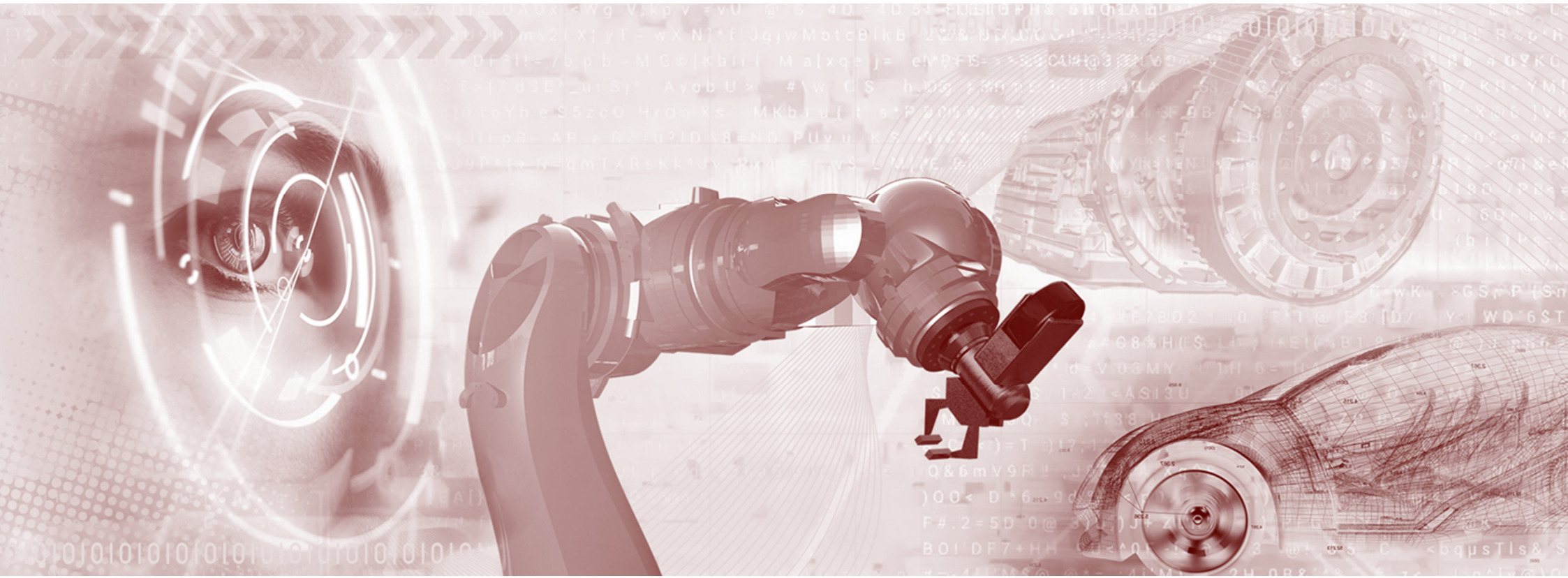
Universität Stuttgart
Institute of Aircraft Design

# Digitaler Prototyp

## Infiltration Simulation and Virtual Permeability Determination for the Digital Prototype



ARENA2036

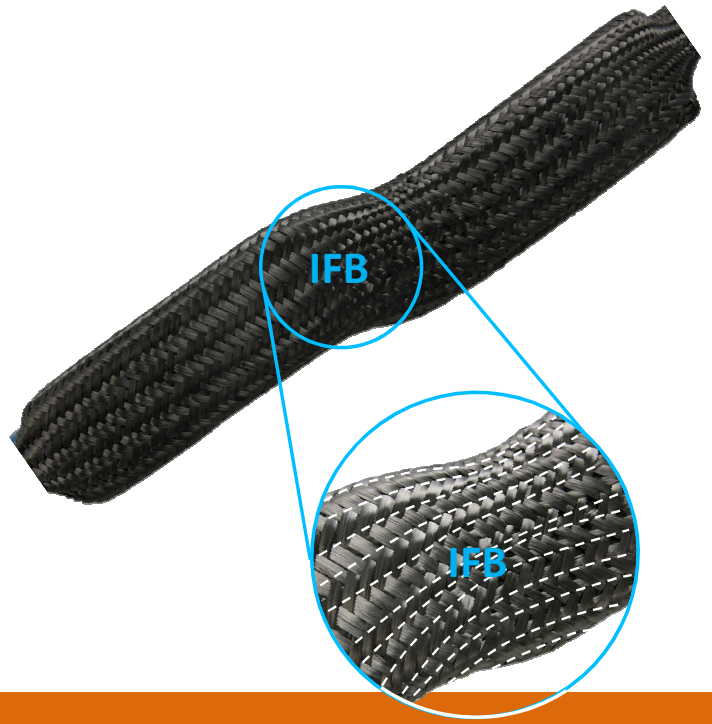
Datum: 25 – 26. Juni 2018
Ort: 15. Deutsches LS-Dyna Forum, Bamberg, 2018

DigitPro - J. Dittmann, P. Middendorf

# PERMEABILITY PREDICTION

ARENA2036

- How to predict permeability values of near-net-shape parts with varying fibre orientations ?



# BEFORE DIGITPRO

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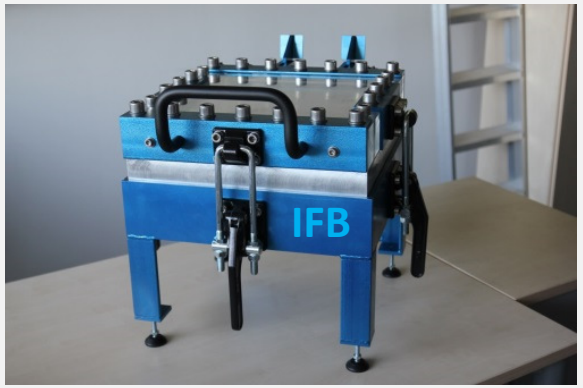
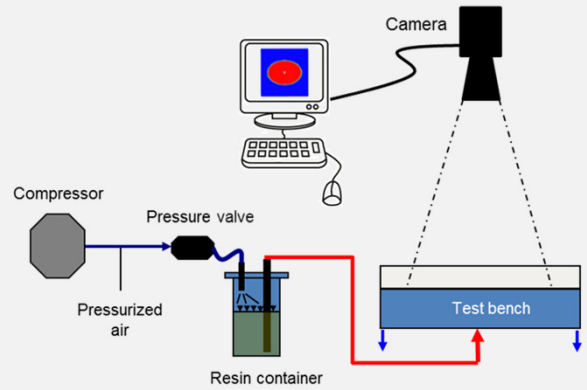
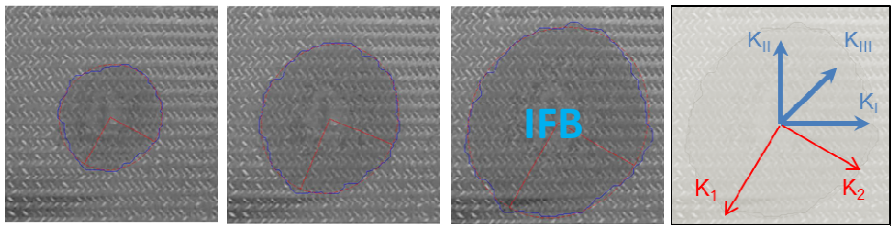


