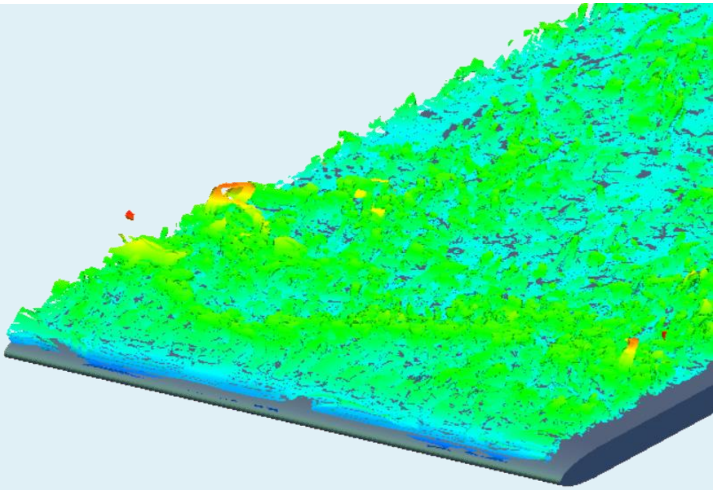


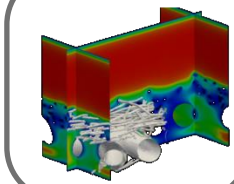
SIMULATION OF BOUNDARY LAYER FLOW OVER POROUS MEDIA WITH A LATTICE BOLTZMANN MODEL

Sonja Uphoff, Kostyantyn Kucher and Manfred Krafczyk, 10/01/2013

Überblick

Goal

simulation of turbulent flow over porous media



Methods

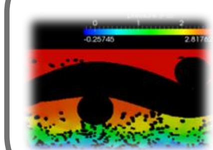
Lattice Boltzmann

$$M^{eq}_{x^l y^k z^l} = \mu^{eq}_{x^l y^k z^l} - \dots$$

Validation & Applications

Permeability, Tortuosity, Slip Coefficient

Turbulent boundary layer flow



Conclusions & Outlook

Porous Media

Groundwater flow, Stokes flow

Acoustics of porous media

(turbulent) boundary layer flow

Why pore-resolved simulations?

-> uncertainty of measurement methods

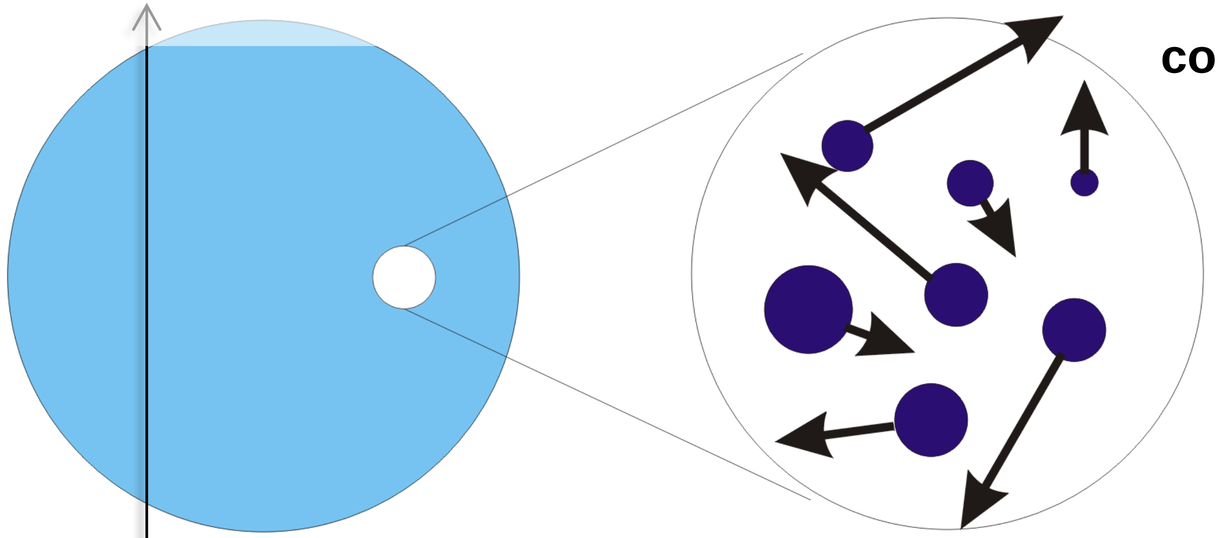
-> very low permeabilities

-> velocities at very small scales (e.g. in a turbulent boundary layer)

