MODELLIERUNG, SIMULATION UND VALIDIERUNG FÜR MELTBLOWN-PROZESSE

09.10.2023 – Hofer Vliesstofftage 2023

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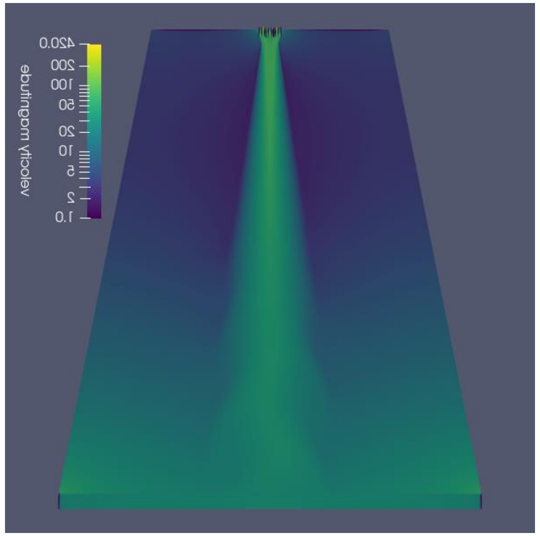

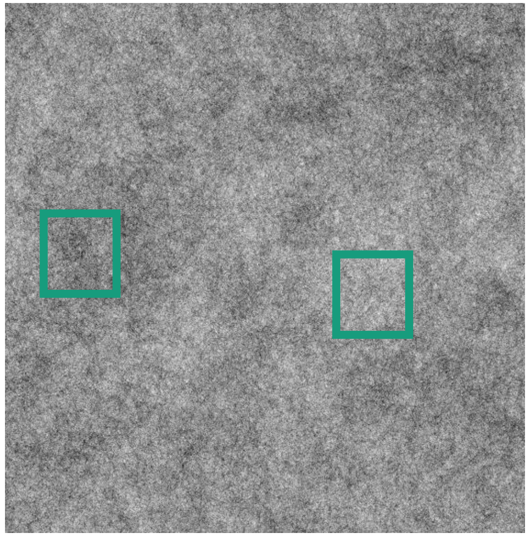

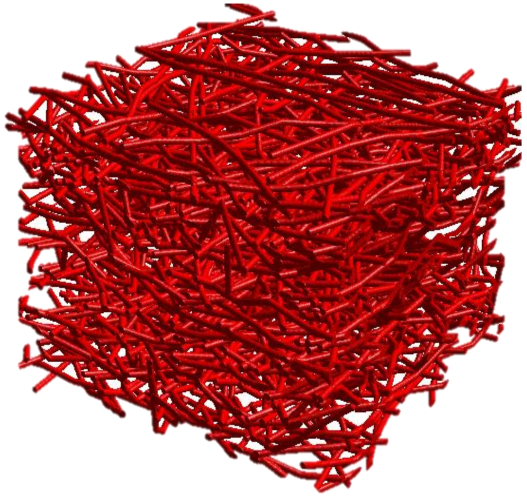

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Overview

- Air Filter Media
- Virtual Production
  - Air Flow Simulation
  - Filaments Simulation
- Measurements and Validation

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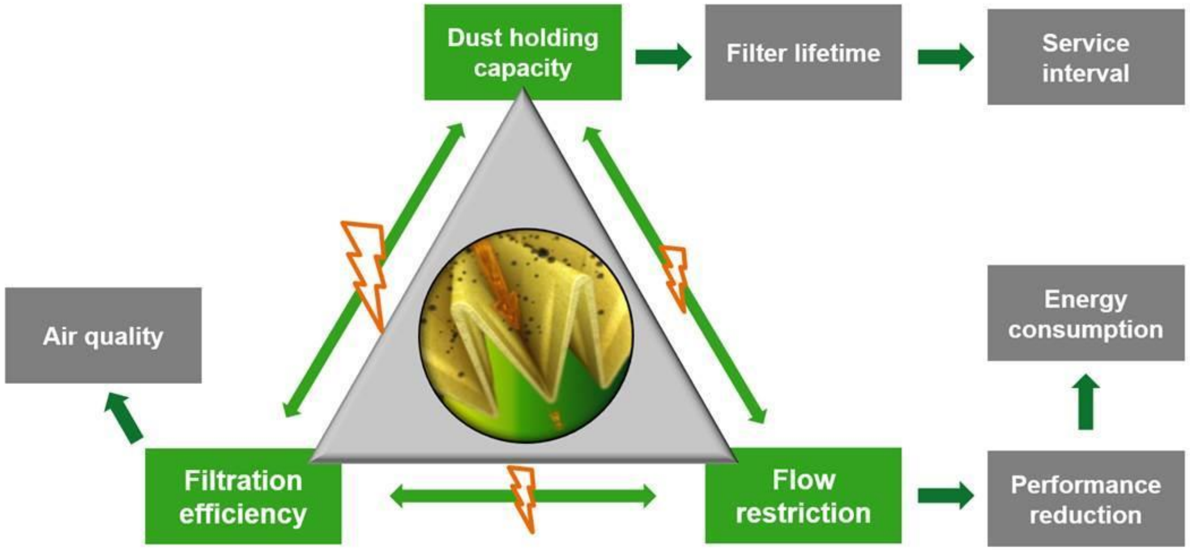
Development of New Filter Media

- Optimization of
  - Filtration efficiency
  - Energy requirements in operation
  - Production cost
  - Lifetime
  - Recyclability
- Energy consumption important for CO_2 reduction

