Presented at the COMSOL Conference 2010 Paris

Analysis of particle trajectories for magnetic drug targeting

Alexandra Heidsieck, Bernhard Gleich

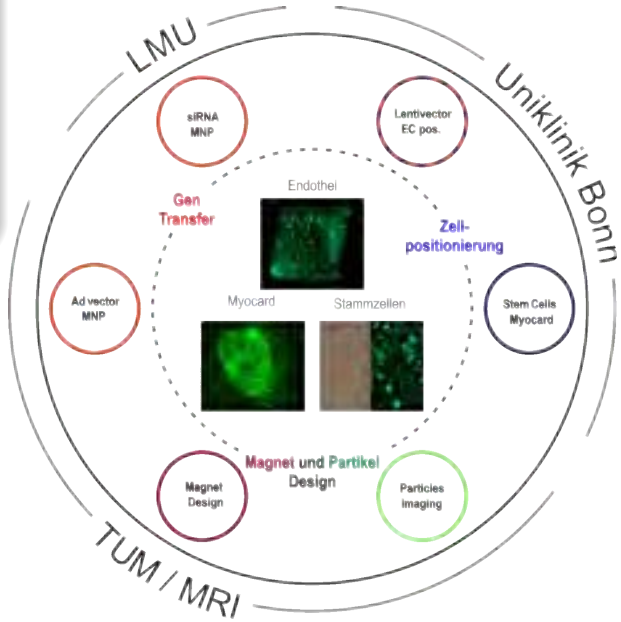
Deutsche Forschungsgemeinschaft DFG

Overview

Nanoguide

Goals

- Magnetic labeling of cells and viral vectors with magnetic nanoparticles
- Targeted transfer of genetic material in the cardiovascular system
- Accumulation of the labeled material in blood vessels and the heart



Nanoguide

Optimized field sources

- Homogeneous distribution of particles in artery
- Accumulation of particles in a certain region

➡ Prediction and manipulation of particle trajectories

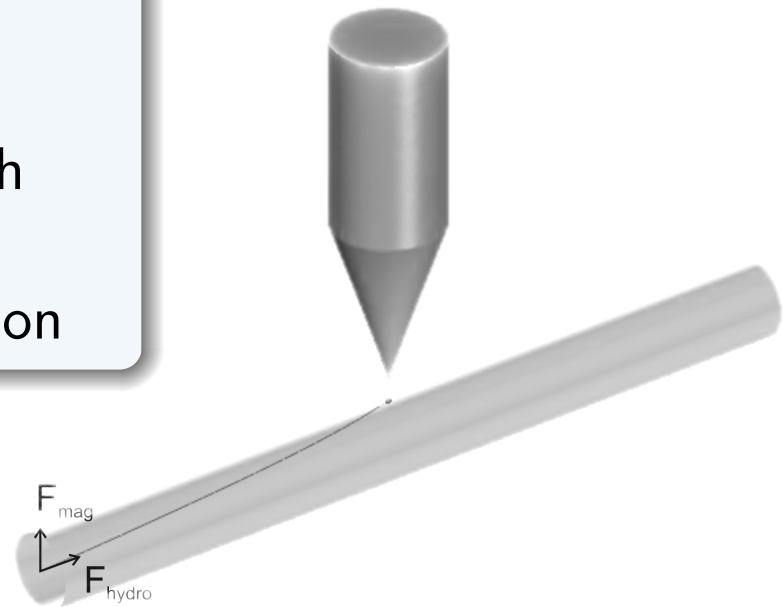
Theory

Forces on the particles

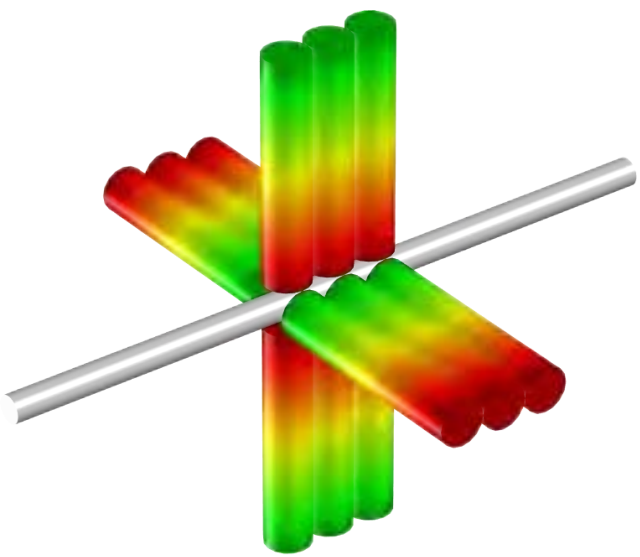
- Magnetic force ($\propto \nabla|B|$)
- Hydrodynamic force (Stokes Law)
- Minor forces (e.g. gravitation, avalanche effect, . . .)