-> scaled models need calibration: VANS, Macroscopic acoustics models

Lattice-Boltzmann - Idea

Navier-Stokes (incompressible)



colliding particles

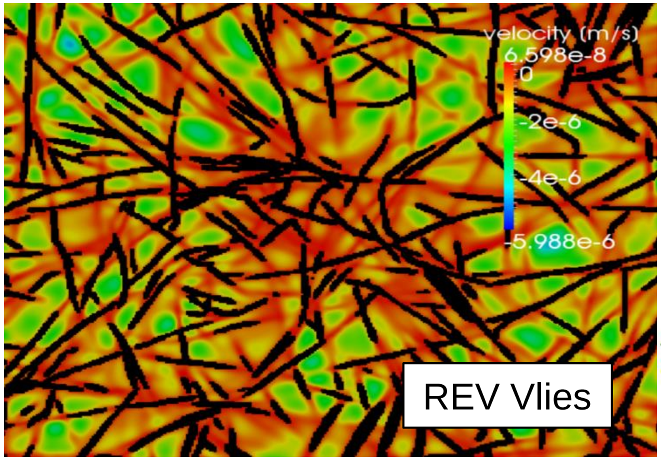
Stochastic description
Boltzmann-Equation

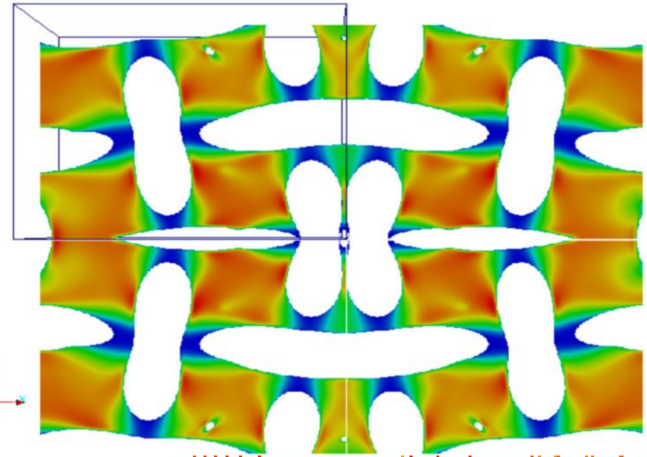
Small Mach- and
Knudsen numbers

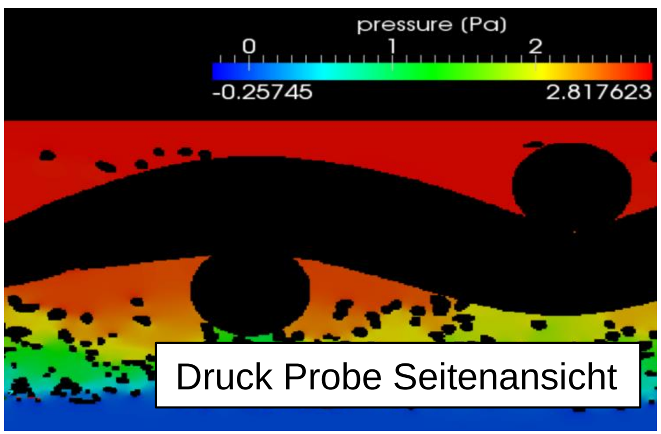
Linearized collision
discretization (velocity, space, time)

