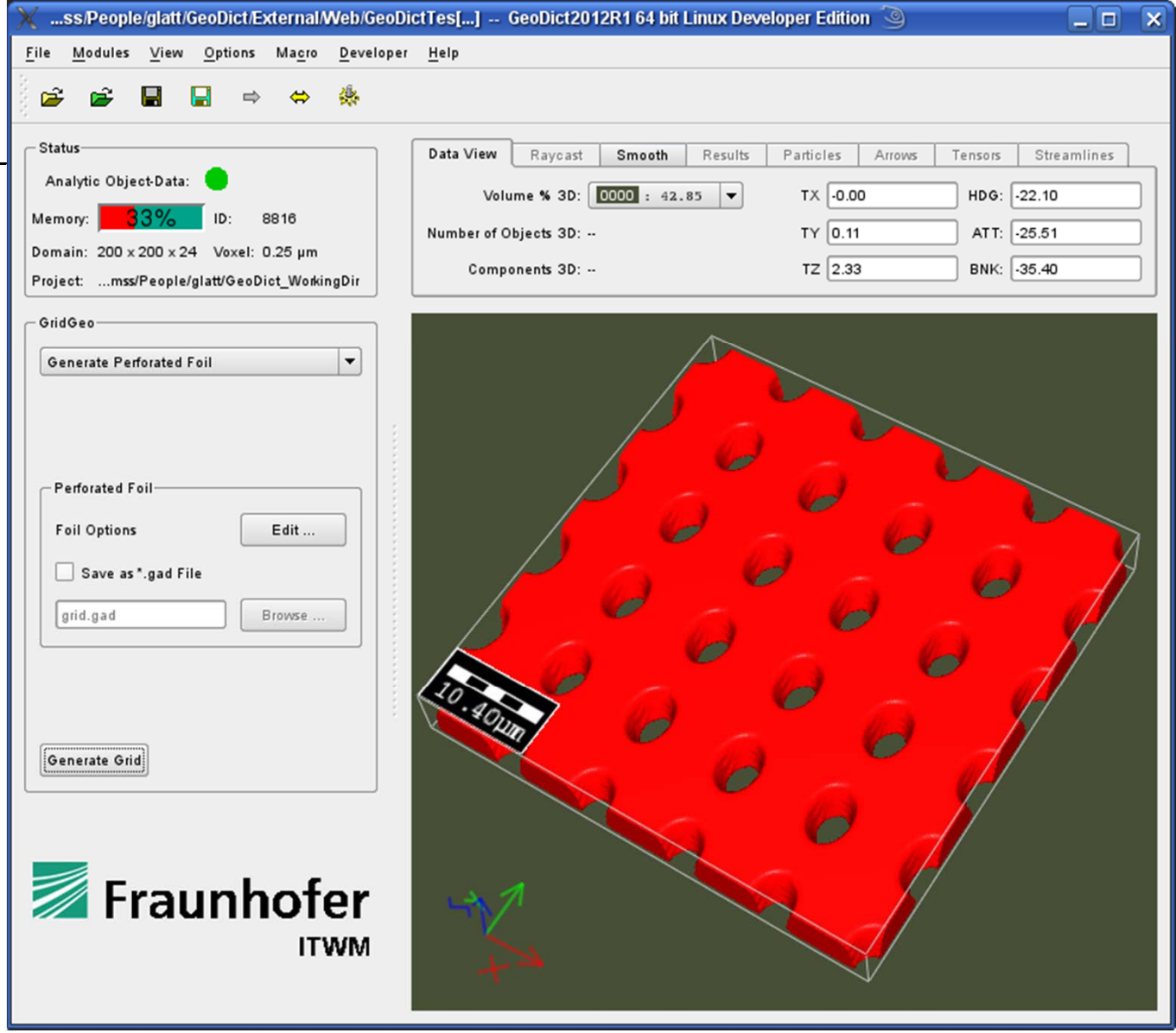
Virtual felt: woven, nonwoven & needling

felt.gmc



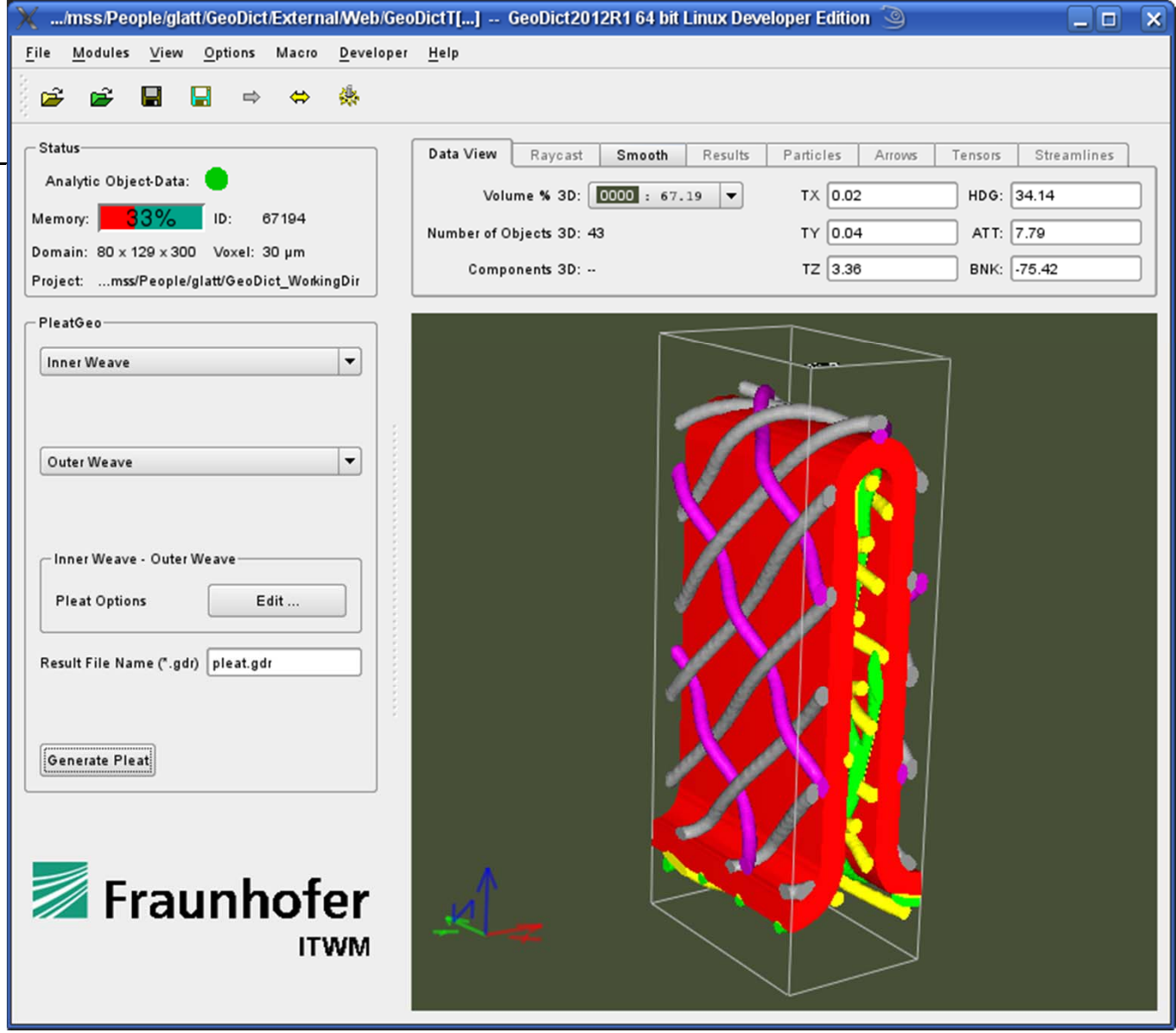
Virtual foil: oval & conical holes in arbitrary patterns