➡ Major forces can be calculated with Comsol

➡ Algorithm for the equation of motion



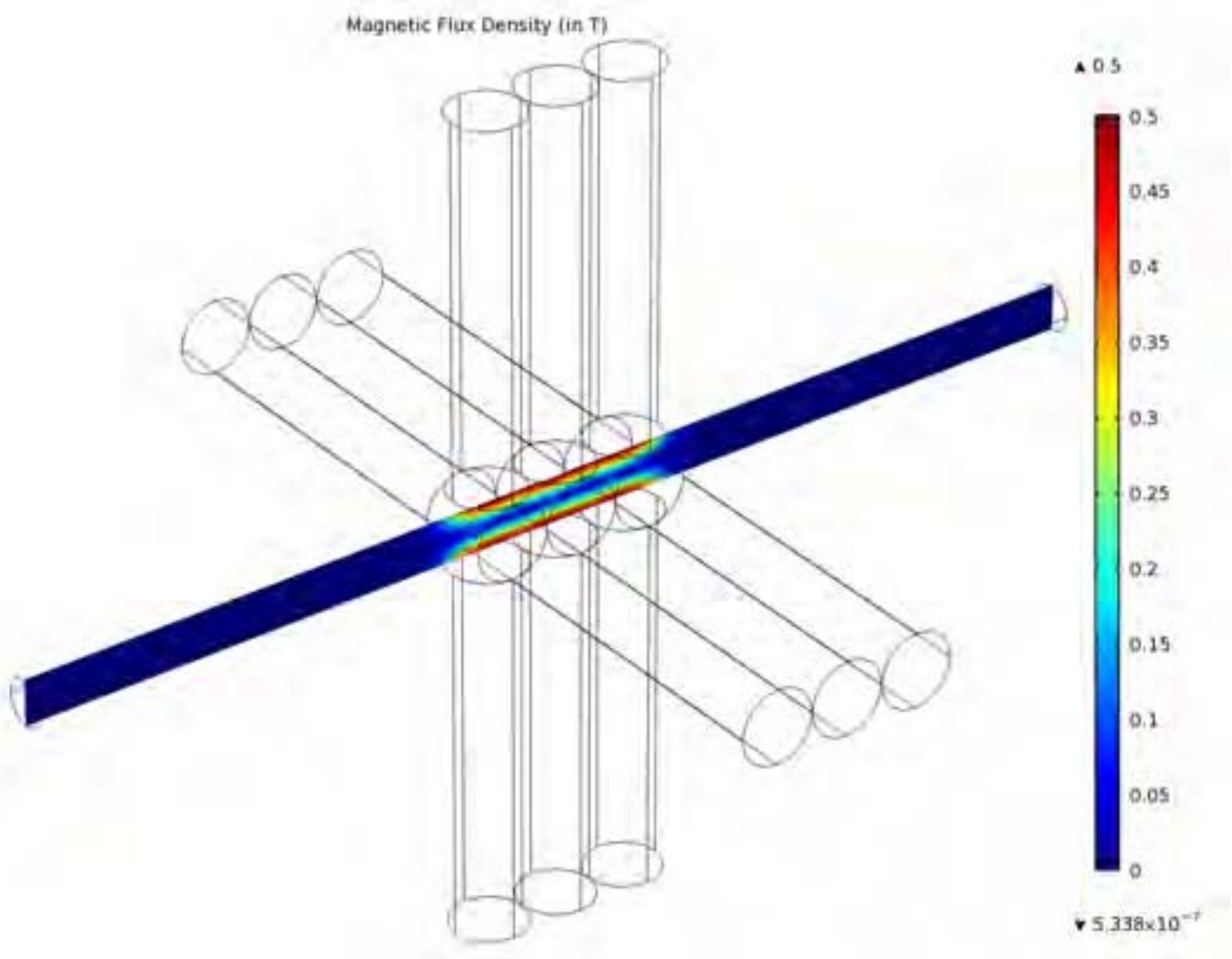
Homogeneous distribution of particles