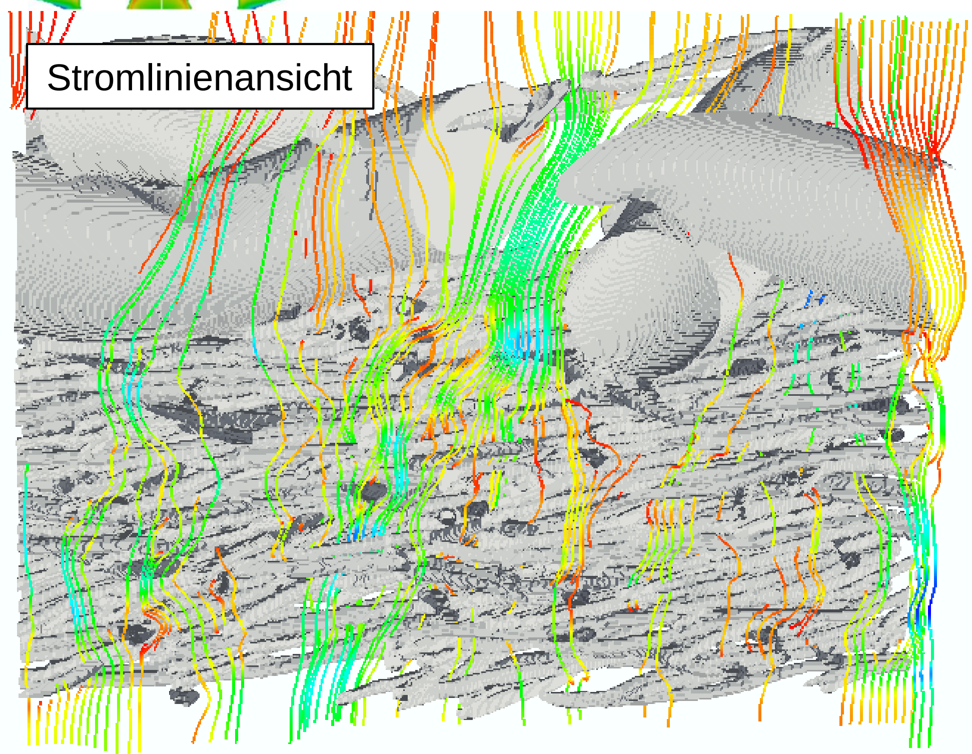
Lattice-Boltzmann-Equation

Permeability







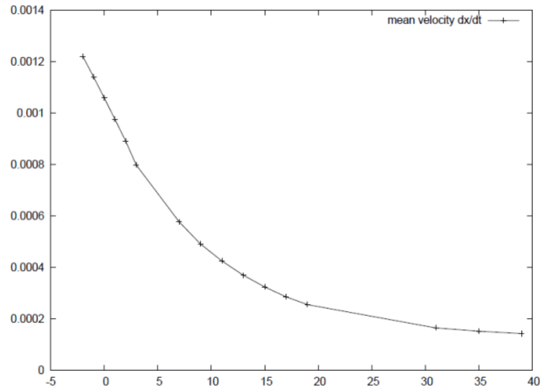


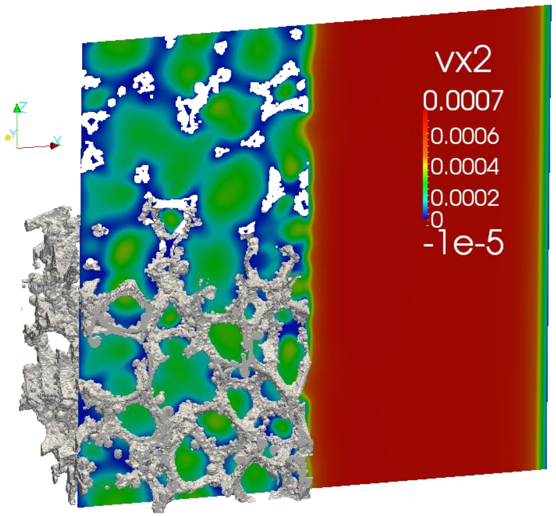
Permeability

Probe	Messung PTB	Simulation iRMB	Fehler [%]
Metal Sheet 1	2.51E+005	**2.20E+005**	-12.13
Metal Sheet 2	8.12E+005	**7.02E+005**	-13.47
Metal Sheet 3	3.66E+005	**3.70E+005**	1.27
Metal Sheet 4	9.42E+004	**1.47E+005**	56.12
Sintered Fibre Felt 40	6.37E+004	**7.37E+004**	15.79
Sintered Fibre Felt 120	3.14E+004	**3.09E+004**	-1.72
Sintered Fibre Felt 150	*1.89E+04*	**1.99E+004**	4.97
Sintered Fibre Felt 100	*5.70E+04*	**3.50E+004**	62.73
Sintered Fibre Felt 3 (based on simulations of individual layers)	*3.71E006*	**2.4E+006**	54.64
Metal Foam 450	1.10E+004	**9.59E+003**	15.01