foil.gmc

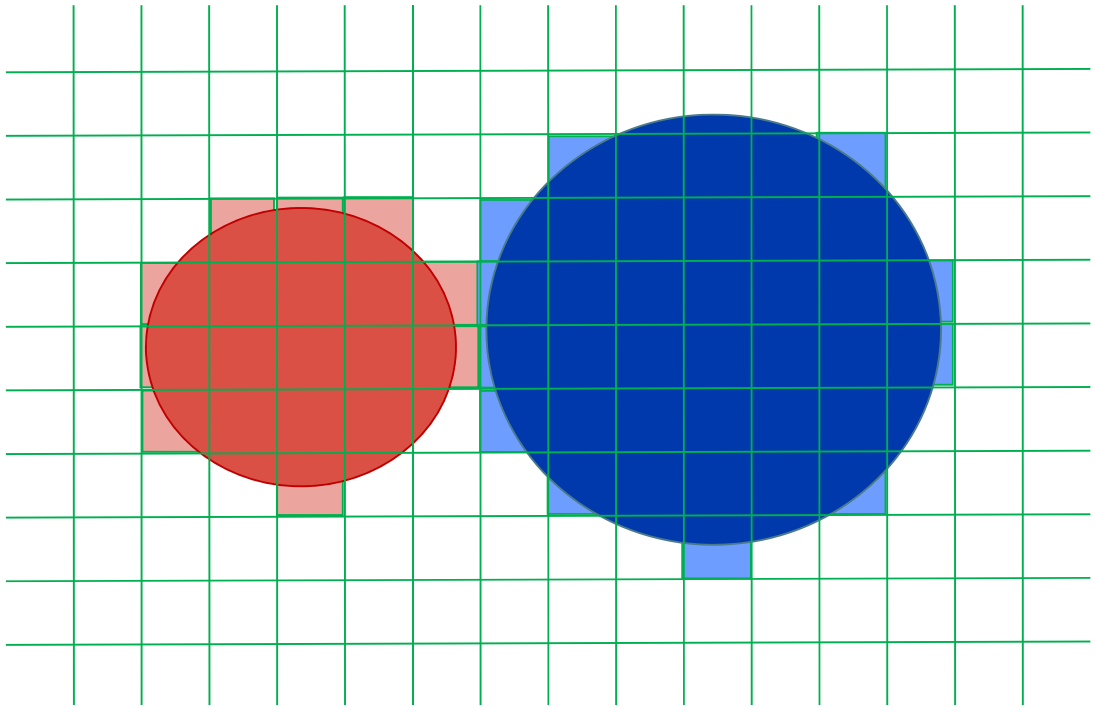


Virtual pleat: filter media + interior and exterior support structures

pleat.gmc



GeoDict structures & simulations are based on infinitesimal cubes



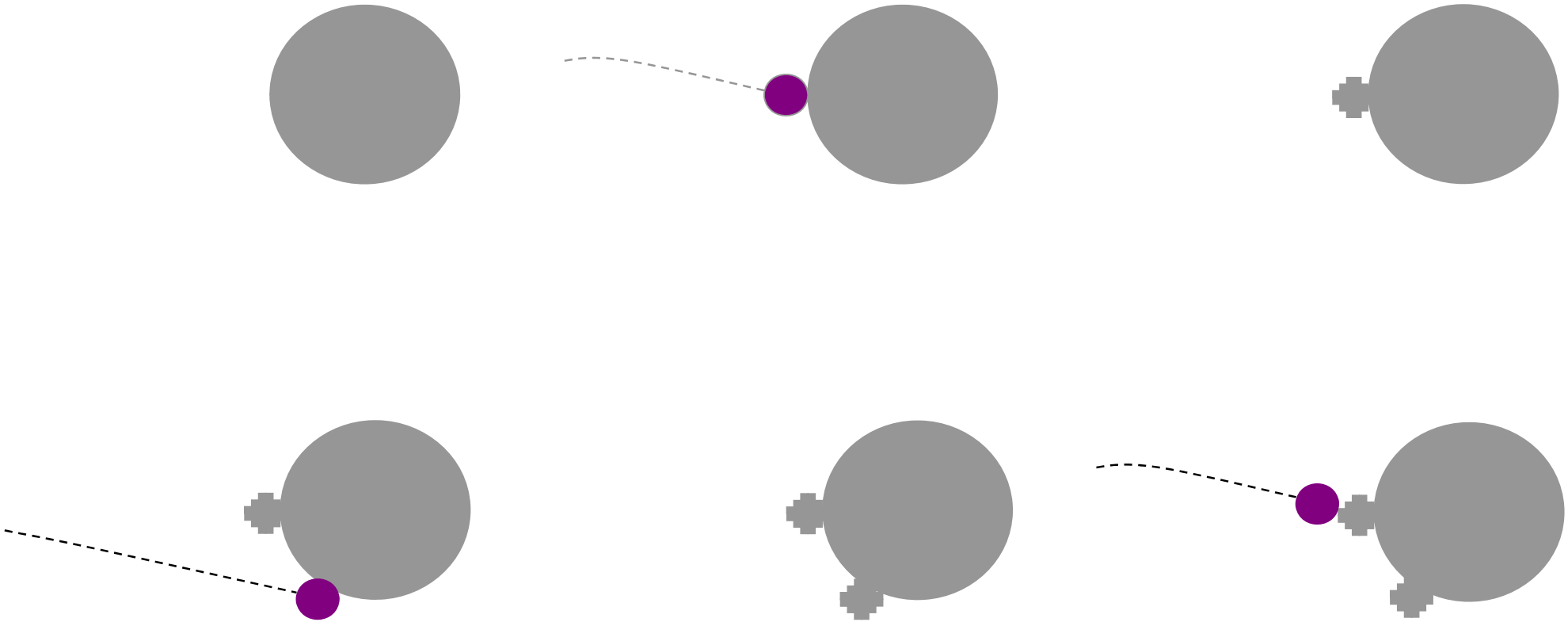
Advantages

- Saves grid generation times
- Compatible with computer tomography
- Straight forward structure generation
- Straight forward solver implementation
- Straight forward parallel computations