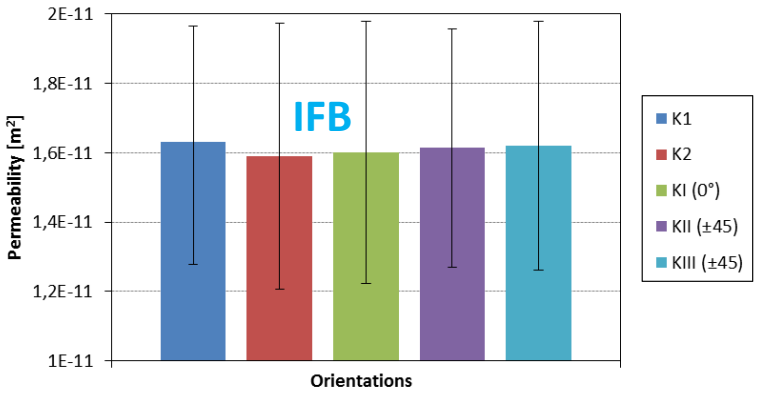

Experimental permeability determination




Flow front development after 28,3 s; 43,3 s und 63,3 s

**Data / alternative Facts:**

- Infiltration pressure: 2 bar
- FVC: 52 %
- 4 layer triaxial braid: Toho Tenax 12K (589 g/m²; 0/±45)
- Fluid: Glycerol 85 %
- Aluminum bottom mould
- PMMA top mould + Steel stiffeners