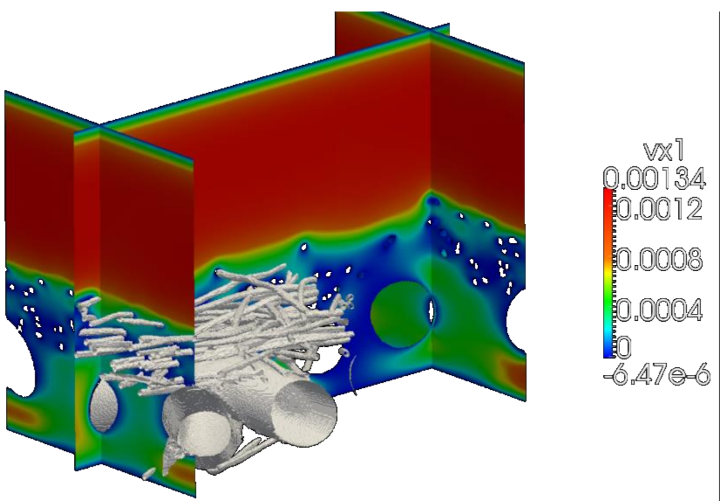
Slip Coeffizienten/Strukturfaktor Poröse Medien

- Messe Ableitung der Geschwindigkeit in Normalenrichtung
- Bestimme slip-coeffizienten α über
- $\frac{\partial ux}{\partial y}_{Interface} = \beta \left(u_{Interface} - u_{Darcy}\right)$
- $\alpha = \beta \sqrt{K_{parallel}}$





Material	alpha	+/-
Felt 3	0.66	0.03
Metal 450	1.29	0.04
Felt 150	0.7	0.15 -> multi-layered material, conceptional difficulties

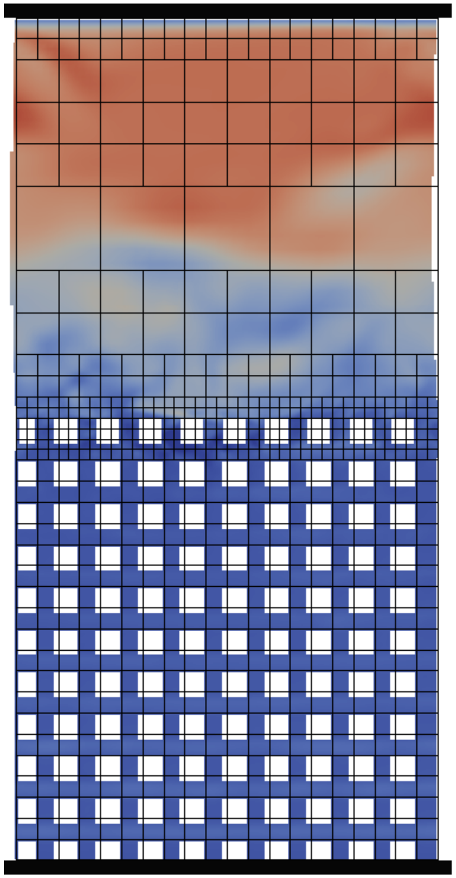


Turbulente Kanalströmung mit permeabler Wand - Setup

Re=5500 bezogen auf halbe Kanalhöhe H
und Kanalmitten-Geschwindigkeit
Porosität=0.875
LB Modell: CCLB
20 dx pro Würfel → $y^+=1$
4 Level

