Design of a High Field Gradient Electromagnet for Magnetic Drug Delivery to a Mouse Brain

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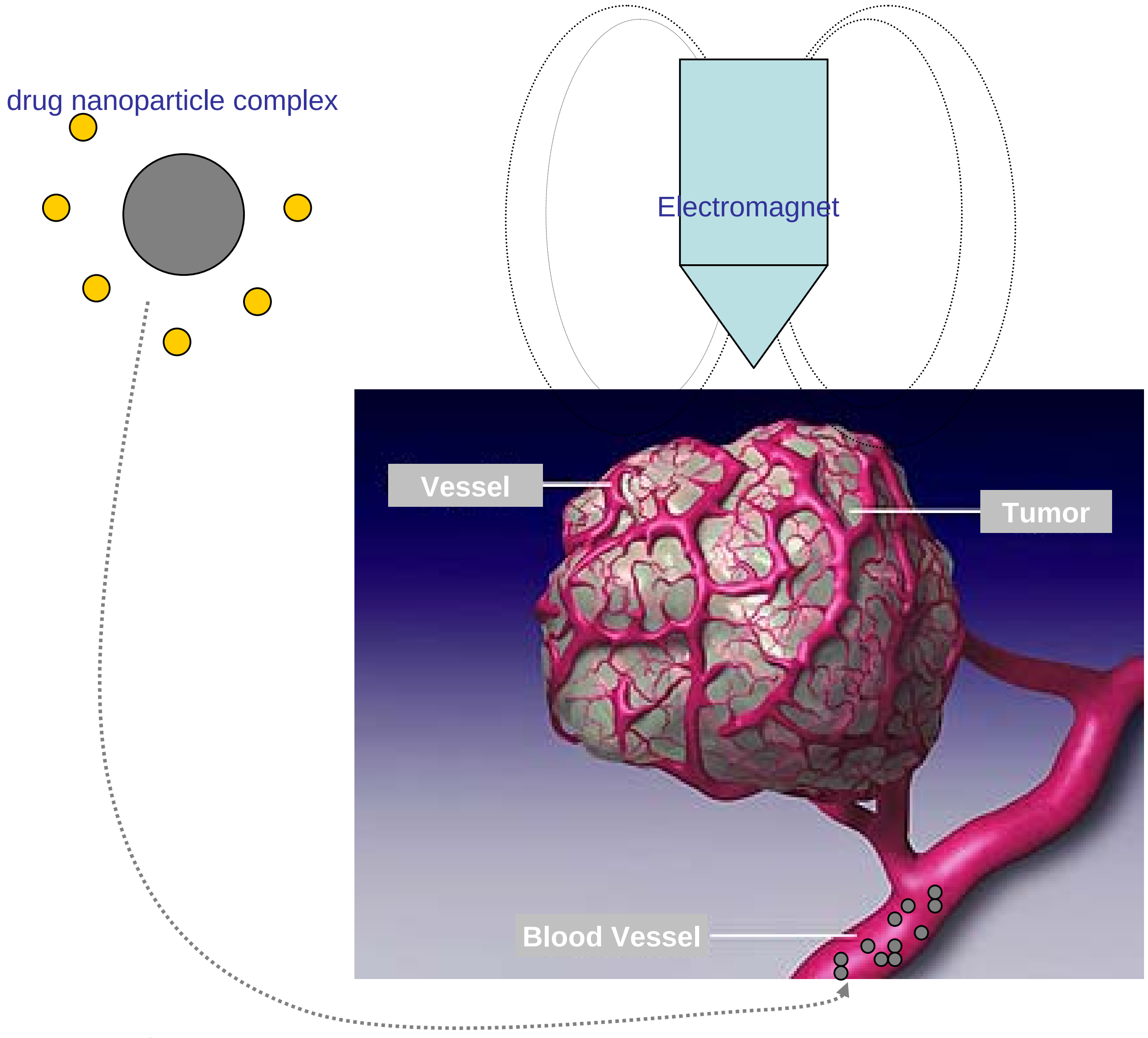
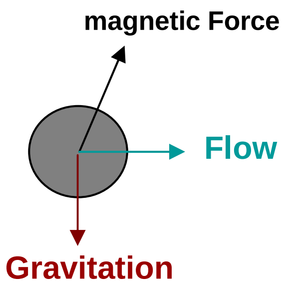
Principle of Magnetic Drug Targeting