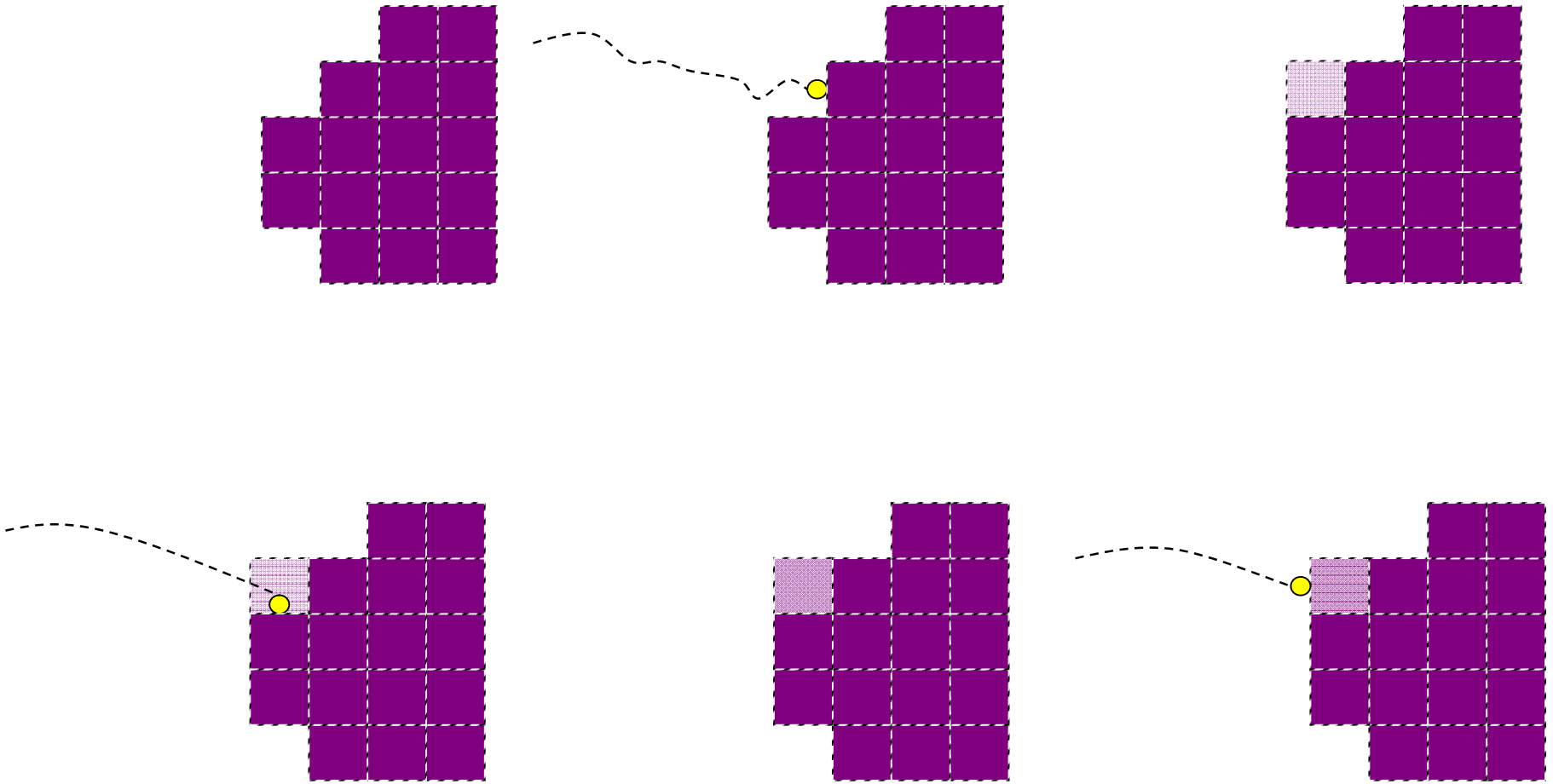
Disadvantages

- Resolved features require many grid cells
- Leads to very large scale computations