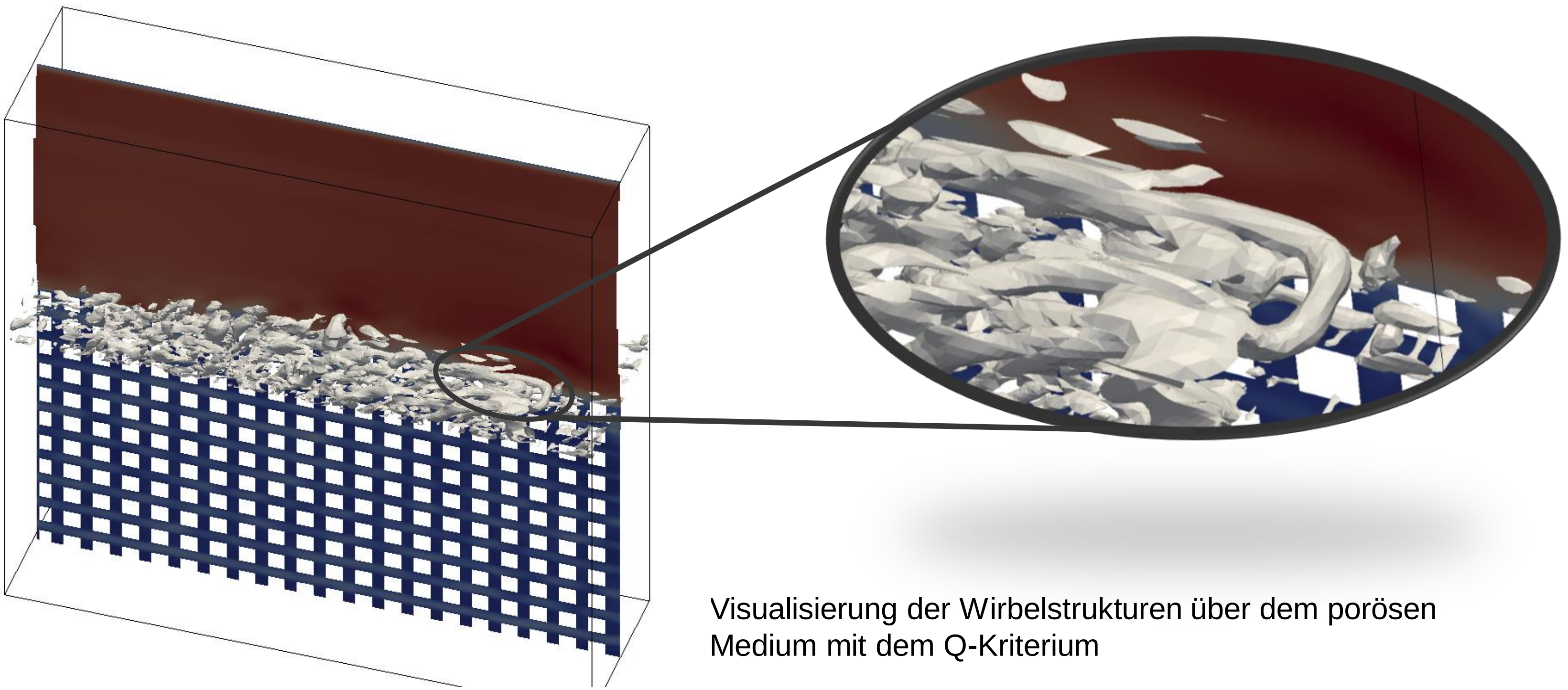
Vorläufiges Setup:
Gebietsabmessungen: 2H x H x H
5Mio Knoten

Entgültiges Setup
Gebietsabmessungen: 2H x 3H x 5H
75Mio Knoten



Numerisches Gitter, jeder Block enthält 9^3 Knoten

Turbulente Kanalströmung mit permeabler Wand



Visualisierung der Wirbelstrukturen über dem porösen Medium mit dem Q-Kriterium

DNS Data:
Phys. Fluids **17**, 025103 (2005); http://dx.doi.org/10.1063/1.1835771
Direct numerical simulations of turbulent flow over a permeable wall using a direct and a continuum approach,
W. P. Breugem and B. J. Boersma