- Multi-criteria optimization
- Conflicting goals



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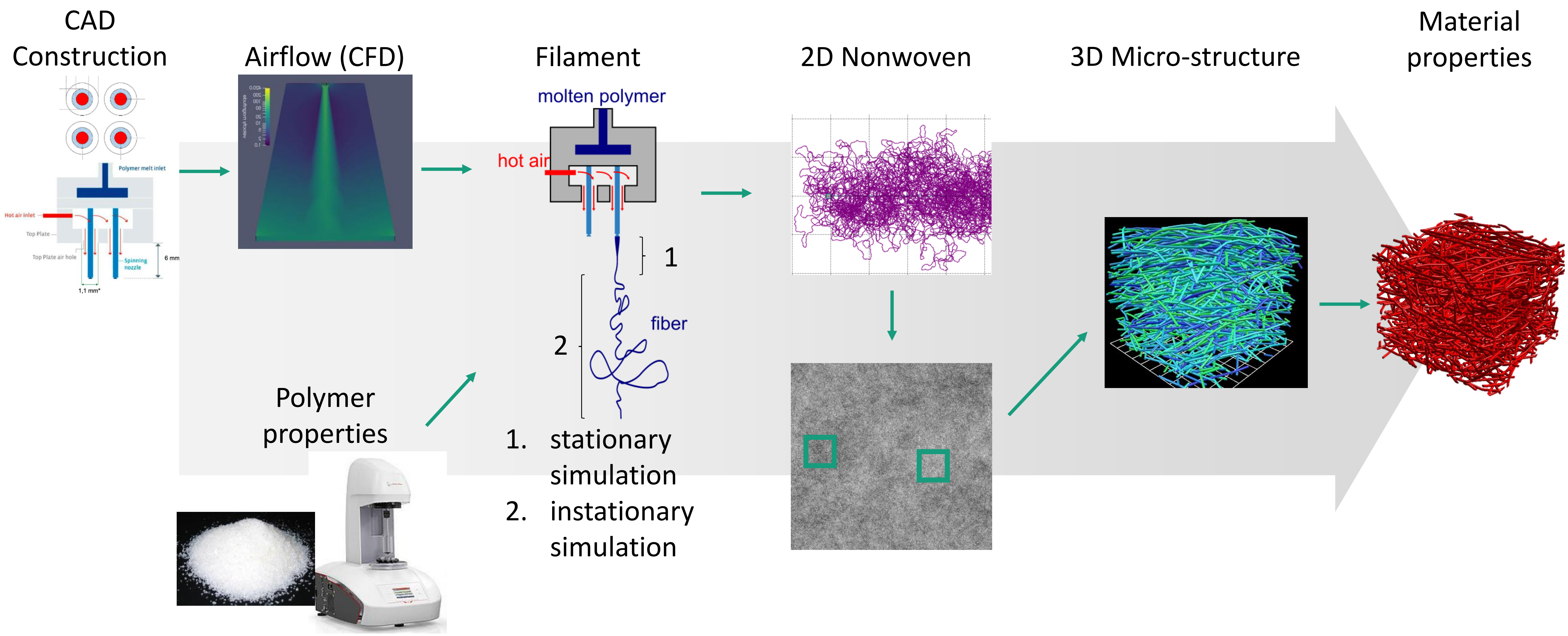
Simulation Pipeline for a Spunblown Process



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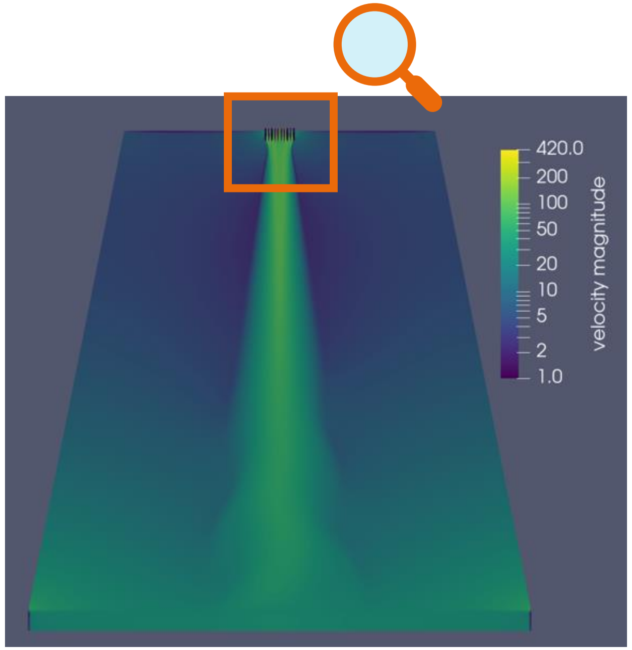
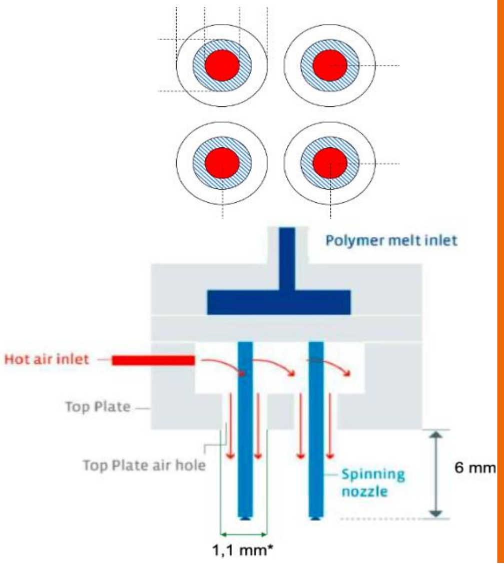
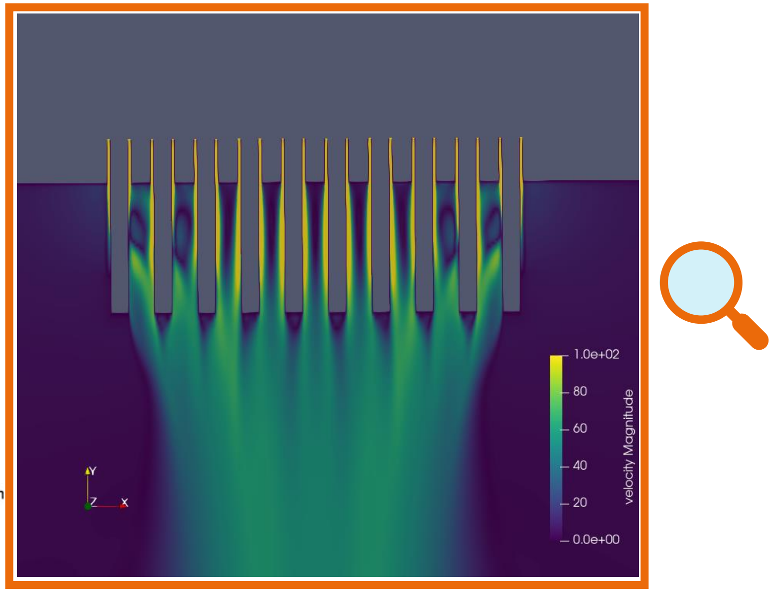
Airflow Simulation



- Simulation of airflow in Spunblown process
- Cylindrical air inlet nozzles need to be resolved
- Periodic 3D slice in cross-machine direction
- 8 rows of polymer spinning nozzles (+2 inactive nozzles)
- Simulated quantities:
  - Velocity
  - Temperature
  - Pressure
  - Turbulent quantities
- Using CFD software: Ansys Fluent®