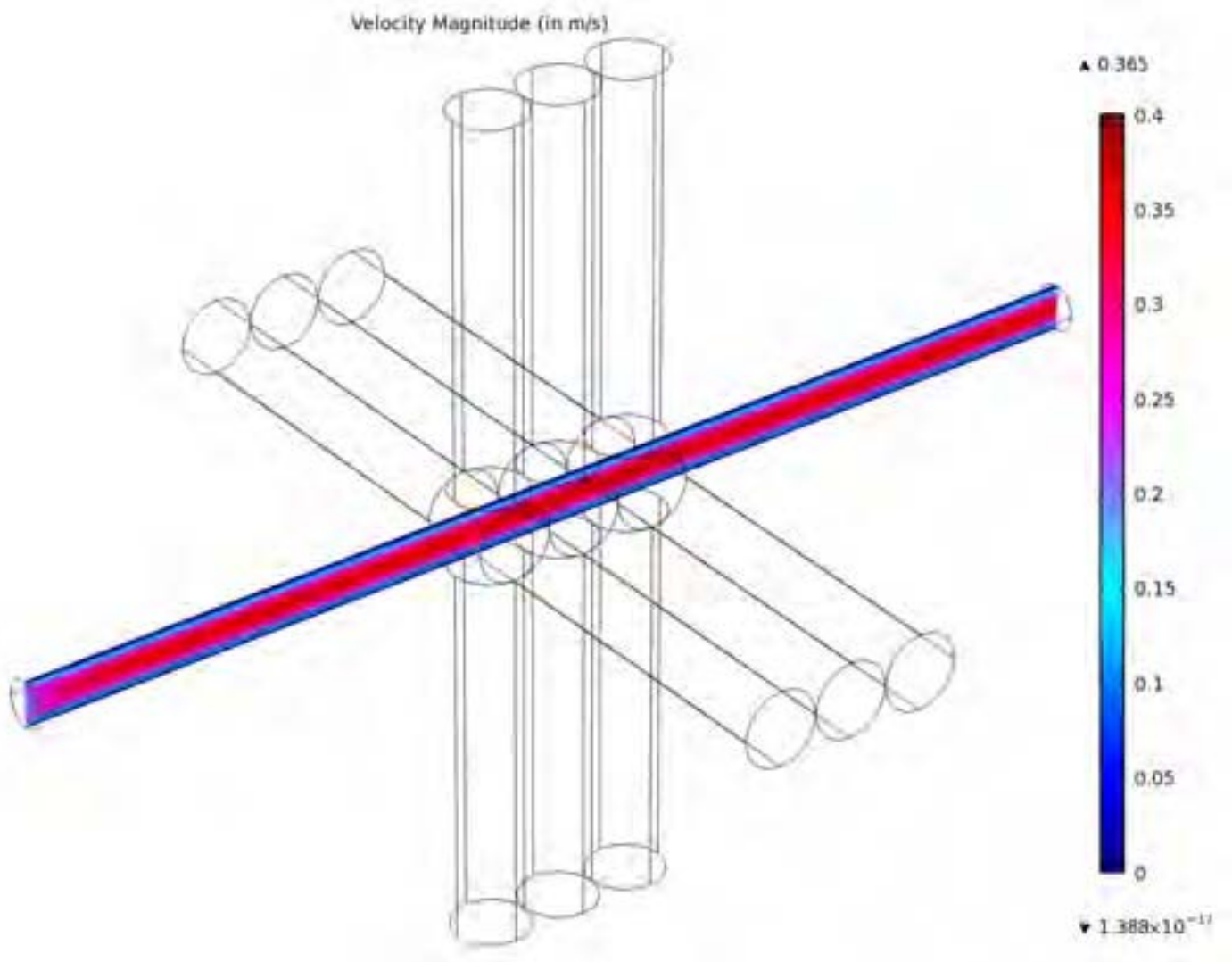
Geometry

- Mouse aorta
- Surrounded by four groups of three magnets
- Laminar inflow, constant outlet pressure
- Non-newtonian fluid (Carreau Model)