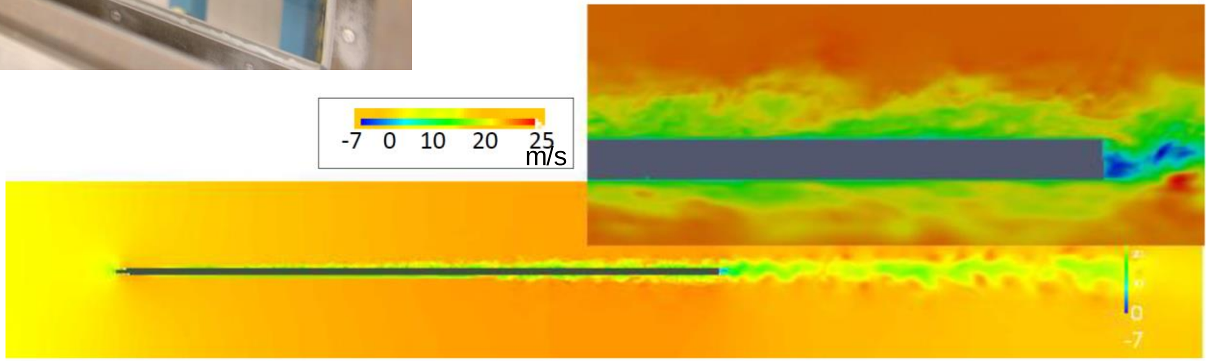
VANS Method to be used for Comparison:
M. Mössner, R. Radespiel, Simulating flow over Porous media Using Volume Averaged Navier Stokes Equations
SFB 880 – Biennial Report

Developing turbulent boundary layer

Experimental setup

Flow around a flat plate:
Experimental results by M. Mösner, TU Braunschweig

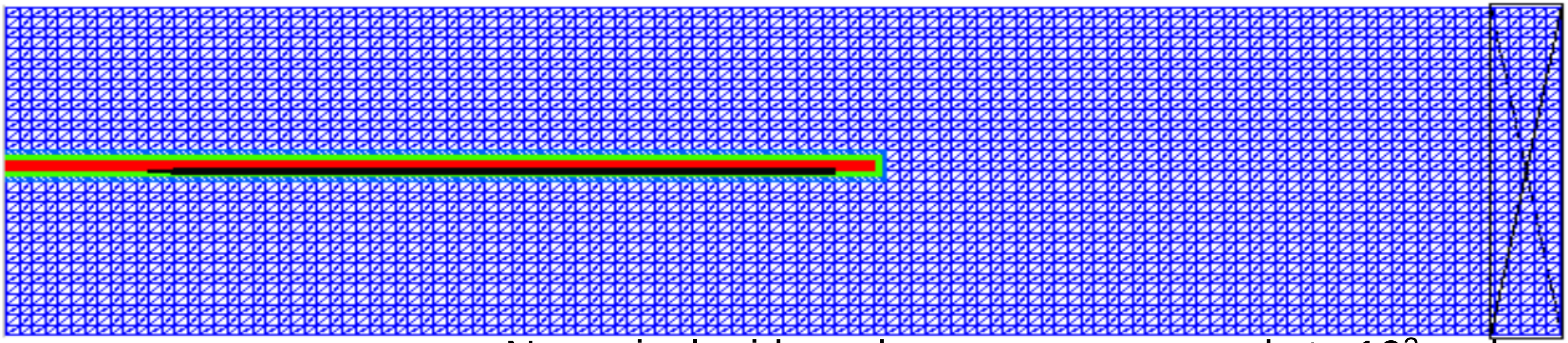
Rigged ribbon on upper side leads to rapid development of turbulent boundary layer