Nano-Mode: particle resolved by voxel grid



Mikro-Mode: particle not resolved by voxel grid

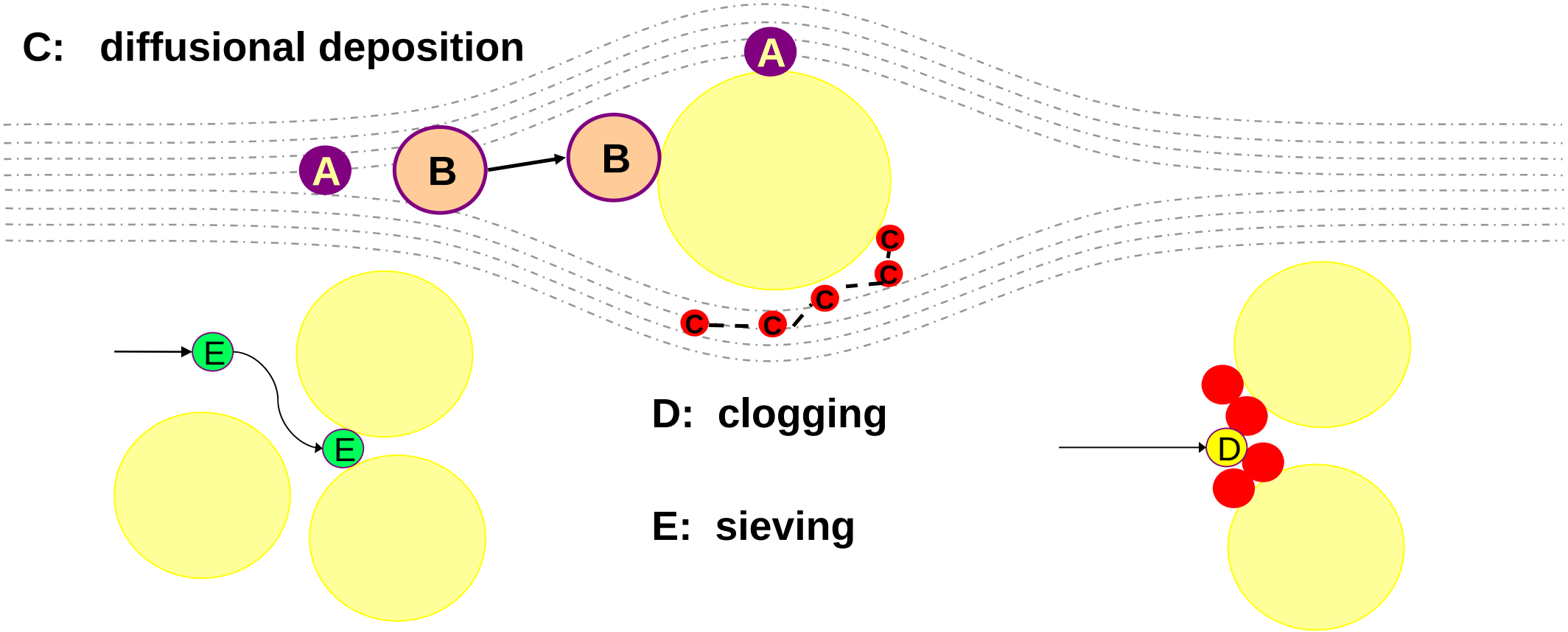


Filtration Effects I

A: direct interception

B: inertial impaction

C: diffusional deposition

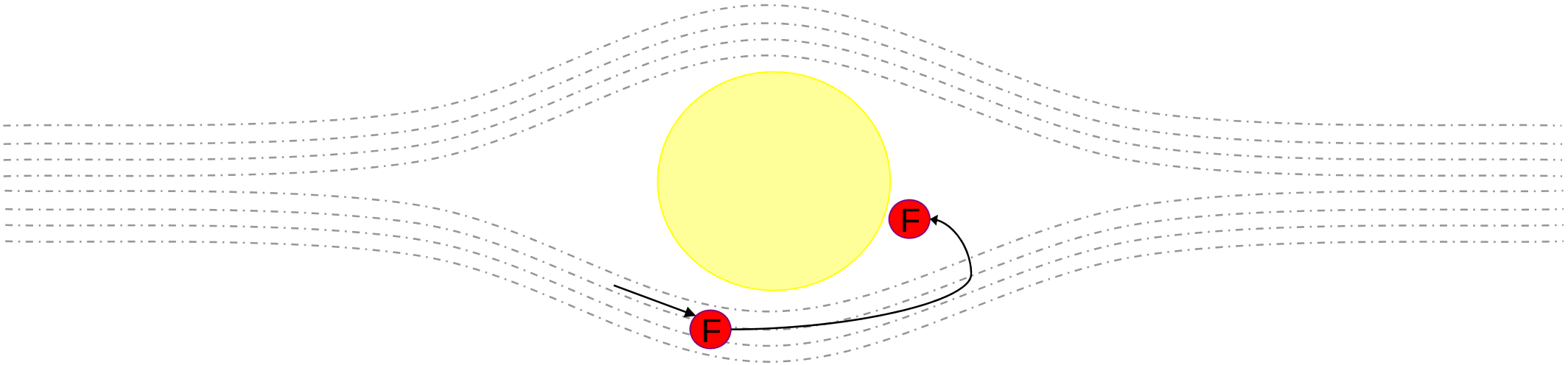


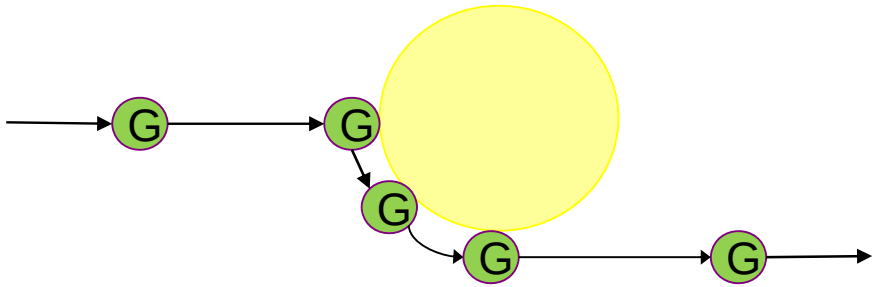
D: clogging

E: sieving

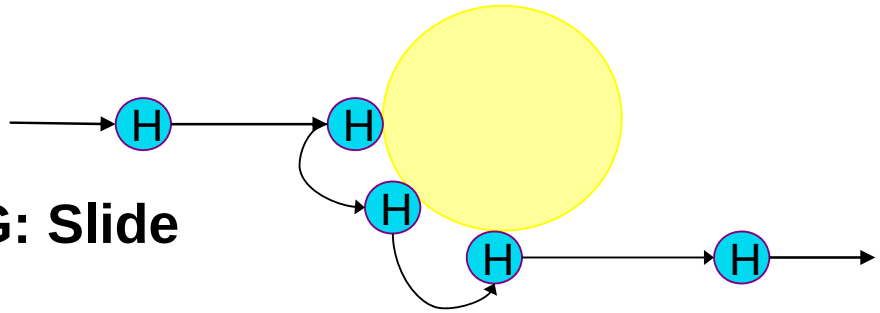
Filtration Effects II and modes of particle motion

F: electrostatic attraction





G: Slide



H: Bounce

Description of particle motion

GEO DICT

$$
\begin{aligned}
d\vec{x} &= \vec{v}\,dt, \qquad \text{Friction with fluid} \quad \text{Electric attraction} \quad \text{Diffusive motion}\\
d\vec{v} &= -\gamma \times (\vec{v}(\vec{x}) - \vec{v}_\circ(\vec{x}))\,dt + \frac{Q\vec{E}_\circ(\vec{x})}{m}dt + \sigma \times d\vec{W}(t),\\
C_c &= 1 + Kn\left(1.142 + 0.558e^{-0.999/Kn}\right),\\
\gamma &= 6\pi\rho\mu\frac{R}{C_c m},\\
\sigma^2 &= \frac{2k_B T\gamma}{m},\\
\left\langle dW_i(t), dW_j(t)\right\rangle &= \delta_{ij}dt,\\
Kn &= \frac{\lambda}{R},\\
\lambda &= \frac{k_B T}{\sqrt{32}\pi R^2 P}
\end{aligned}
$$

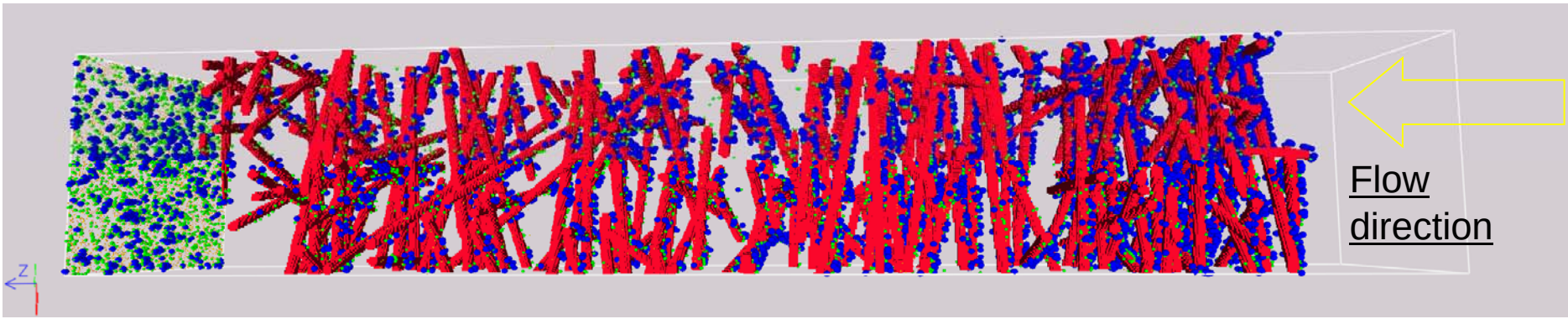
t:	time
$\vec{x}$:	particle position
$\vec{v}$:	particle velocity
R:	particle radius
m:	particle mass
q:	particle charge
T:	ambient temperature
P:	total pressure
$d\vec{W}(t)$:	3d probability (Wiener) measure