Magnetostatics



Fluiddynamics



Particle Trajectories

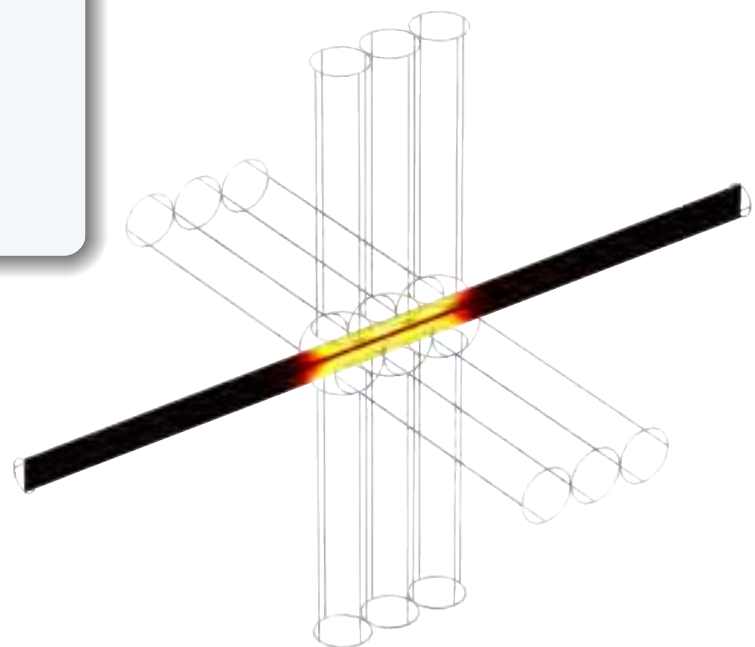
Problems with Comsol

- Gradient on the mesh
- Stiff differential equation
- No “random“ parameters

Processing in Matlab

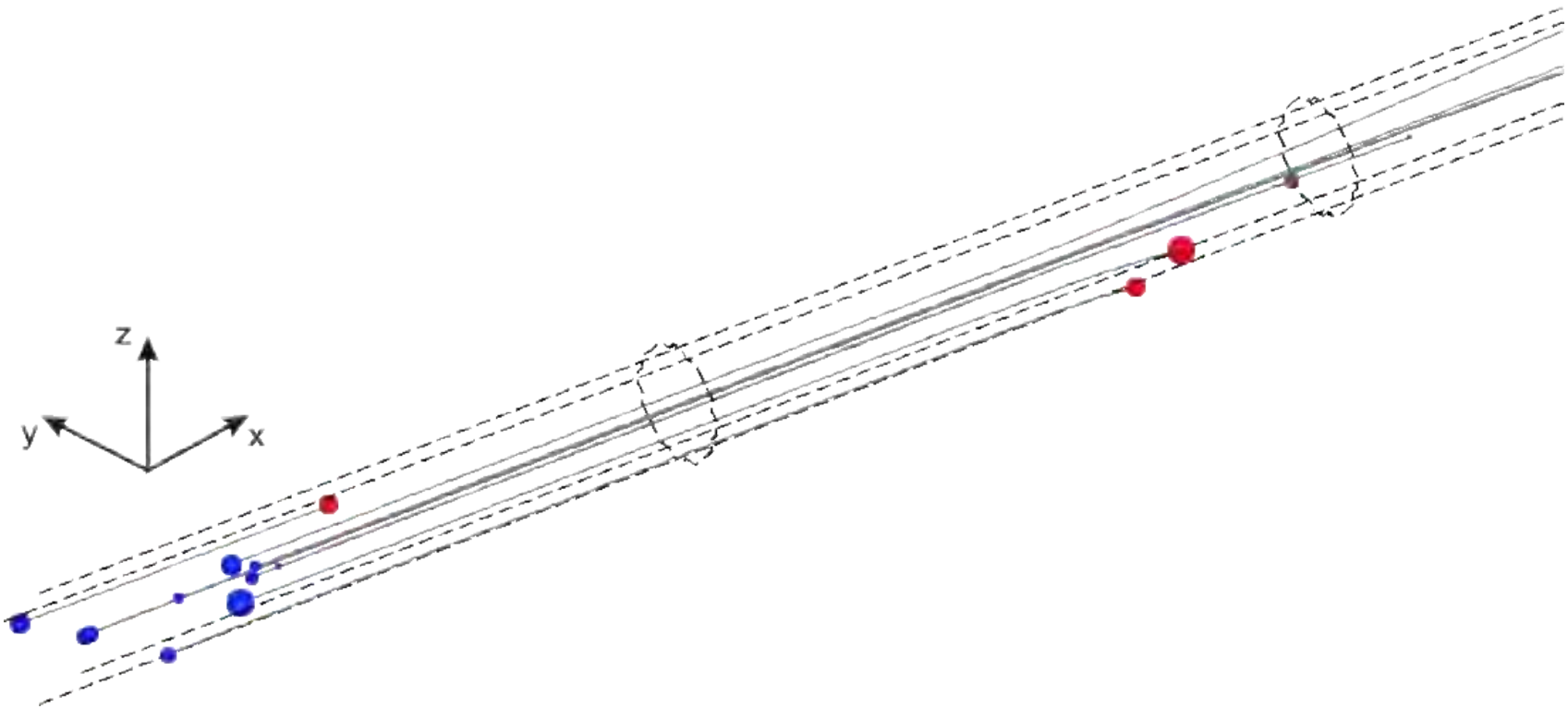
Matlab

- Export into Matlab
- Spline interpolation of the magnetic and fluidic fields
- Gradient on the Spline
- Generating particle properties
- Solving the differential equation