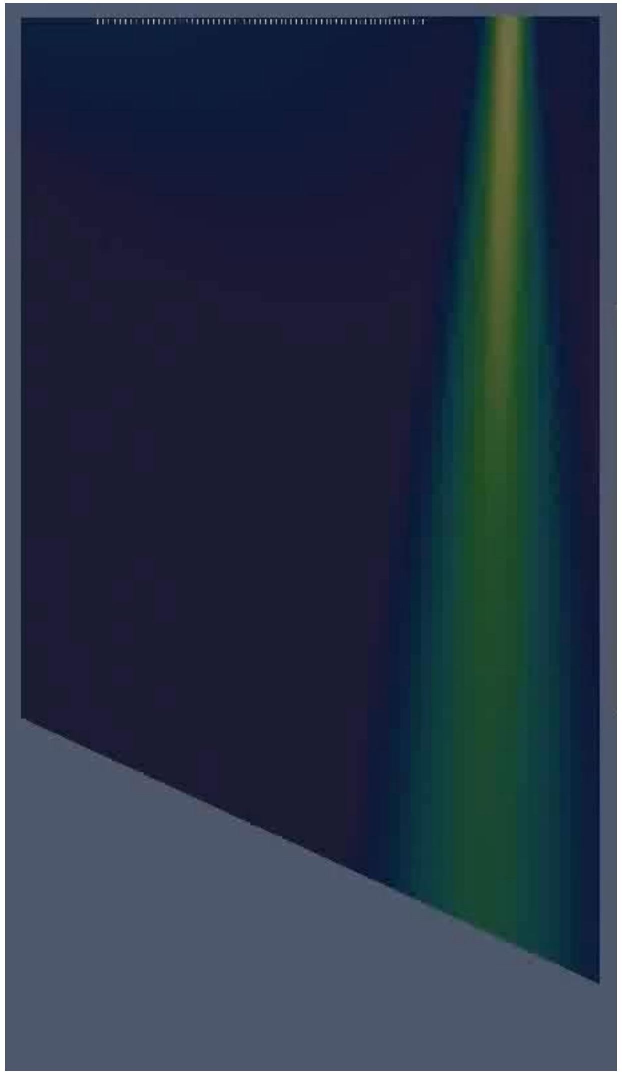




Filament Simulation – Overview

- Software FIDYST by Fraunhofer ITWM

- Simulation of individual filaments in airflow
- Fully physics-based
- Quantities: velocity, temperature, diameter, tension, etc.
- Cooling and stretching through airflow
  - Transfer of heat and momentum
  - Turbulence is a key influence factor
- Input:
  - Process parameters
  - CFD simulation
  - Polymer material properties (rheology measurement)



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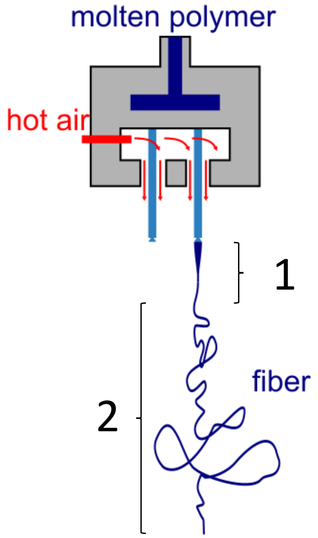
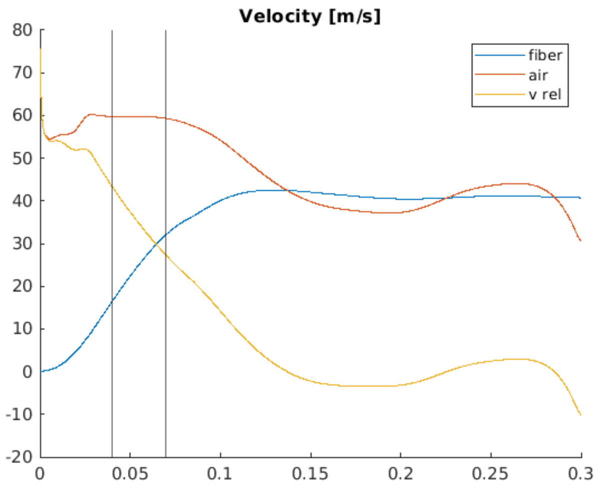
Filament Simulation – Part 1: Stationary Spinning



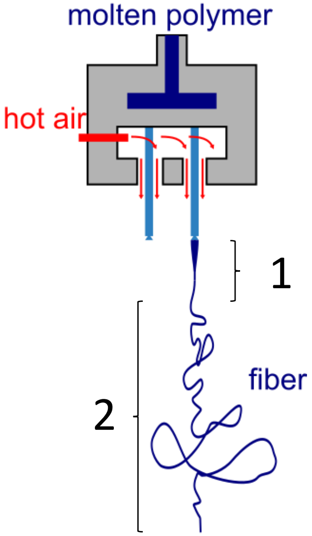
- Stationary simulation
  - Fiber simulated as 1D curve (centerline, circular cross-section)
  - Nonlinear ODE system, boundary-value problem
- Viscous material behavior
- Directly below spinning nozzle (~30mm)
- High relative air speed, low filament speed
- Negligible horizontal movement
- Turbulence can be ignored
- Stretching of several orders of magnitude (~100x-500x)