Simulated velocity field

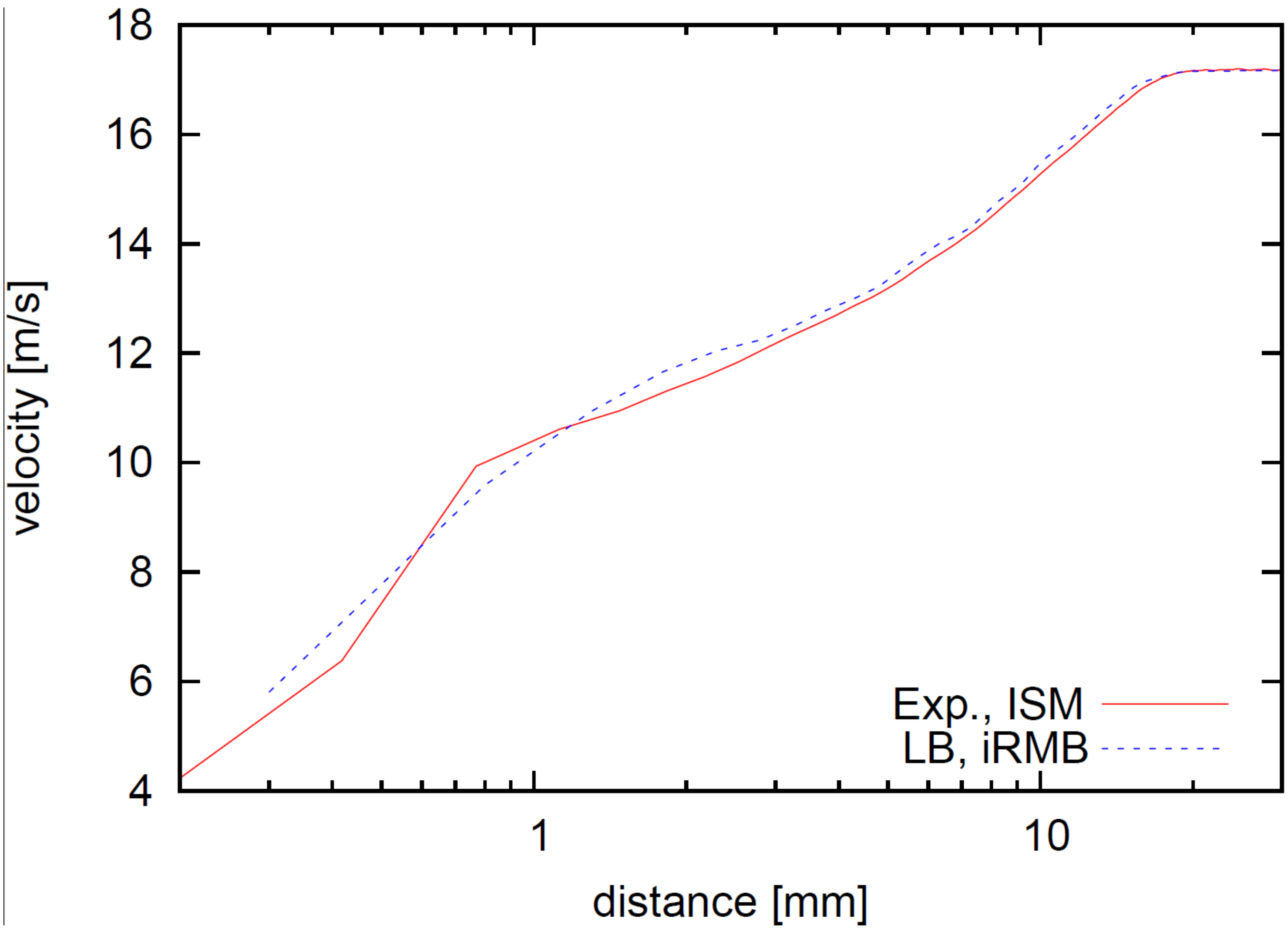
Developing turbulent boundary layer - Setup

Parameter	value
Re	$1.13 \cdot 10^6$
u_{in}	$17m/s$
Δx_{fine}	$0.000234283m$
Δt_{fine}	$3.98e-7s$
Level	4
domain length (x)	$2.25m$
domain width (y)	$0.0825m$
domain height (z)	$0.6m$
length of the plate	$1m$
number of nodes	235 Mio
Smagorinsky constant	$0.17 - 0.18$