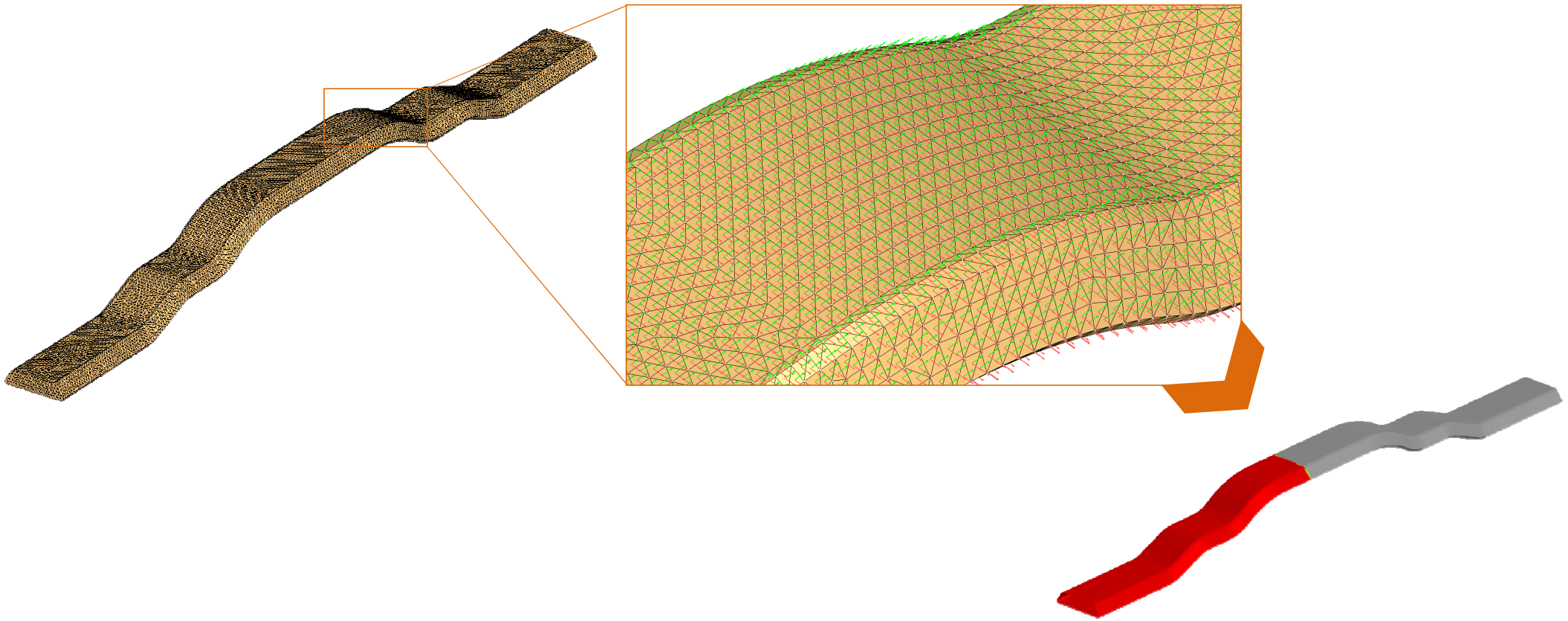



Radial in-plane permeability determination

**Classical way of permeability determination.**

# BEFORE DIGITPRO

ARENA2036

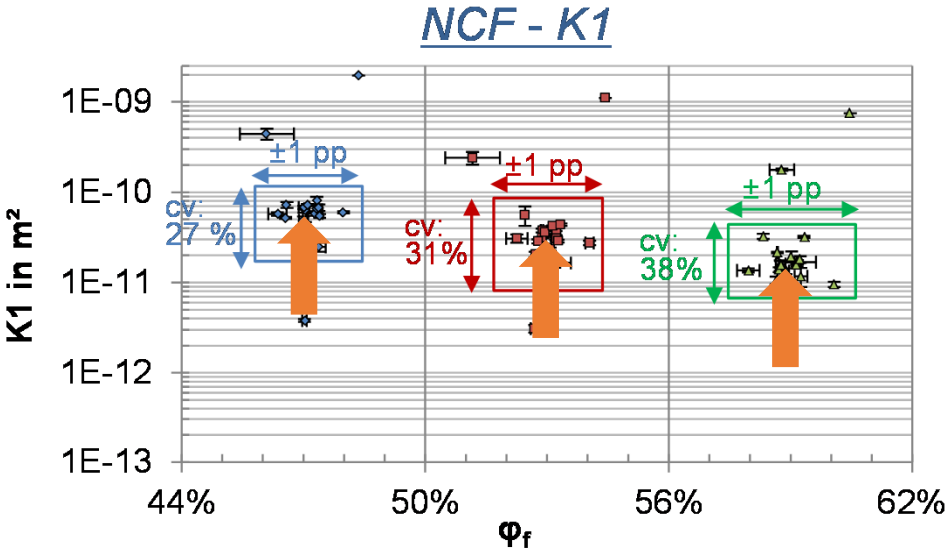


**Classical way of FEM filling simulation.**

# CHALLENGES IN DIGITPRO AND IN THE WORLD

ARENA2036

- How to predict permeability values of near-net-shape parts with varying fibre orientations ?
- What to do with big variations in permeability results ?
- How to validate permeability values if we don‘t know what is right ?




**$\varphi_f$** = fiber volume content, calculated with fvc-wise averaged areal weight, cavity deformation NOT considered

**cv** = coefficient of variation (referring to original values, NOT logarithmitc values)

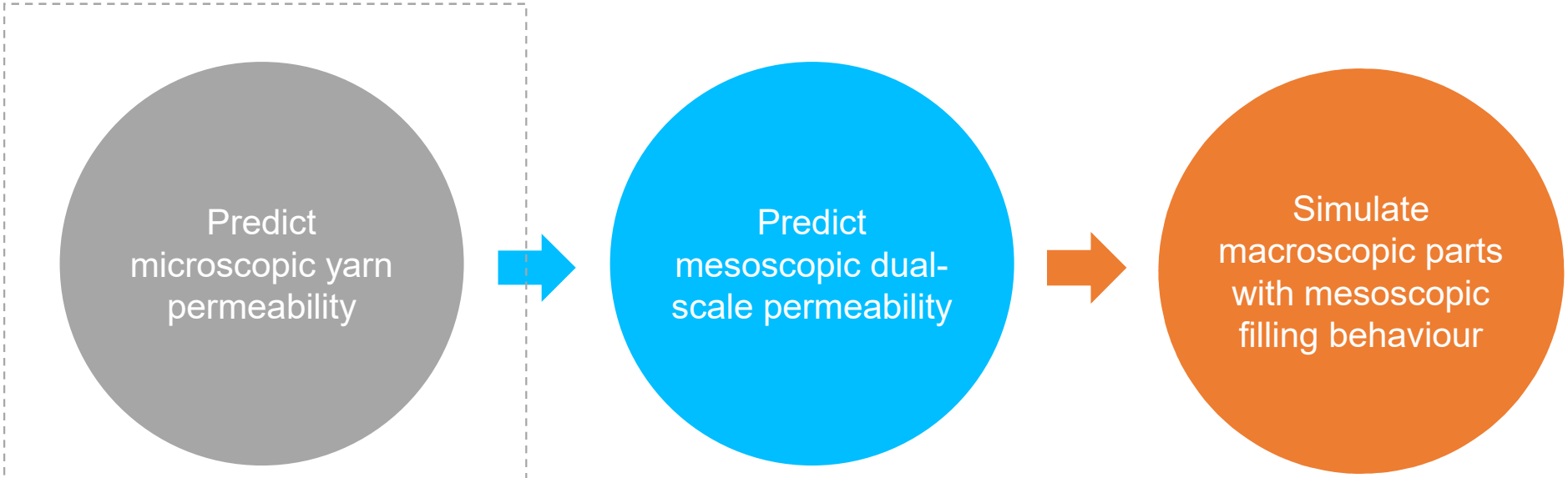
**pp** = percentage points

[1]

[1] D. May, A. Aktas and A. Yong, International Benchmark Exercises on Textile Permeability and Compressibility Characterization, ECCM, 2018

# THE PLAN




Predict microscopic yarn permeability
Predict mesoscopic dual-scale permeability
Simulate macroscopic parts with mesoscopic filling behaviour

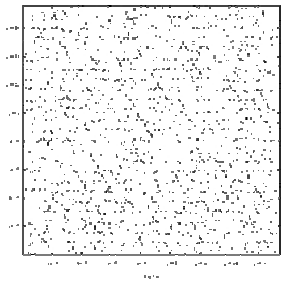
# Multi-Scale Fiber Architecture & Flow Simulation