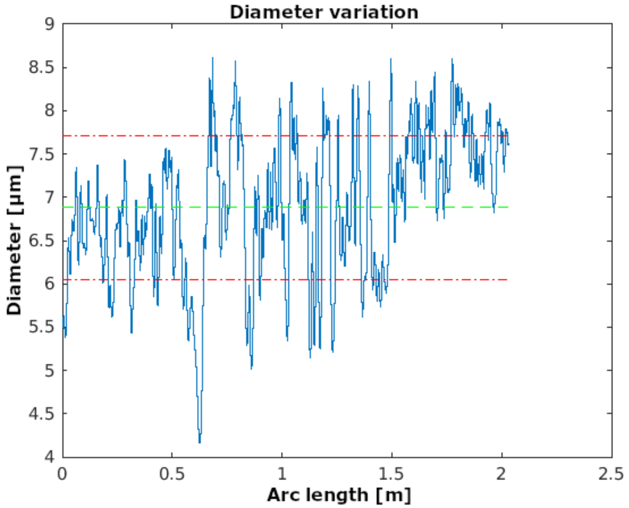


Filament Simulation – Part 2: Instationary Stretching

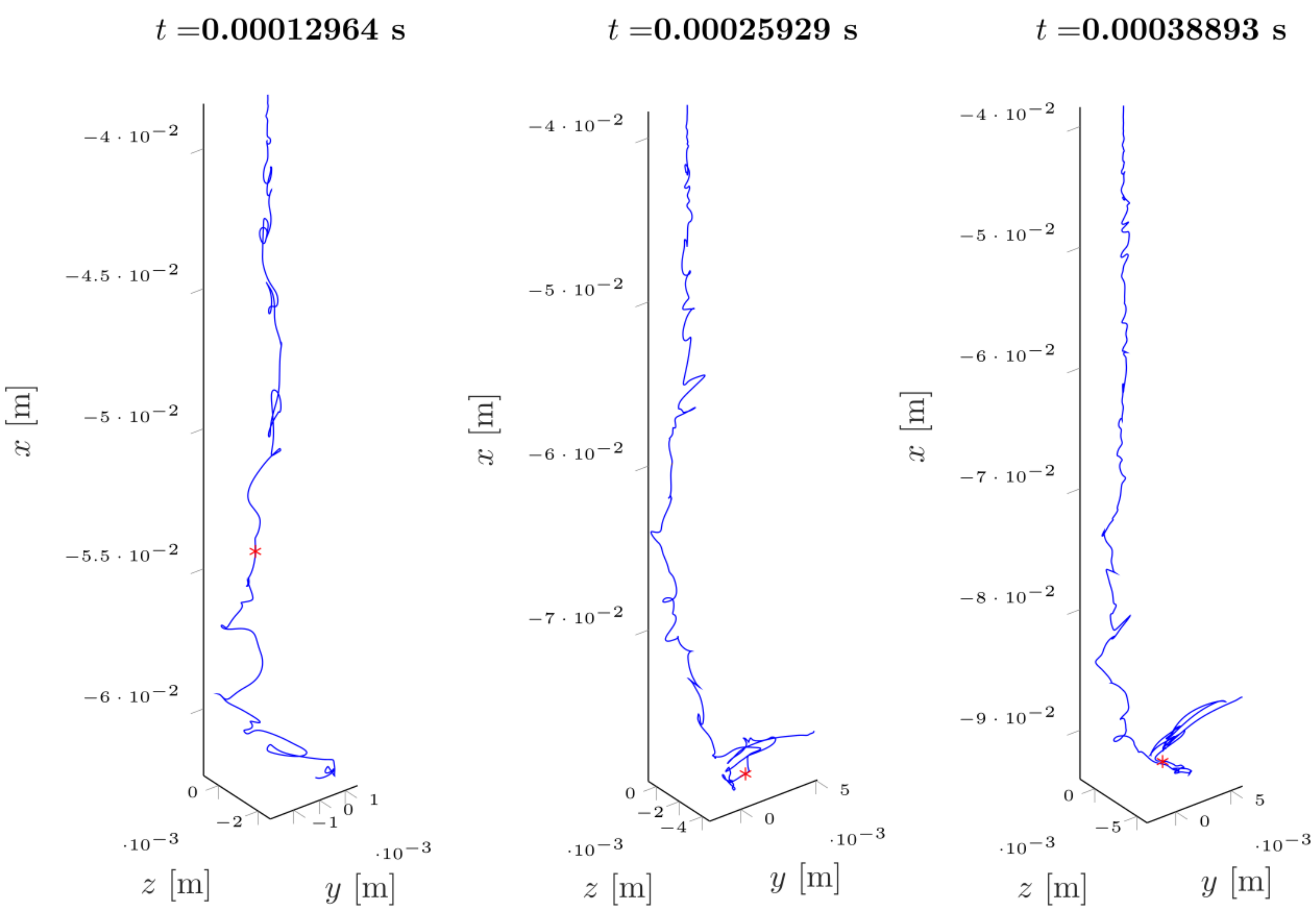
- Instationary simulation
  - Nonlinear PDE system
- Visco-elastic material behavior
  - Asymptotic Upper-Convective Maxwell
- Additional stretching due to turbulence
- Final diameters can only be explained in instationary simulation

$$\partial_t \mathbf{r} = \mathbf{v},$$
$$\partial_\varsigma \mathbf{r} = \boldsymbol{\tau},$$
$$\partial_t \mathbf{v} = \partial_\varsigma \left(\sigma \frac{\boldsymbol{\tau}}{e^2} \right) + \frac{1}{\mathrm{Fr}^2}\mathbf{e_g} + \mathbf{f}_{air},$$
$$\partial_t T = -\frac{\mathrm{St}}{\varepsilon} e \pi d \alpha (T - T_\star),$$
$$\mathrm{De}\left(\partial_t \sigma - (2\sigma + 3p)\frac{\partial_t e}{e} \right) + \frac{\sigma}{\theta} = \frac{3}{\mathrm{Re}}\frac{\mu}{\theta}\frac{\partial_t e}{e},$$
$$\mathrm{De}\left(\partial_t p + p\frac{\partial_t e}{e} \right) + \frac{p}{\theta} = -\frac{1}{\mathrm{Re}}\frac{\mu}{\theta}\frac{\partial_t e}{e}.$$