γ:	friction coefficient
k_B:	Boltzmann constant
$\vec{E}_\circ$:	electric field
$\vec{v}_\circ$:	fluid velocity
ρ:	fluid density
μ:	fluid viscosity

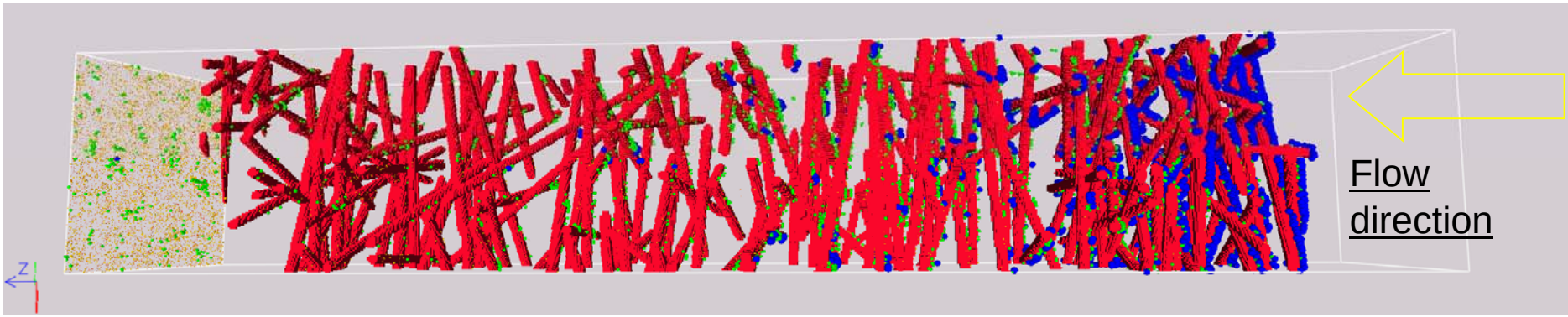
α = 0.05,
d_F = 14,
v = 0.1m/s

Deposition effects

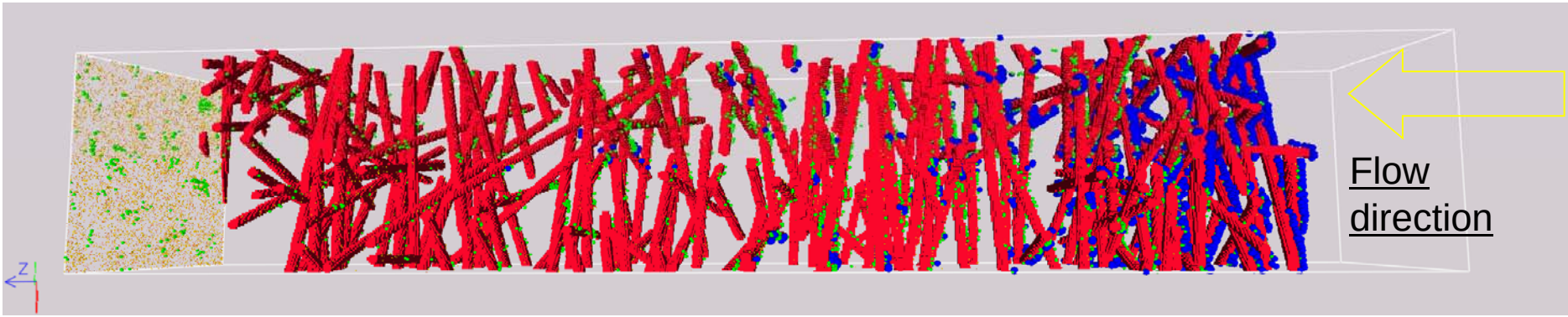
Interception



Interception
+ Impaction



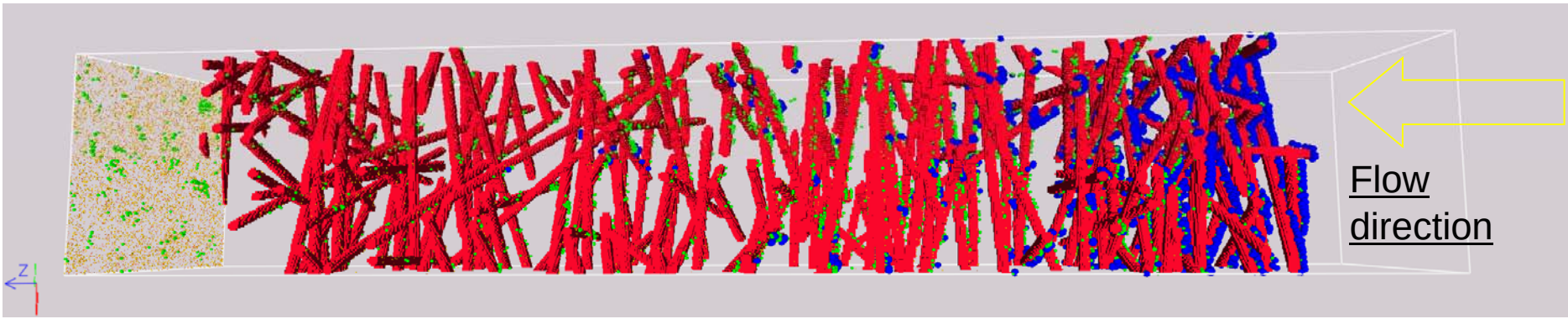
Interception
+ Impaction
+ Diffusion



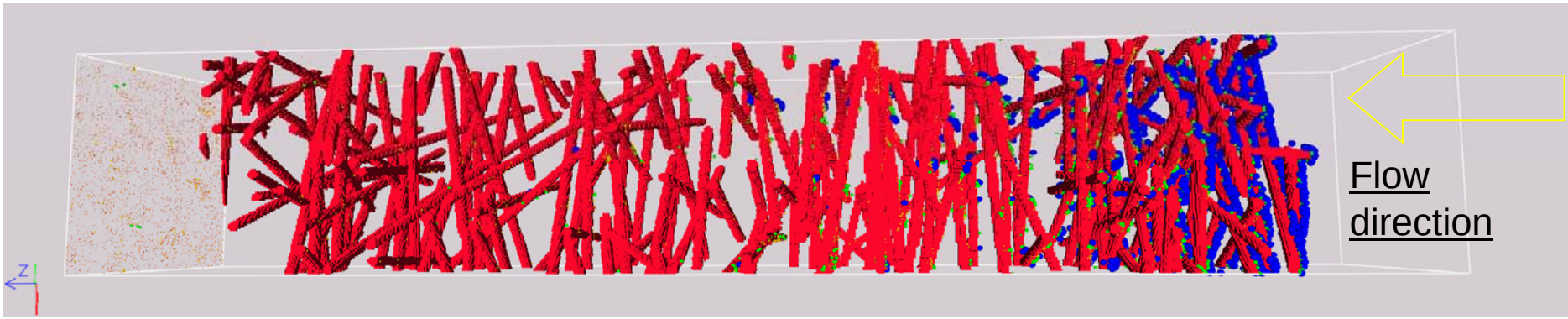
α = 0.05,
dF = 14,
Interception + Impaction + Diffusion