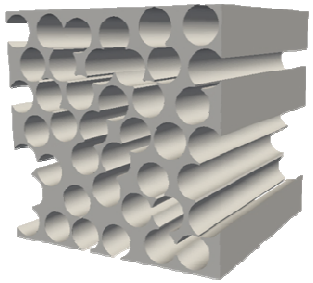
# MULTI-SCALE FIBRE ARCHITECTURE

ARENA2036

**RVE-Level**
(RVE - Fibre)

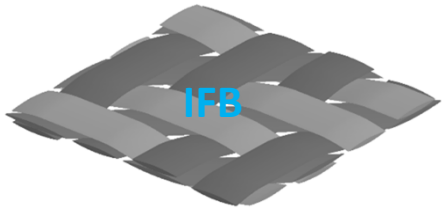
**Open-FOAM**





**Unit cell-Level**
(RVE – Preform)

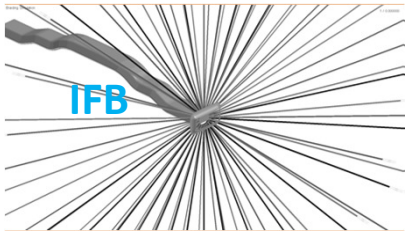
**TexGen**

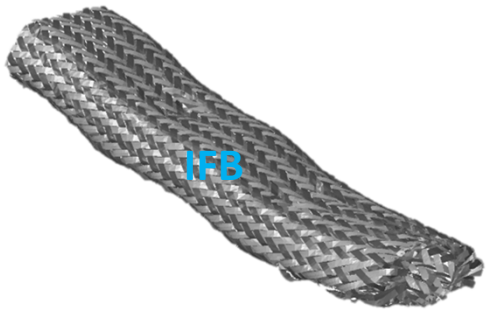




**Part-Level**
(Near-net-shape)

**PAM-CRASH**
**LS-DYNA**



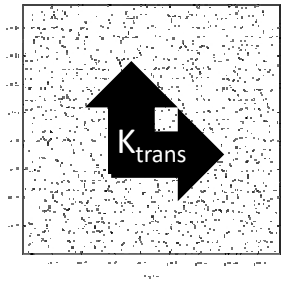

**How to model micro/meso textile architecture ?**

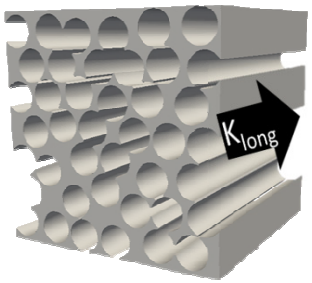
# MICROSCOPIC FIBRE ARCHITECTURE

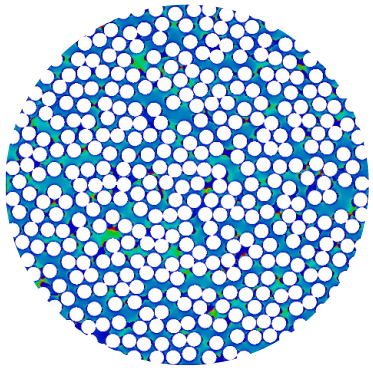
ARENA2036

**RVE-Level**
(RVE - Infiltration)

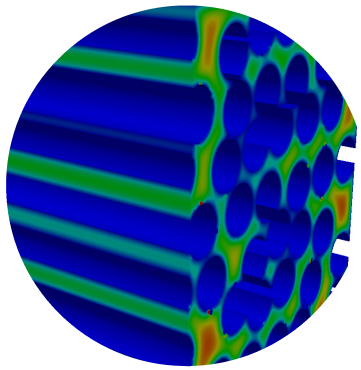
**Open-FOAM**



Yarn permeability (perpendicular)



Yarn permeability (longitudinal)

# TRANSFER TO MESOSCOPIC FIBRE ARCHITECTURE

ARENA2036

**RVE-Level**
(RVE - Infiltration)

**Microscopic yarn permeability values**

**Unit cell-Level**
(RVE – Infiltration)

**Open-FOAM**



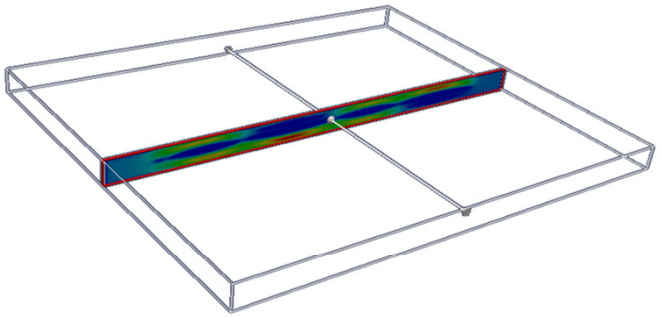
```
porosity1
{
    type            DarcyForchheimer;
    active          yes;
    cellZone        porosity;

    DarcyForchheimerCoeffs
    {
        d   d [0 -2 0 0 0 0 0] (5e7 -1000 -1000);
        f   f [0 -1 0 0 0 0 0] (0 0 0);

        coordinateSystem
        {
            e1  (0.70710678 0.70710678 0);
            e2  (0 0 1);
        }
    }
}
```

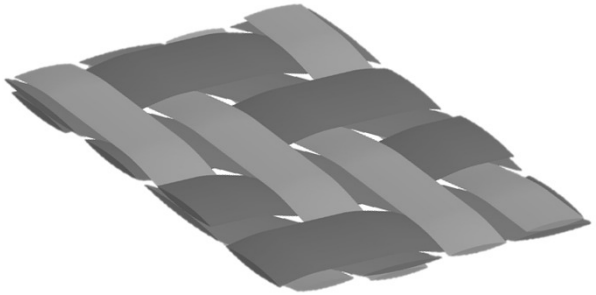
$$d = \left(\frac{\Phi}{K_x}\ \frac{\Phi}{K_y}\ \frac{\Phi}{K_z}\right)$$

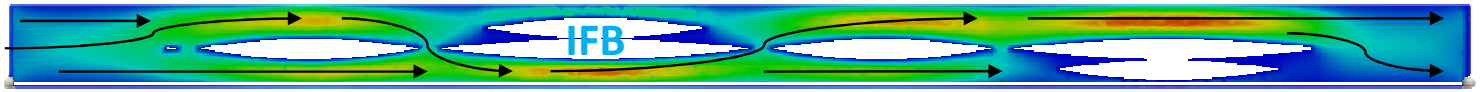
*d:* Darcy coefficient
$\Phi$: Porosity
$K_{xyz}$: Permeability

**How to implement yarn permeability ?**

## Dual Scale Flow – How does it work in OpenFoam?








Inter tow flow


Inter tow flow + Intra tow flow = Dual scale flow

# TRANSFER TO MESOSCOPIC FIBRE ARCHITECTURE

ARENA2036

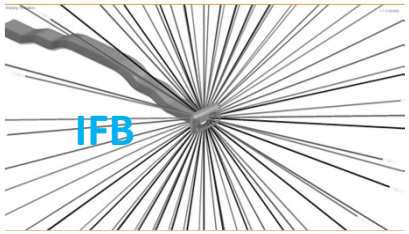
**RVE-Level**
(RVE - Infiltration)