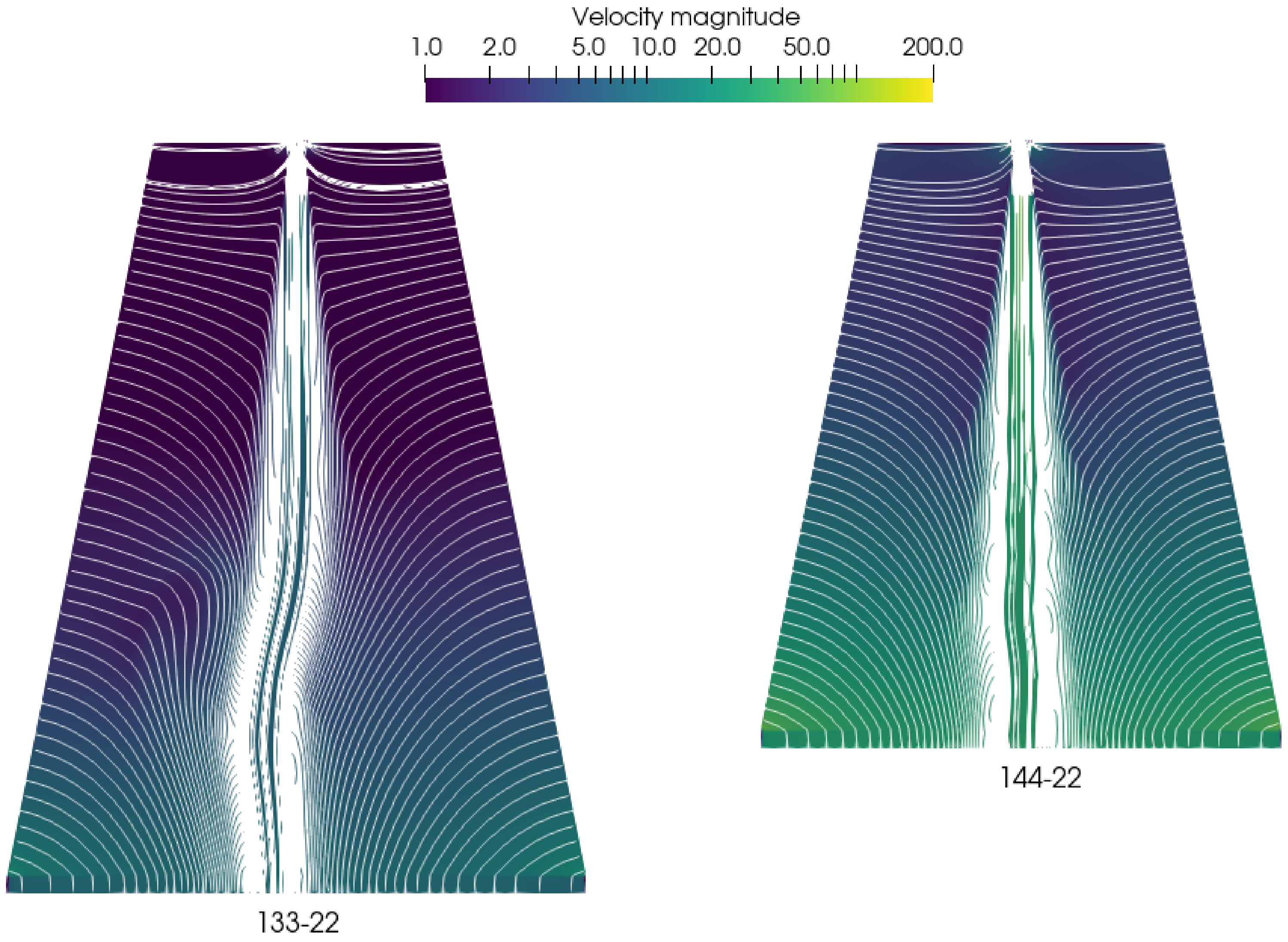
Meltblown Paradox – Explained by Simulation, Stretching Is Factor 10 Or Even More Than Theoreticly Possible by Maximum Air Speed



Results CFD Simulations, Comparison Different DCD

DCD 500 mm

DCD 300 mm



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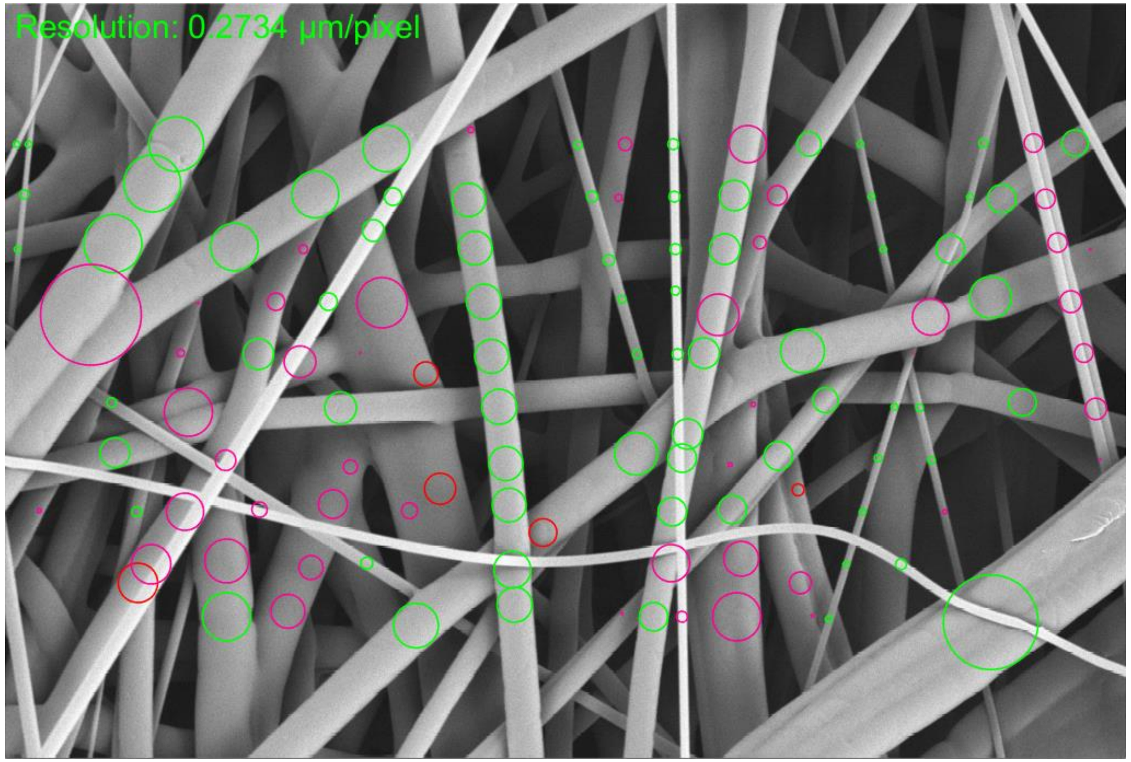
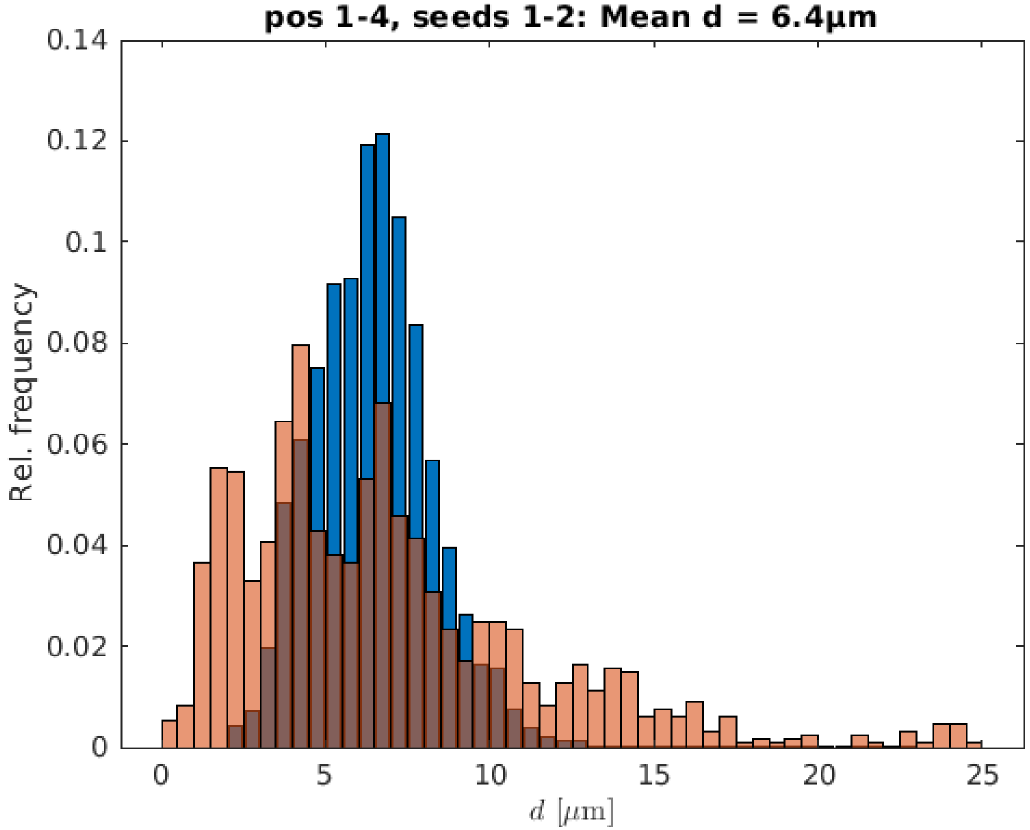
Validation of Process Model Against Reference Samples