Velocity Effects

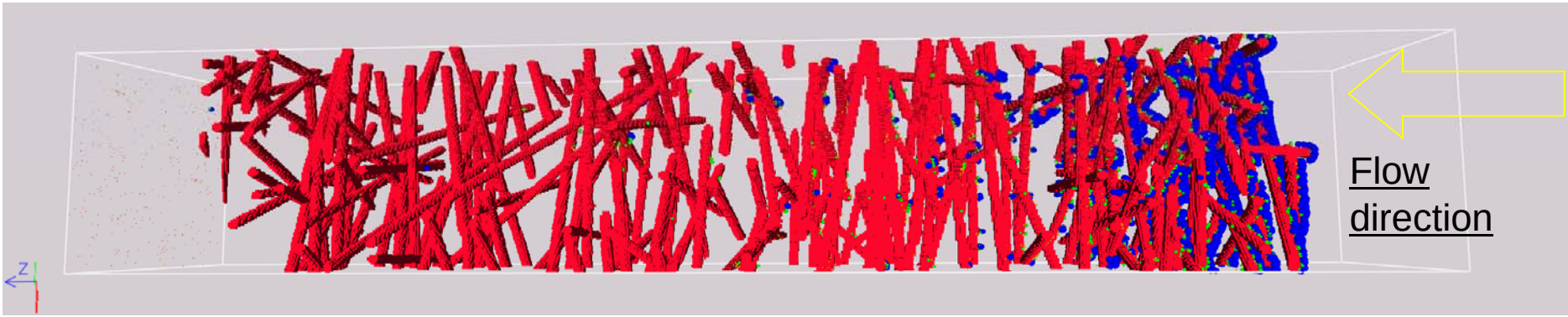
Velocity
v = 0.1 m/s



Velocity
v = 1 m/s



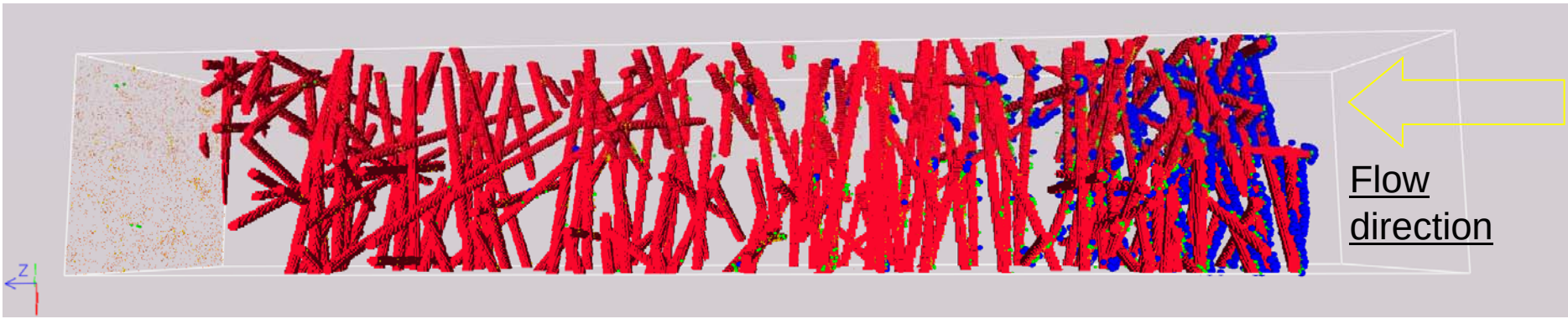
Velocity
v= 10 m/s



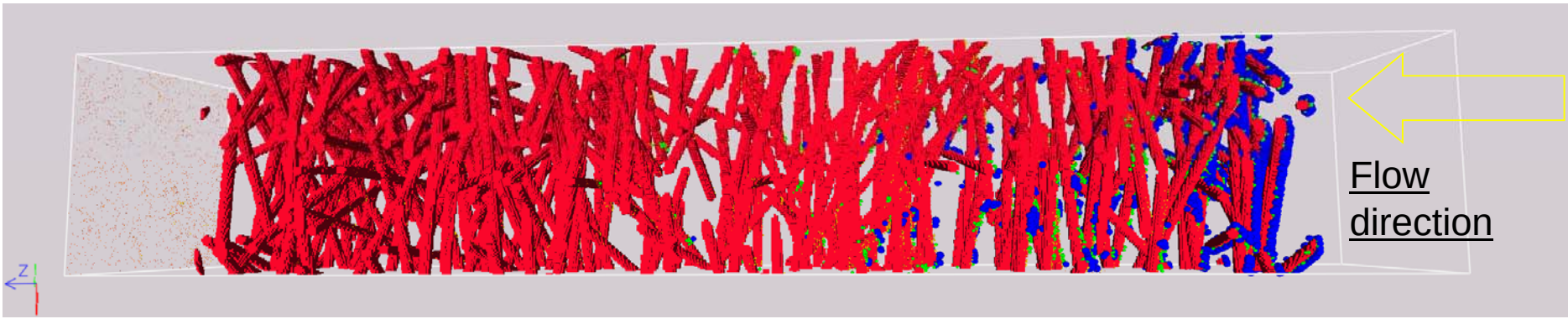
dF = 14,
v = 1 m/s,
Interception + Impaction + Diffusion

Effect of grammage (here: SVF)