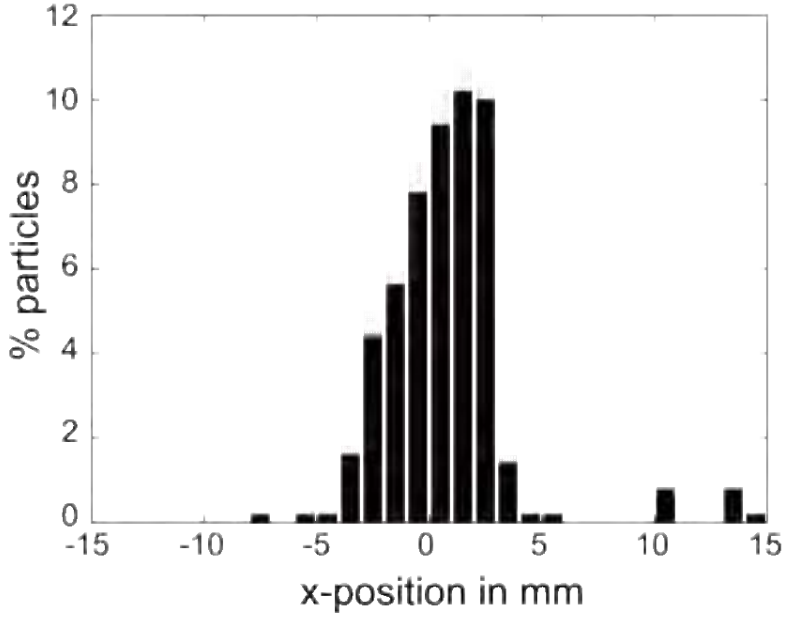


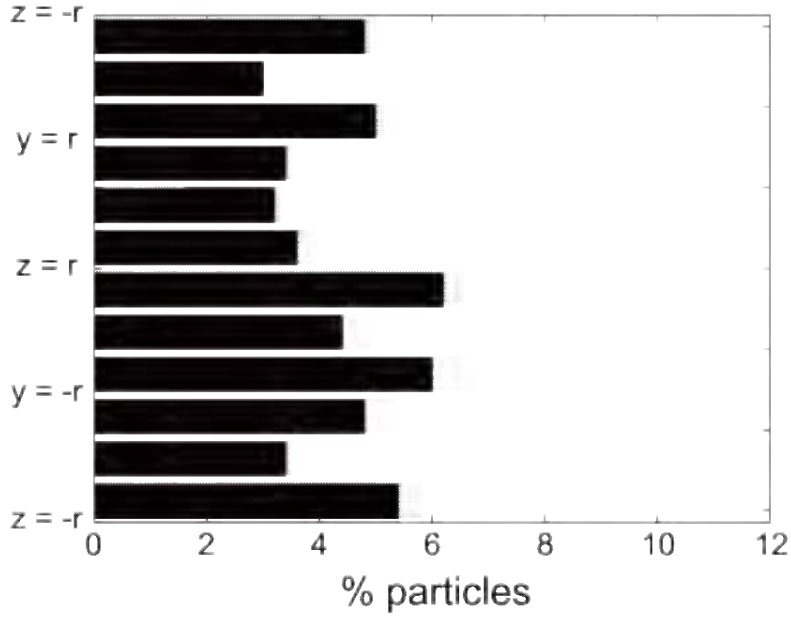
Particle Trajectories

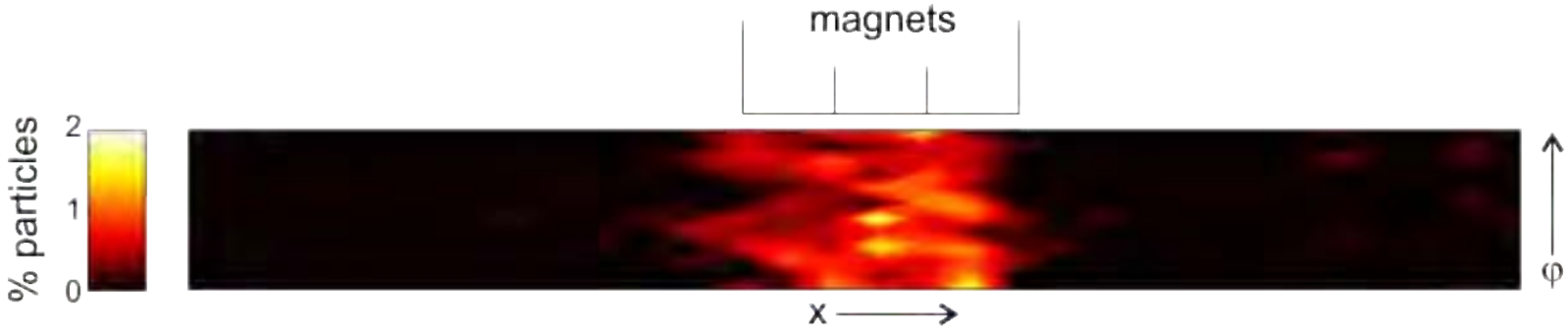