**Microscopic yarn permeability values**

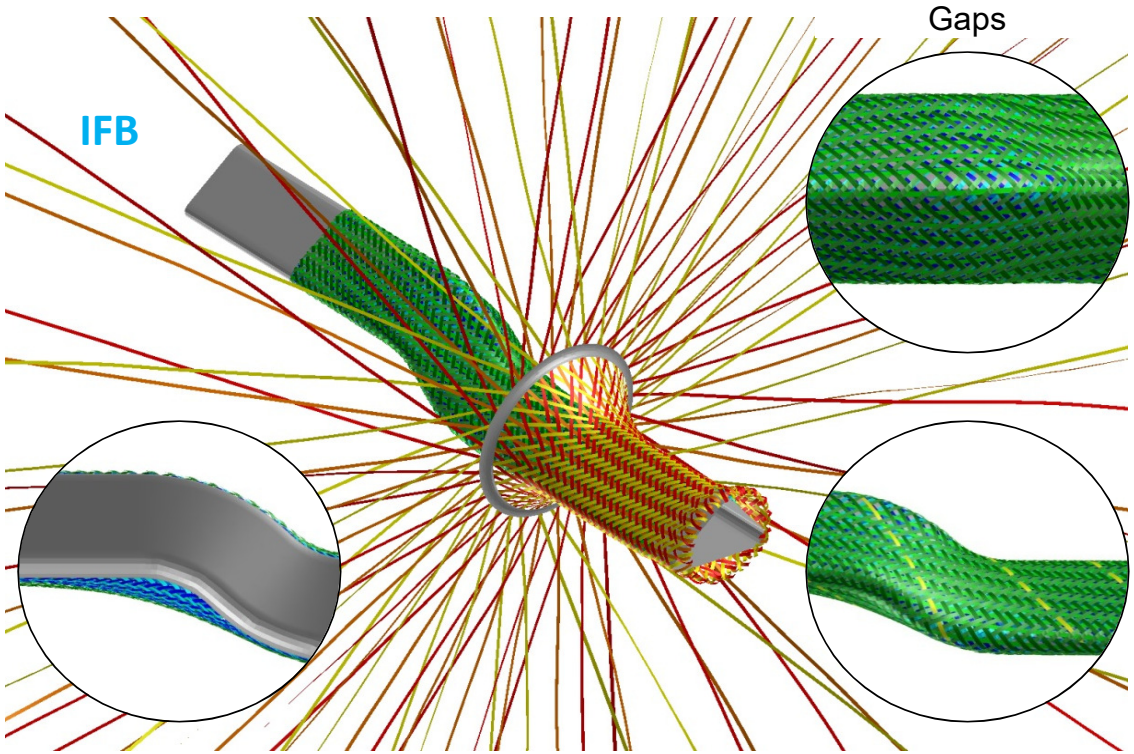
**Unit cell-Level**
(RVE – Infiltration)

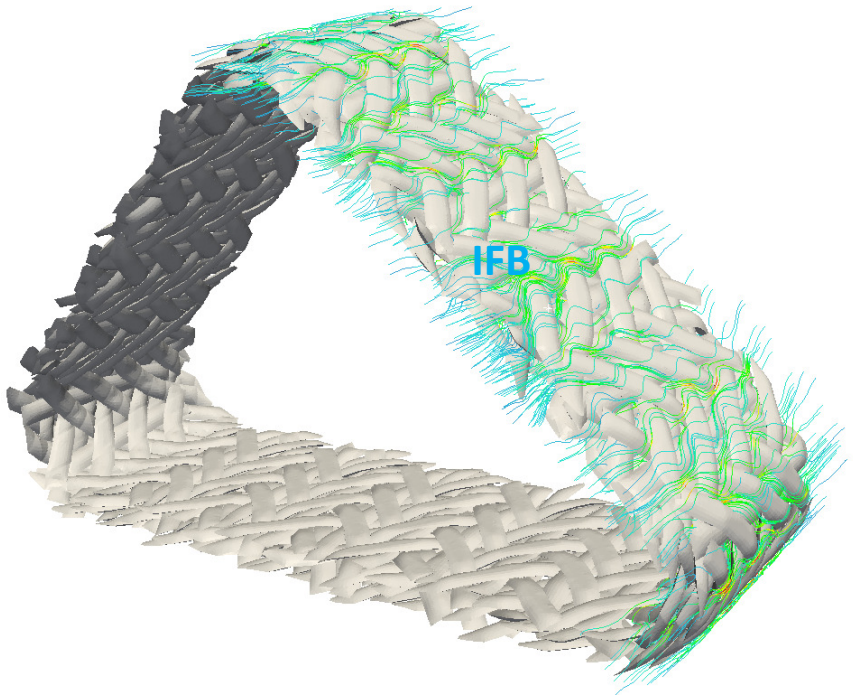
**Part-Level**
(Near-net-shape)

**PAM-CRASH**
**LS-DYNA**




Mesoscopic braiding simulation




Local fibre angle orientation

# THE PLAN

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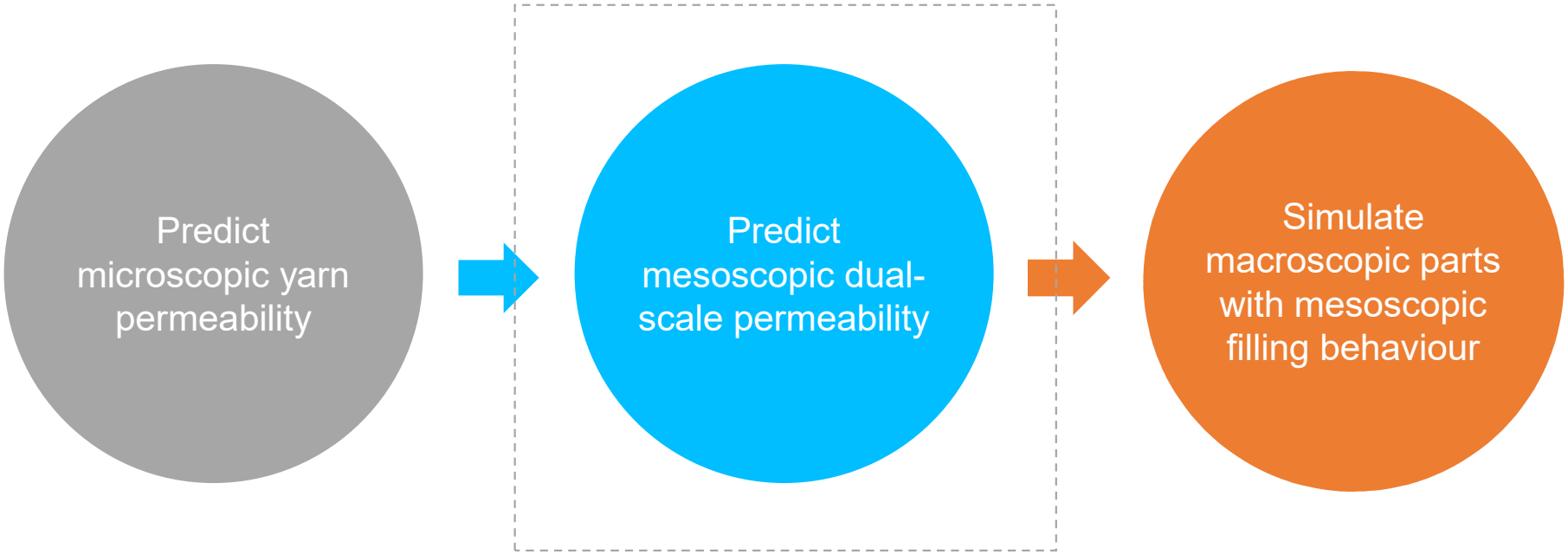
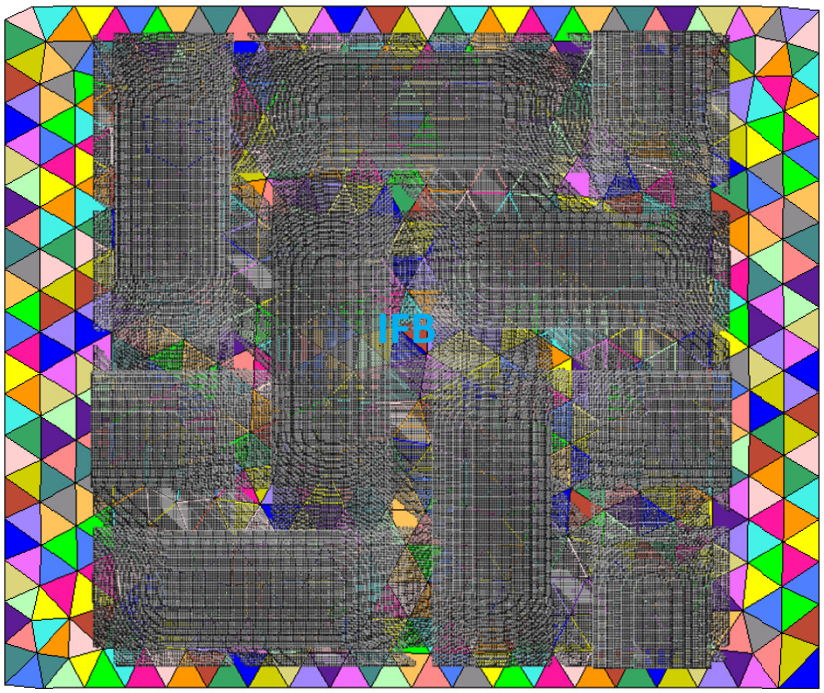
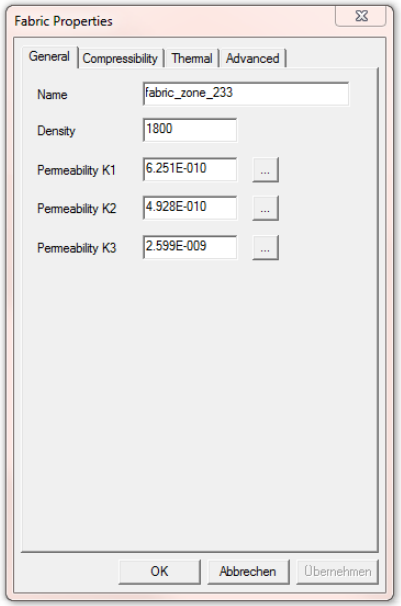