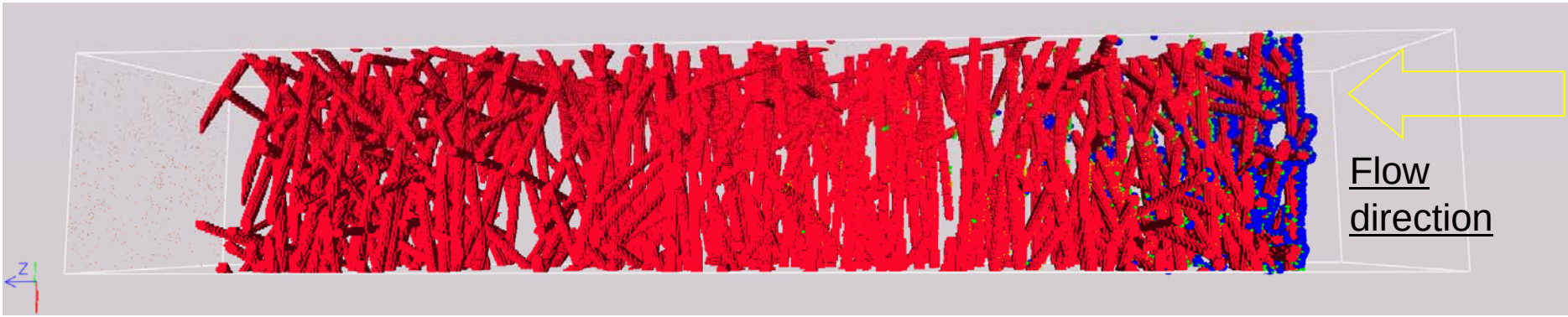
SVF α=0.05



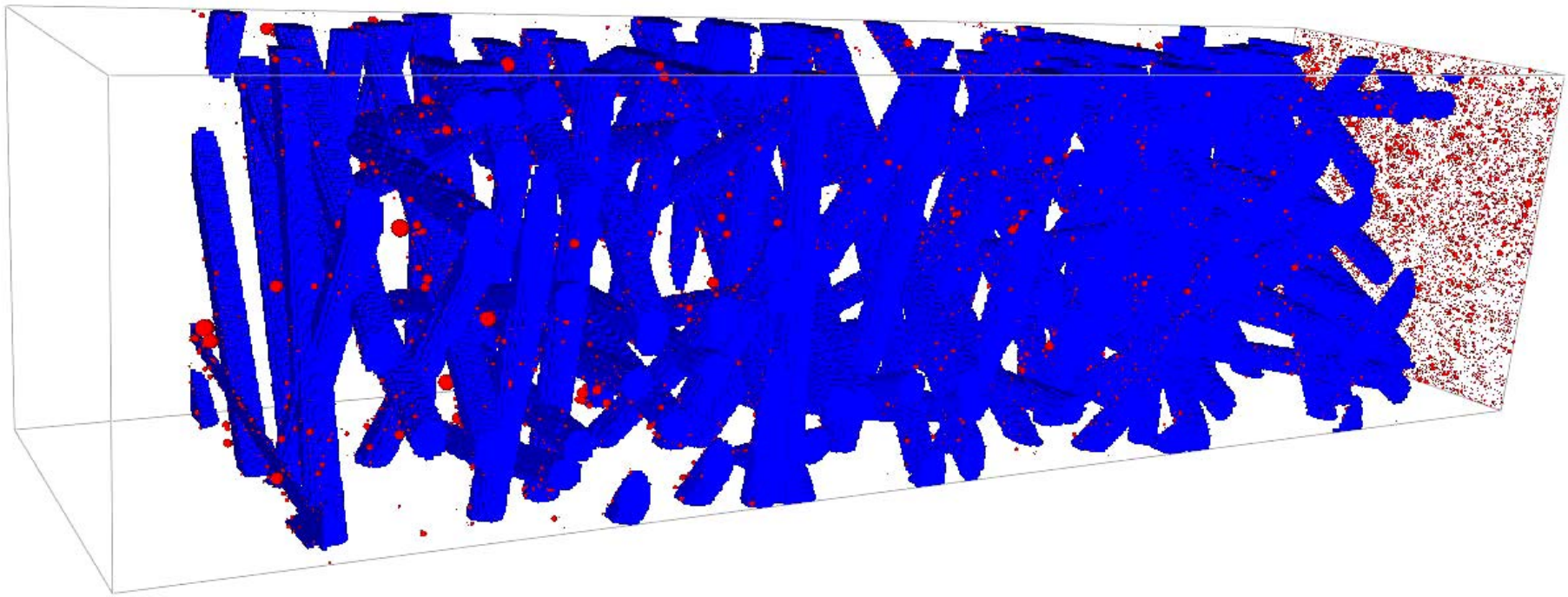
SVF α=0.07



SVF α=0.1

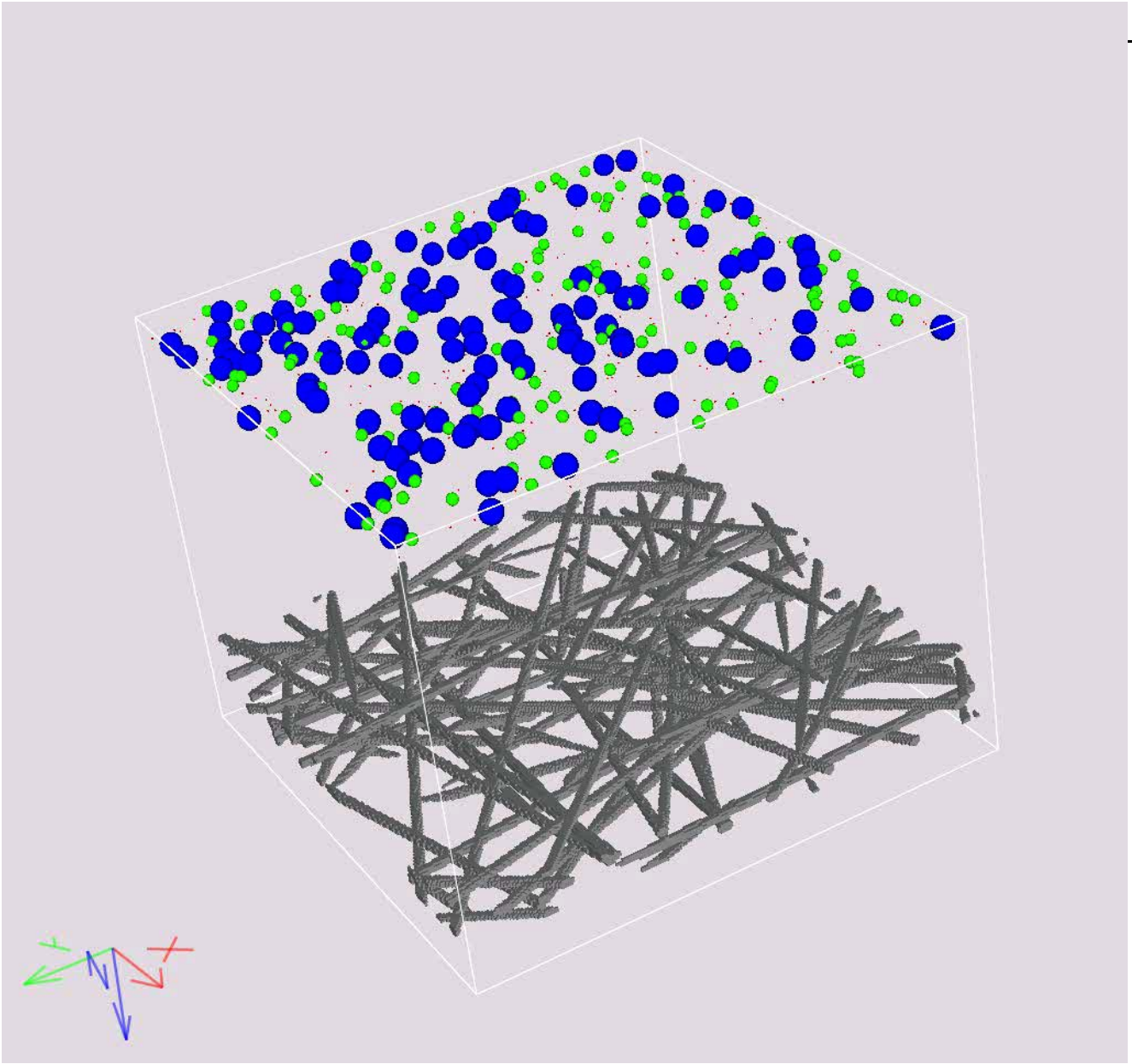


Transition from depth filtration to cake filtration in a single simulation



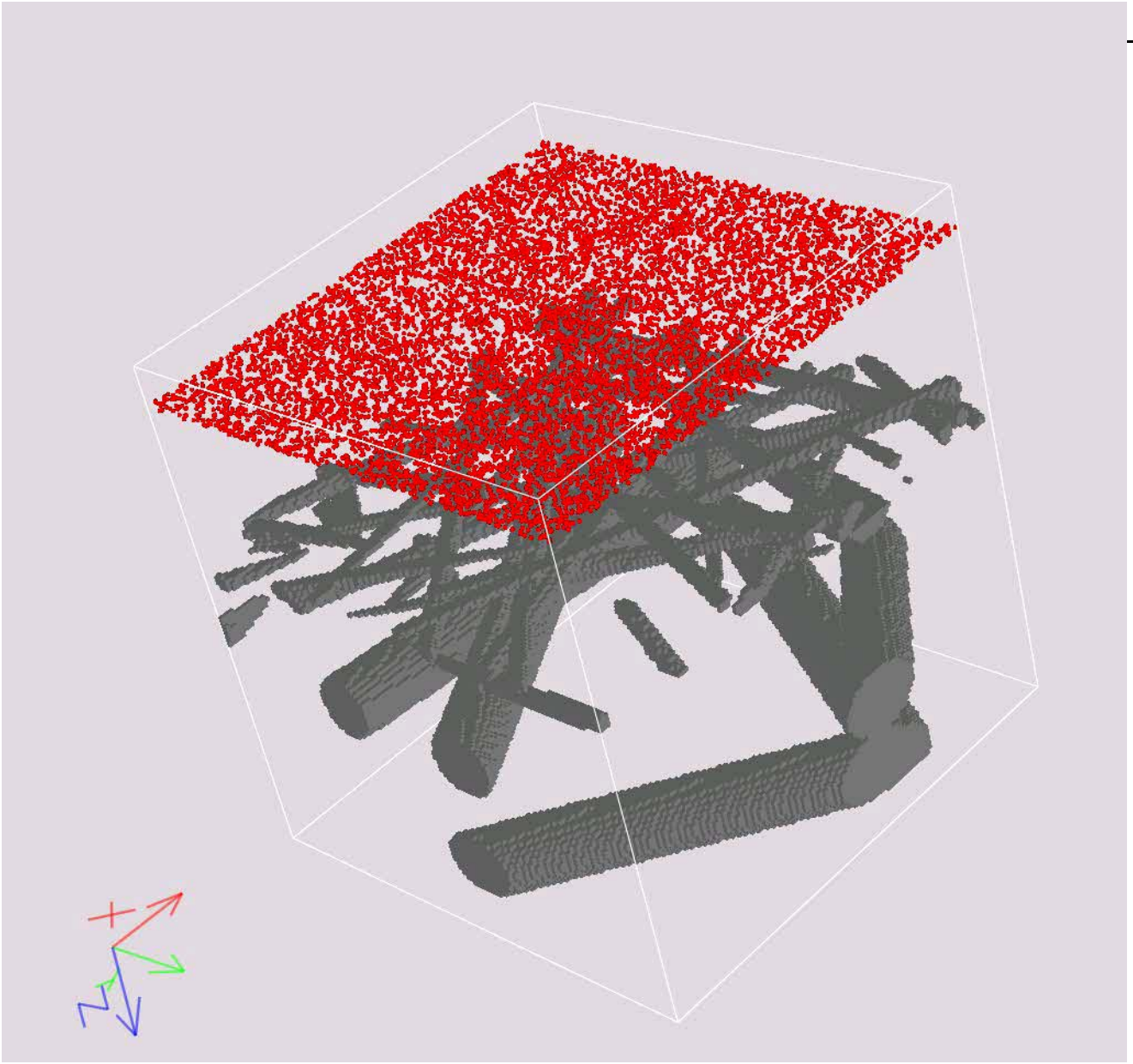
Flow direction

Detail: Cake formation



- Filter Efficiency evolution
- Pressure drop evolution

Detail: Pulse Cleaning



- Uncleaned particles

GeoDict contibutions at Fraunhofer ITWM: 2001 - 2012

GeoDict
Andreas Wiegmann
Jürgen Becker
Erik Glatt
Stefan Rief
Heiko Andrä
Sven Linden
Kilian Schmidt
Ashok Kumar Vaikuntam
Rolf Westerteiger
Christian Wagner
Mohammed Alam
Jianping Shen

UsersGuide
Barbara Planas
Vita Rutka
Stefan Rief
Andreas Wiegmann

PoroDict / MatDict
Erik Glatt
Andreas Wiegmann
Jürgen Becker
Kilian Schmidt
Rolf Westerteiger

PleatDict
Andreas Wiegmann
Oleg Iliev
Stefan Rief
Liping Cheng

FilterDict
Jürgen Becker
Stefan Rief
Arnulf Latz
Andreas Wiegmann
Kilian Schmidt
Christian Wagner
Rolf Westerteiger

ThermoDict EJ Solver
Andreas Wiegmann
Liping Cheng
Rolf Westerteiger

FlowDict Lattice Boltzmann
Peter Klein
Dirk Merten
Konrad Steiner
Dirk Kehrwald
Irina Ginzburg
Doris Reinel-Bitzer

FlowDict EJ Solver
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Aivars Zemitis
Rolf Westerteiger
Donatas Elvikis
Vita Rutka
Qing Zhang

DiffuDict Knudsen Solver
Jürgen Becker

ElastoDict
Heiko Andrä
Matthias Kabel
Liping Cheng
Andreas Wiegmann
Vita Rutka
Donatas Elvikis

FlowDict EFV Solver
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