Exemplary trajectories of ten particles



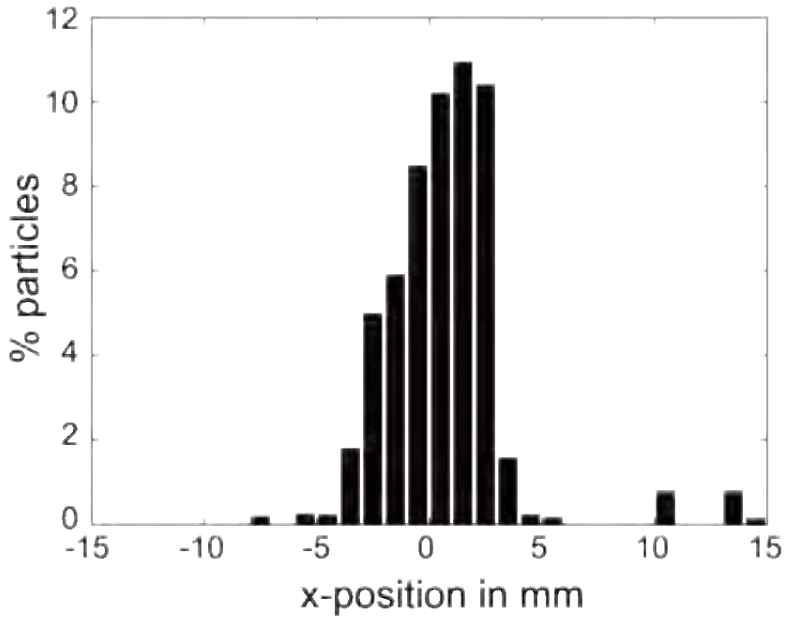
Particle Distribution

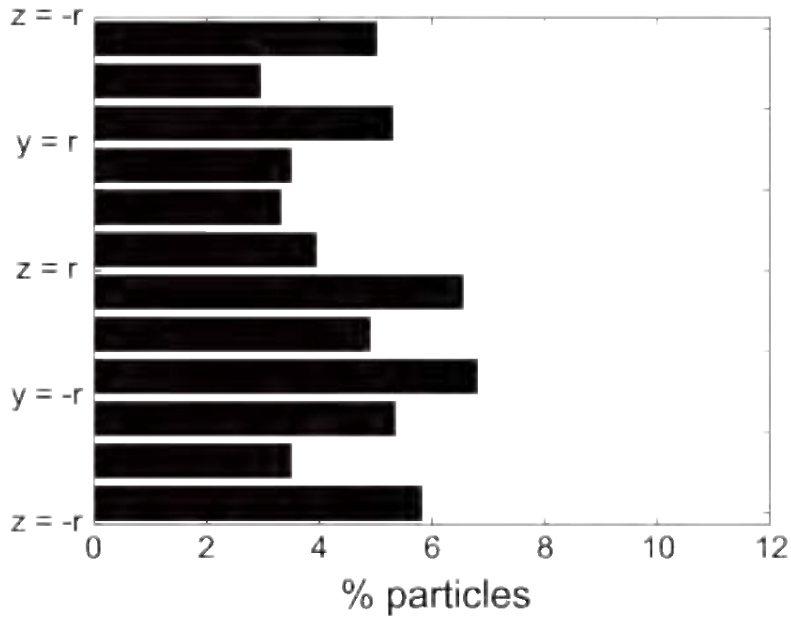