- Mean simulation 6.4 µm, mean measurements 6.5 µm
- Thicker fibers due to sticking, wider spread by missing surface tension





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Validation of Further Samples

Sample	Domain	Avg. Fiber diameter / µm
A	Real sample	9.6 (-10%)
	Simulated sample	10.7
B	Real sample	11.5 (-10%)
	Simulated sample	12.3
C	Real sample	5.6 (+9%)
	Simulated sample	5.1
D	Real sample	6.2 (-11%)
	Simulated sample	7.0
E	Real sample	3.4 (+3%)
	Simulated sample	3.3
F	Real sample	4.0 (-11%)
	Simulated sample	4.5

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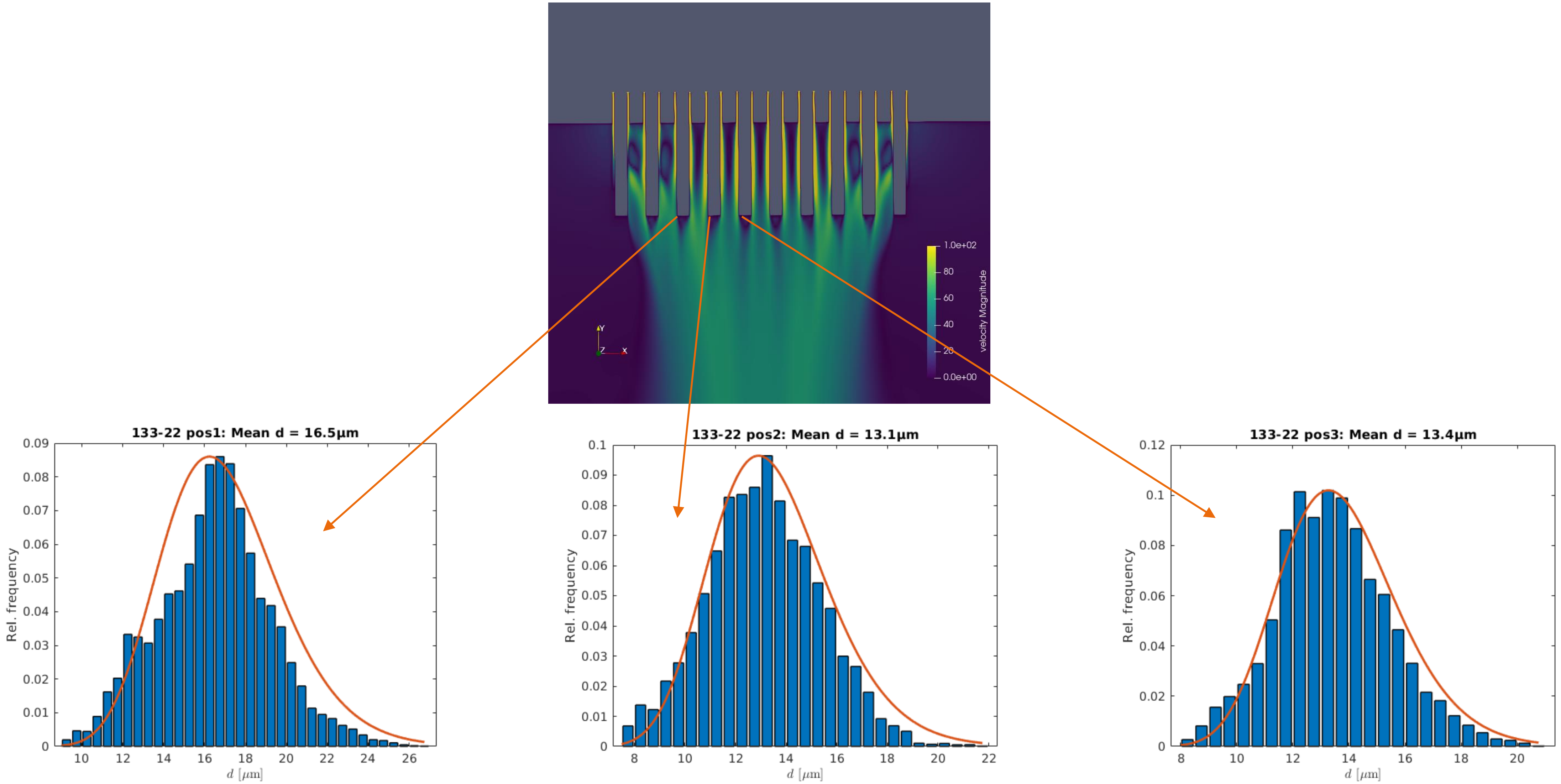
Fiber Simulation: Diameter Distribution Each Nozzle