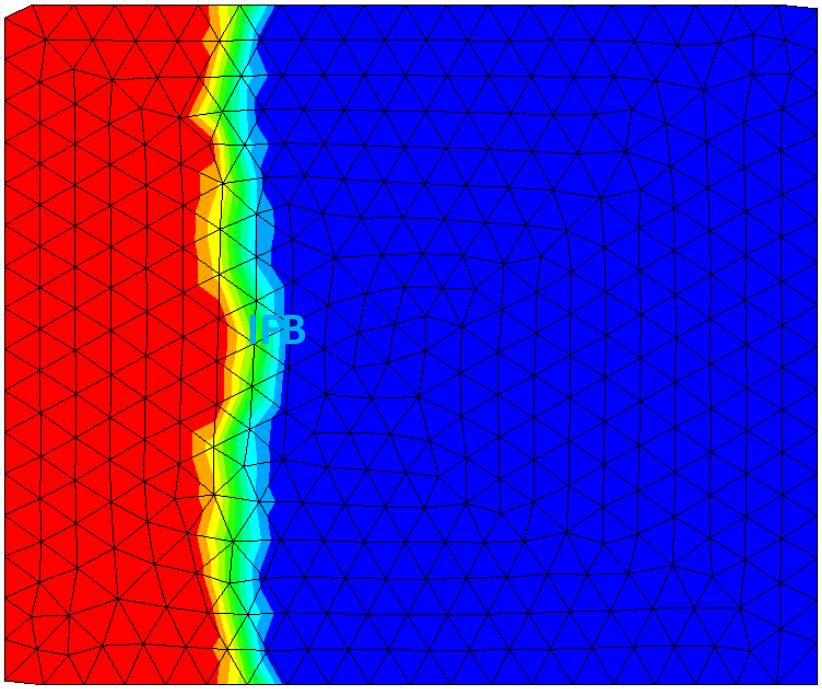
# NUMERICAL PERMEABILITY PREDICTION

ARENA2036

## MAPPING



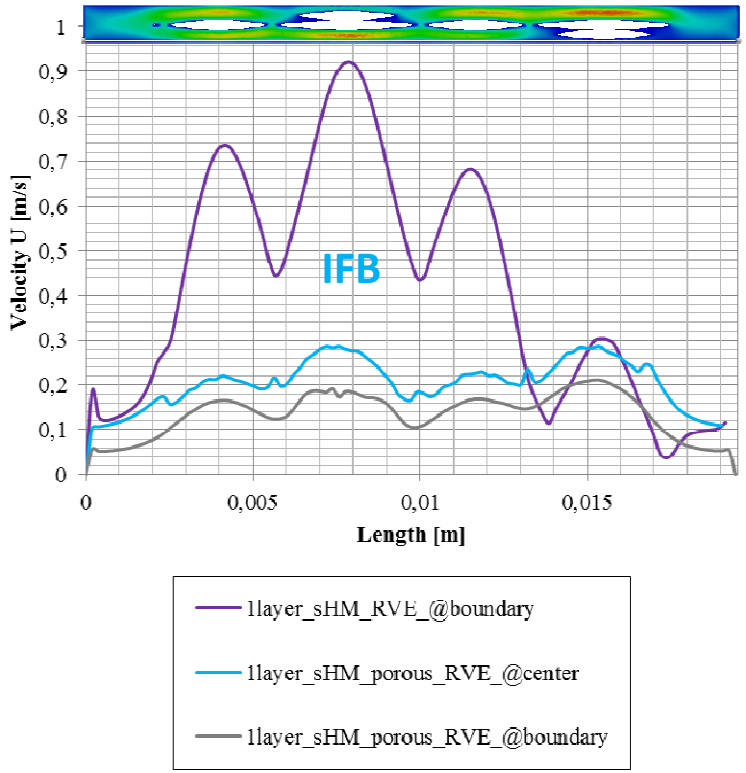



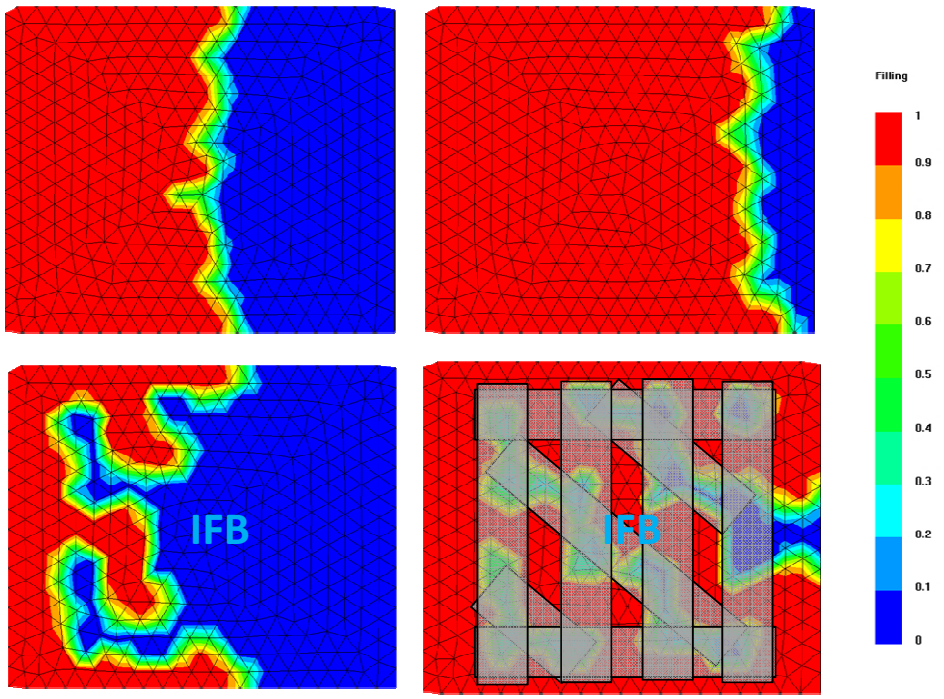

**Filling front, inlet variations, pressure field, etc. fast predictable & practicable**

# NUMERICAL PERMEABILITY PREDICTION

ARENA2036

## Effect of porous yarns in flow simulation



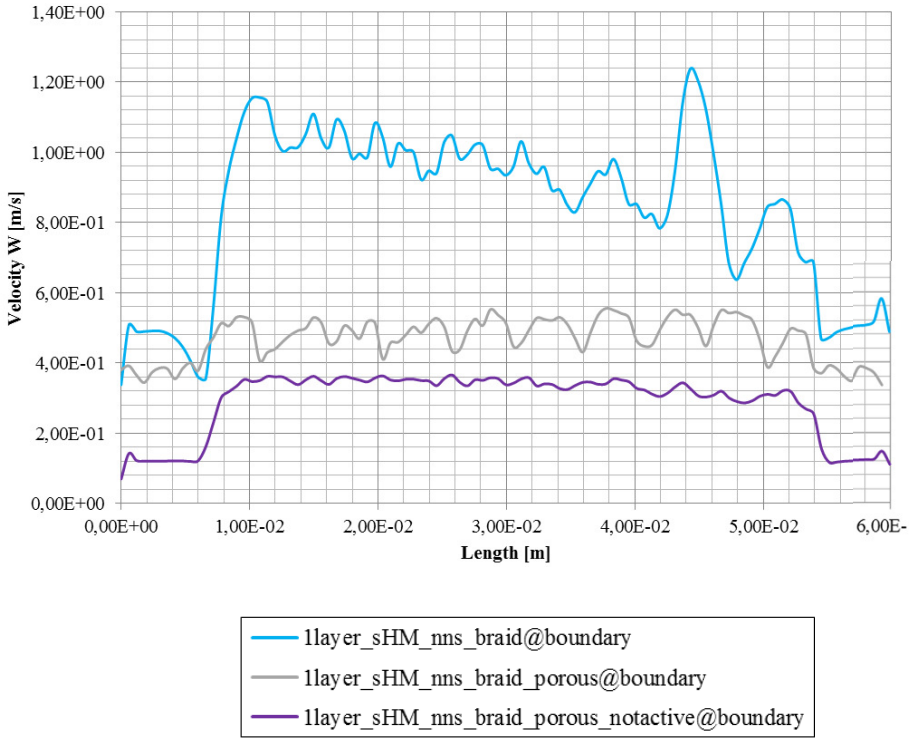




**A characteristic micro/meso simulation with a macroscopic mesh**

# NUMERICAL PERMEABILITY PREDICTION

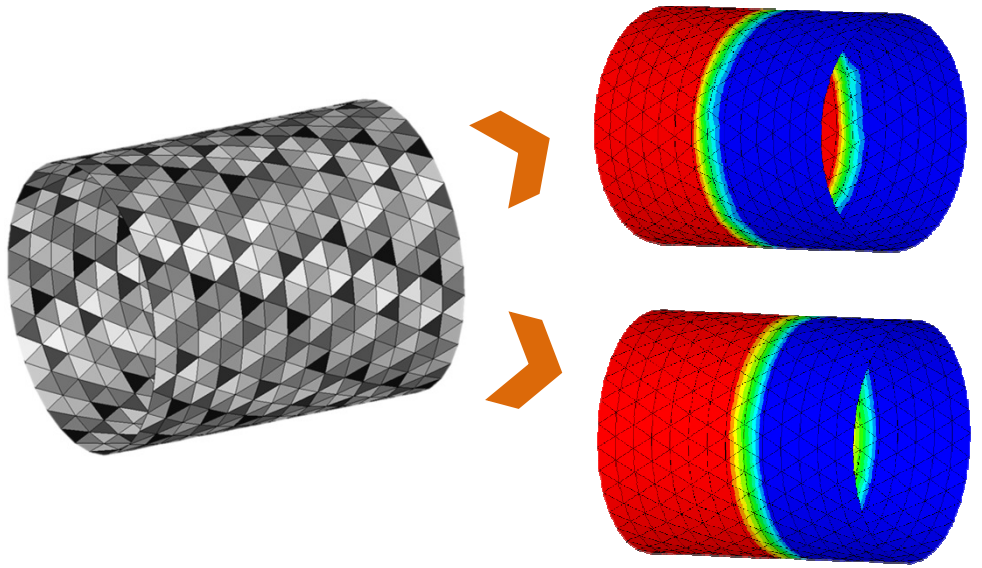
ARENA2036

## Effect of porous yarns in flow simulation



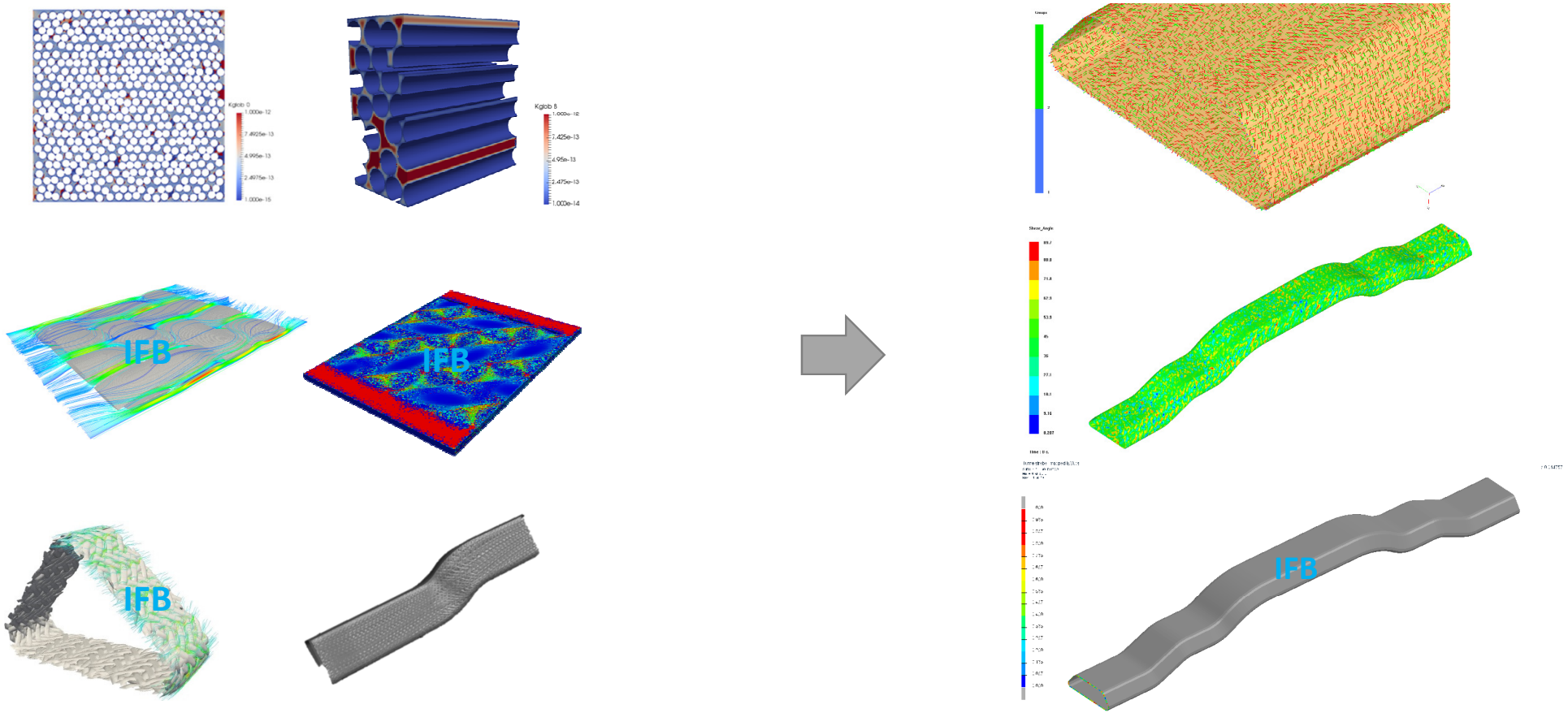