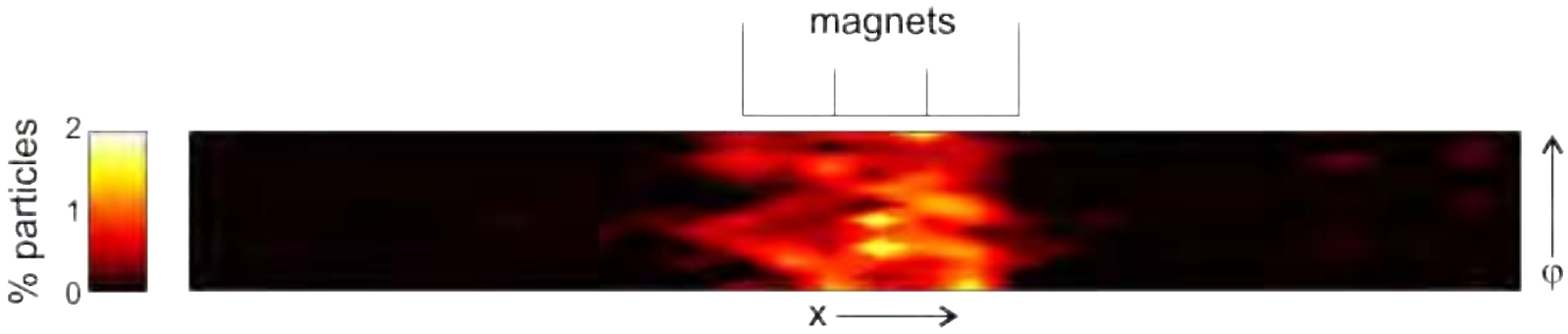




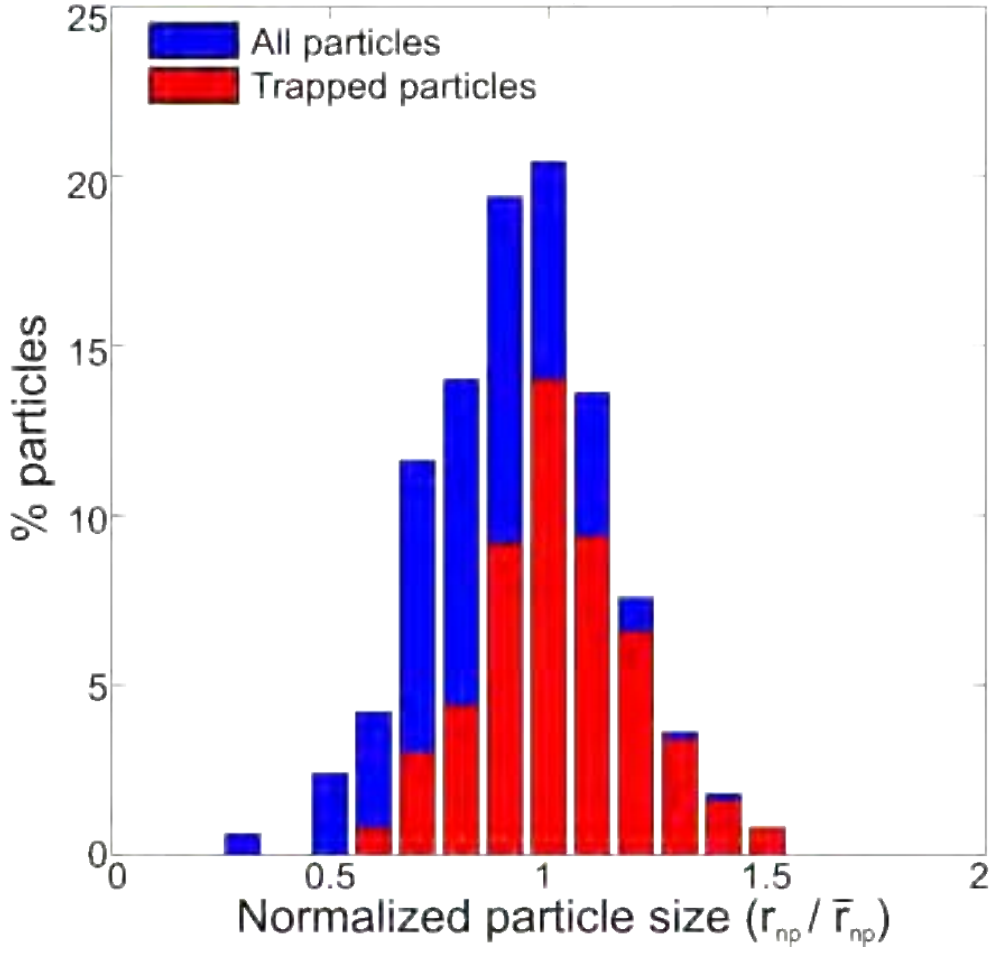
Particle Distribution (weighted by diameter)