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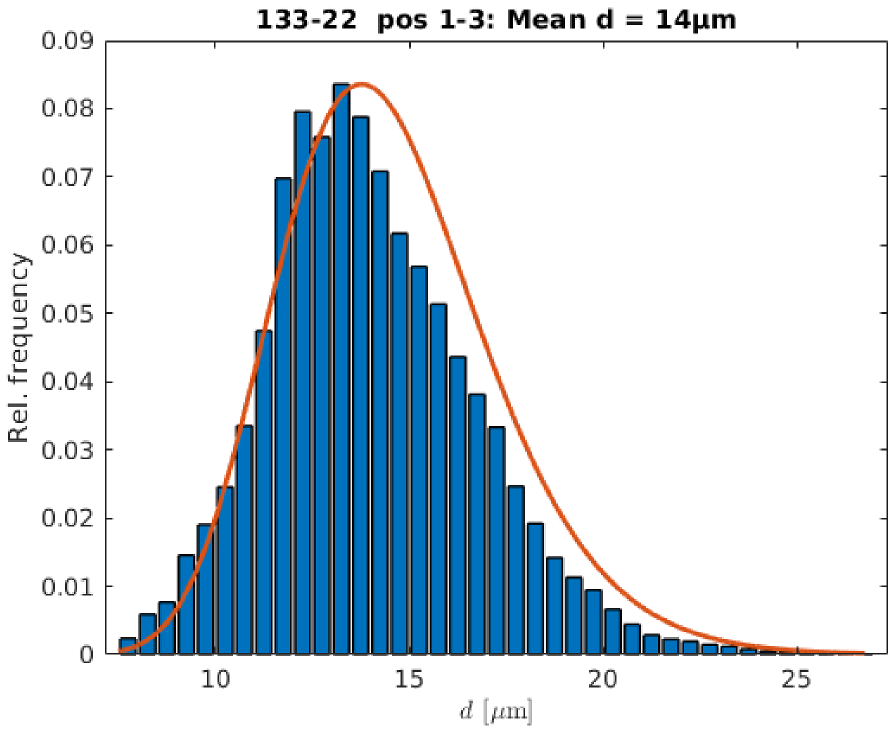
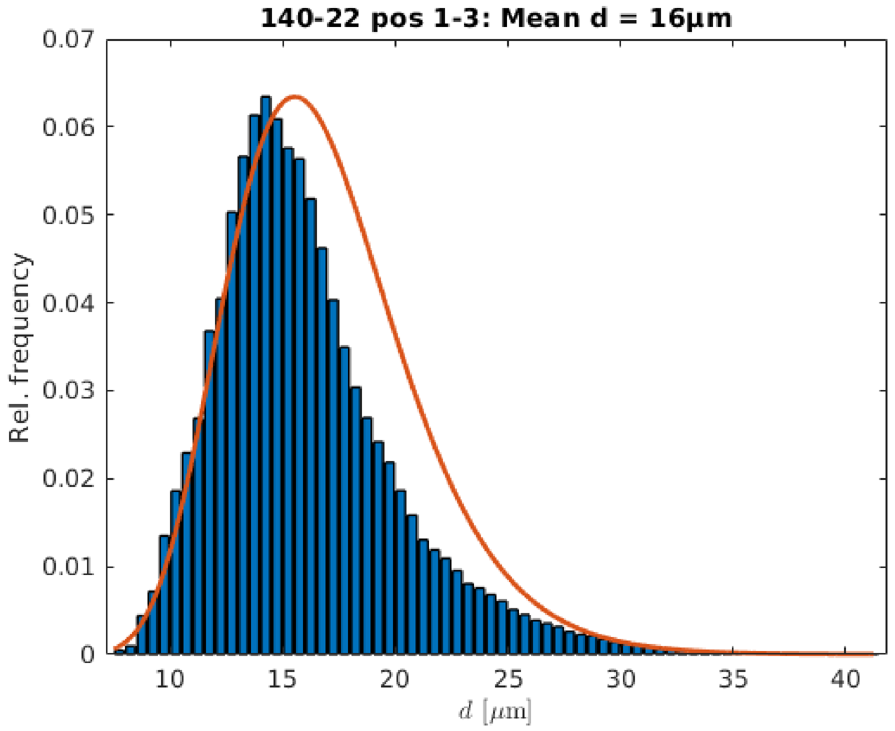
Fiber Simulation: Diameter Distribution All Nozzles for Different DCD