Mean permeability value:

- $\overline{K}_{1layer\_sHM\_nns\_braid}$ = 9.26e-8 $m^2$ (without porous yarns)
- $\overline{K}_{1layer\_sHM\_nns\_braid\_porous}$ = 1.41e-8 $m^2$ (with porous yarns)




**Porous yarns decrease the overall flow velocity and therfore the permeability values**

# AFTER DIGITPRO – NEW WAY OF FEM FILLING SIMULATION




J. Dittmann, S. Hügle, P. Middendorf. „NUMERICAL 3D PERMEABILITY PREDICTION USING COMPUTATIONAL FLUID DYNAMICS", FPCM13 Kyoto, Japan, 2016

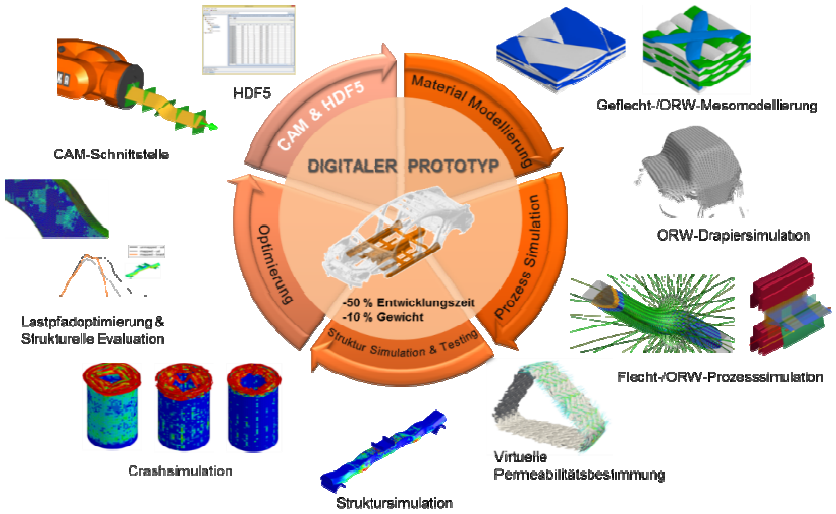
Dittmann, J., Hügle, S., Seif, P., Kauffmann L. and Middendorf, P., Permeability Prediction Using Porous Yarns in a Dual-Scale Simulation with Openfoam, ICCM21 - 21st International Conference on Composite Materials, Xi'an, China, Aug 2017

# OUTLOOK

## Improvements

- Transfer multi-scale approach to other processes (wet moulding, APP, TFP, Pultrusion)
- Handle simulation challenges (meshing, post-processing)
- Simulate void formation and void transport

ARENA2036




# ARENA2036 DigitPro

GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

FORSCHUNGS CAMPUS

öffentlich-private Partnerschaft für Innovationen

PTKA
Projektträger Karlsruhe
Karlsruher Institut für Technologie

**Dipl.-Ing. Jörg Dittmann**
dittmann@ifb.uni-stuttgart.de

Institut für Flugzeugbau
Universität Stuttgart
Pfaffenwaldring 31
70569 Stuttgart