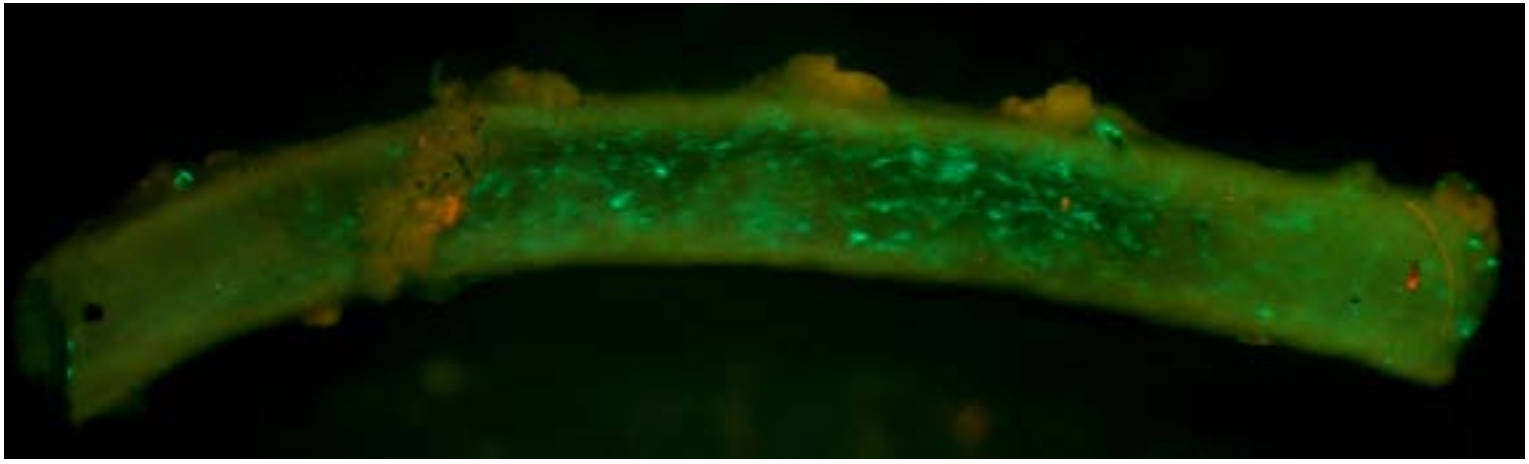




Size Distribution



Experimental Results

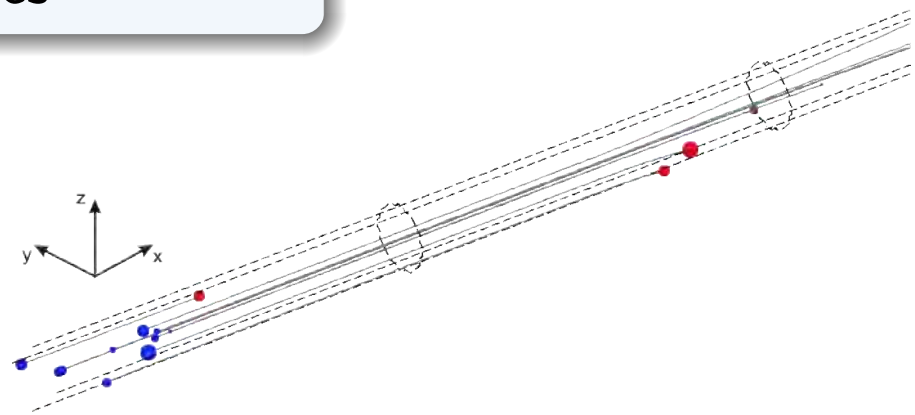


Experimental data by D. Wenzel, Universität Bonn

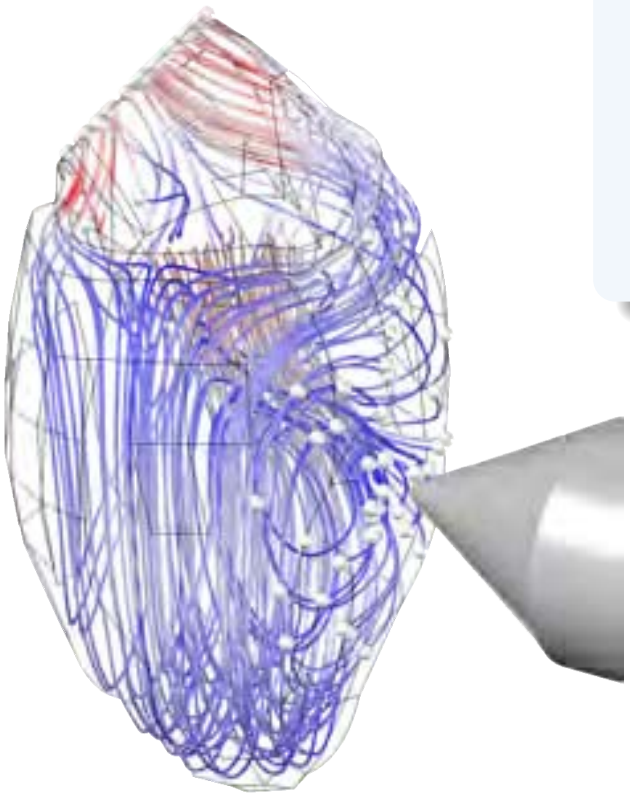
Conclusion

Conclusion

- Successful simulation of particle trajectories
- Possible to find the optimal particle types
- Design of adequate field sources



Outlook



Outlook

- Minor forces
- Magnetisation of particles
- Fluid-structure interaction
- More complicated geometries

The End

Thank You for Your Attention!

Properties

- $v_{in} = 0.2$ m/s
- $\overline{d}_{np} = 100$ nm
- $\overline{m}_{np} = 2 \cdot 10^{-19}$ kg
- $\overline{\mu}_{np} = 5 \cdot 10^{-13}$ Am^2

- $m\dot{\vec{v}} = \mu \nabla B + 6\pi\eta(\dot{\gamma}) r_{np}(\vec{u} - \vec{v}) - m\vec{g}$
- $\eta(\dot{\gamma}) = \eta_\infty + (\eta_0 - \eta_\infty) \cdot \left(1 + (\lambda\dot{\gamma})^2\right)^{n-1/2}$

References

Christoph Alexiou, Wolfgang Arnold, Roswitha J Klein, Fritz G Parak, Peter Hulin, Christian Bergemann, Wolf Erhardt, S Wagenpfeil, and Andreas S Luebbe.
Locoregional cancer treatment with magnetic drug targeting.
Cancer Research, 60:6641–6648, 2000.

Christoph Alexiou, R Jurgons, R Schmid, A Hilpert, Christian Bergemann, Fritz G Parak, and H Iro.
In vitro and in vivo investigations of targeted chemotherapy with magnetic nanoparticles.
J. Magn. Mater., 293:389–393, 2005.

Petra Dames, Bernhard Gleich, Andreas Flemmer, Kerstin Hajek, Nicole Seidl, Frank Wiekhorst, Dietmar Eberbeck, Iris Bittmann, Christian Bergemann, Thomas Weyh, Lutz Trahms, Joseph Rosenecker, and Carsten Rudolph.
Targeted delivery of magnetic aerosol droplets to the lung.
Nature Nanotechnology, 2:495–499, 2007.

Bernhard Gleich, Thomas Weyh, and Bernhard Wolf.
Magnetic Drug Targeting: An Analytical Model for the Influence of Blood Properties on Particle Trajectories.
Applied Rheology, 18(5):1–7, 2008.

S. S. Shibeshi and W. E. Collins.
The Rheology of Blood Flow in a Branched Arterial System.
Applied Rheology, 6:398–405, 2005.