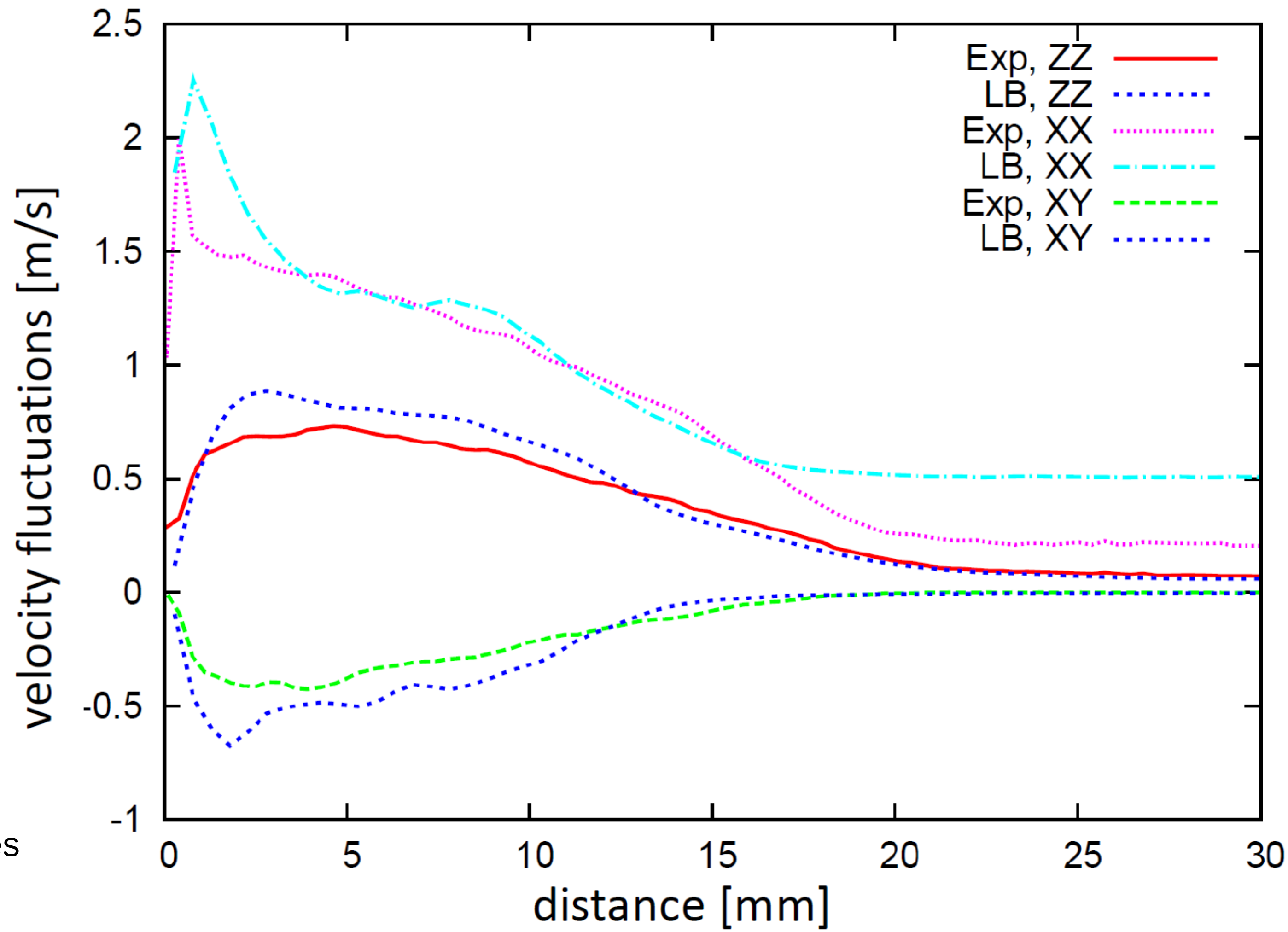


Numerical grid, each square corresponds to 10^3 nodes

Boundary layer – <Vx>



Boundary layer – RMS Values



Deviation LB, XX:
influence of pressure waves

Conclusions

Lattice Boltzmann can be used for pore resolved simulations of porous media
-> input parameters for macroscopic models

- Permeability
- Tortuosity
- Slip coefficient

- Simulation of turbulent flow over porous media
- Simulation of a developing boundary layer

> Outlook: determine triple correlations for calibration of Reynolds stress models