DCD 500 mm

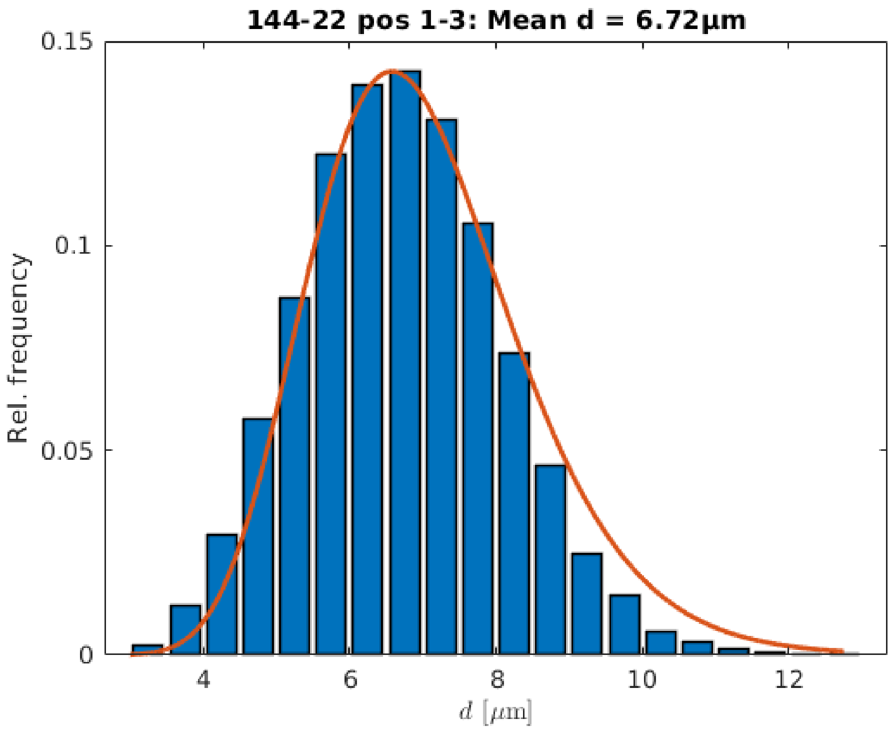


DCD 300 mm

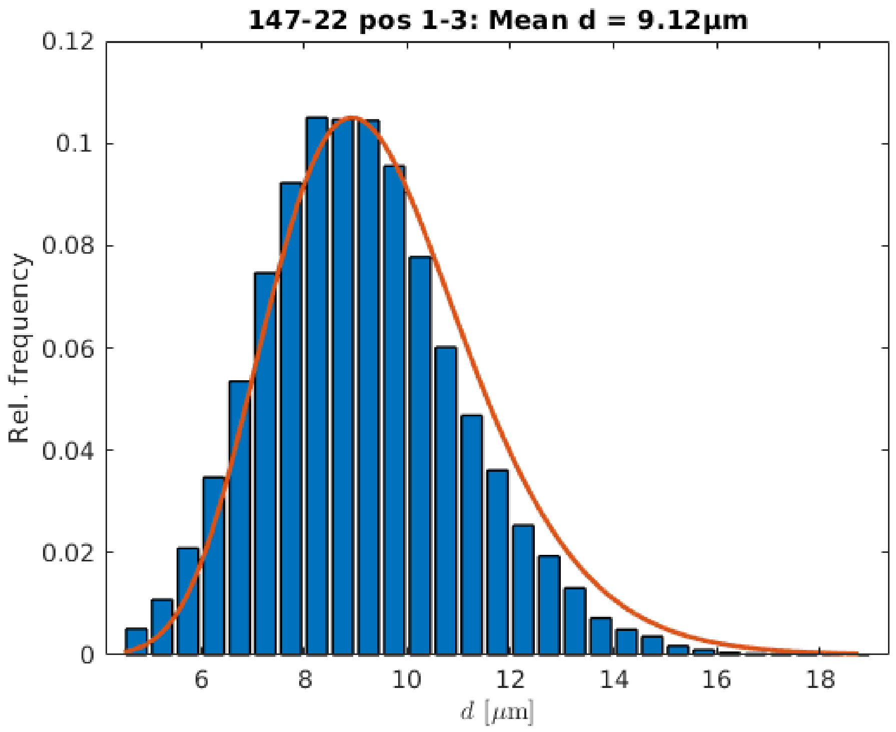


Fiber Simulation: Diameter Distribution for Different Air Flow Amount

800 Nm³/h



500 Nm³/h



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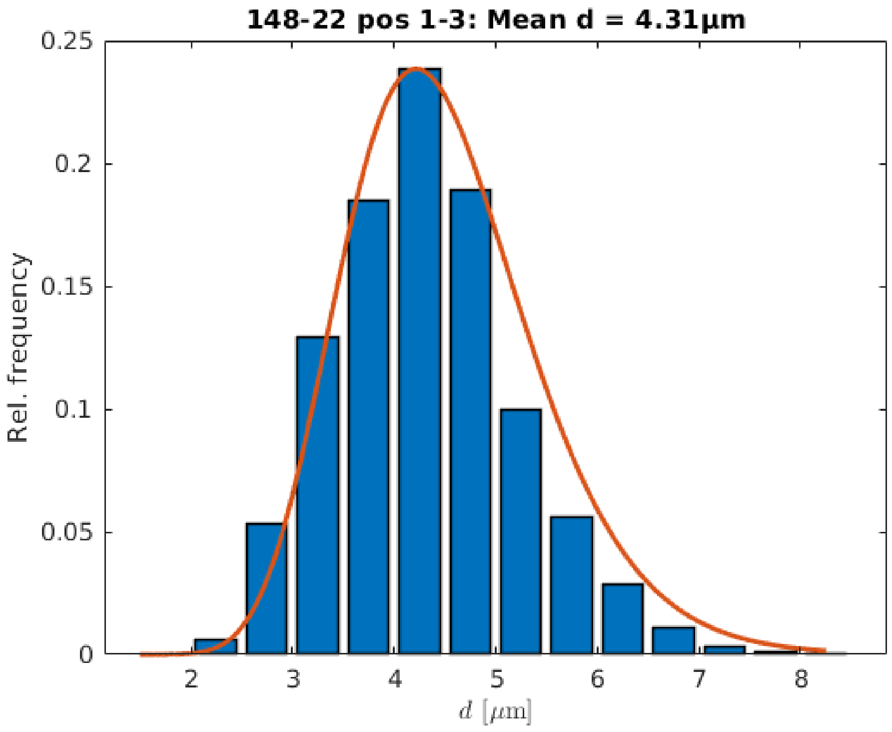
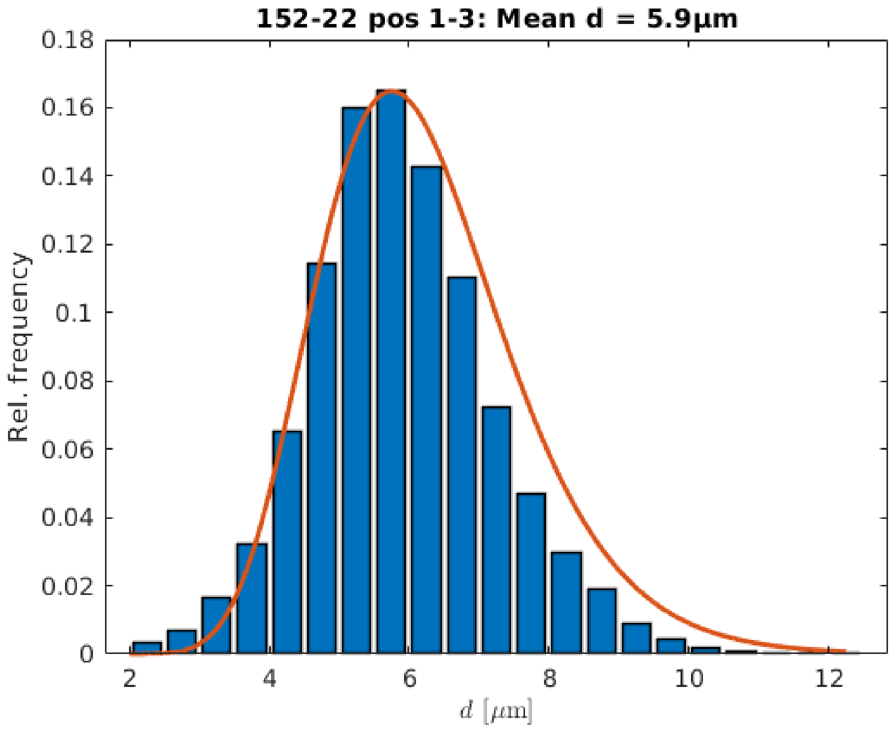
Fiber Simulation: Diameter Distribution for Different Air Flow Amount and Temperature

800 Nm³/h, 255 °C



600 Nm³/h, 280 °C



Conclusion

- Virtual production reduces development time, costs
- Simulation-Driven Design uses virtual twin to optimize complete production chain
- Simulations leads to deep understanding of the process
- Including of surface tension to get more precise diameter distribution

- Cooperations in public and industrial context possible

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Acknowledgements

- Research Project: Virtual Produced Filter Media (ViProFil)
- Partners: MANN+HUMMEL GmbH, Fraunhofer Institute for Industrial Mathematics ITWM
- Funded by the German Federal Ministry of Economic Affairs and Energy (BMWi) in the framework of the 7th Energy Efficiency Research Program

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Gefördert durch:

Bundesministerium für Wirtschaft und Klimaschutz

aufgrund eines Beschlusses des Deutschen Bundestages