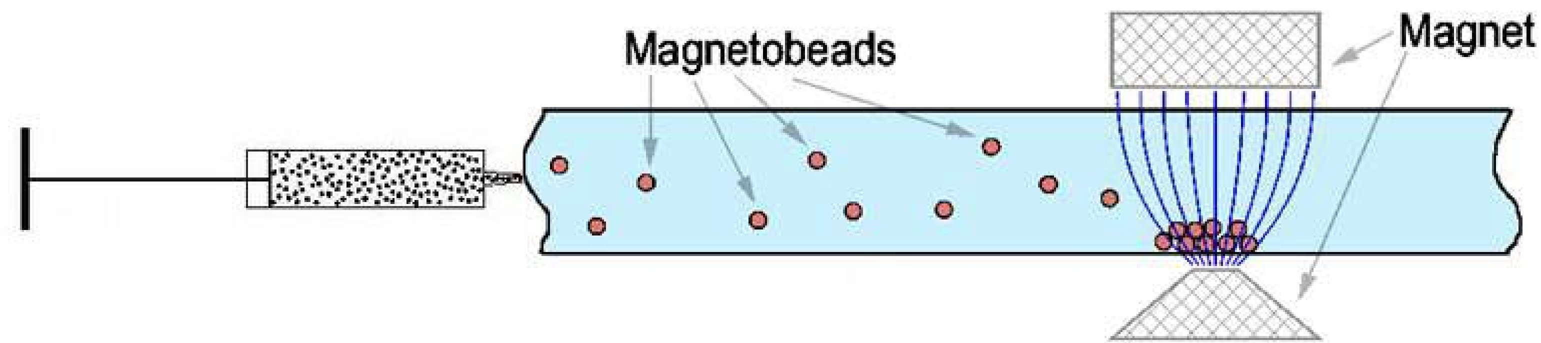


Principle of Magnetic Drug Targeting

F = m x B



→ The magnetic force acting on the nanoparticles depends on its magnetic moment and the gradient of the magnetic field



- Precise targeting of unhealthy tissue (tumor) → increase in therapy efficiency
- Reduction of side effects

The issue

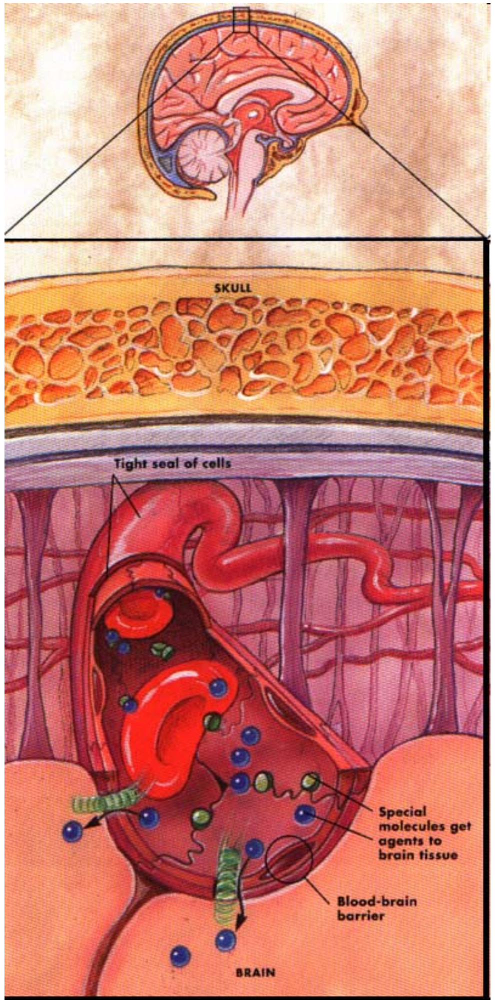
The blood brain barrier is both a physical barrier and a system of cellular transport mechanisms.

It maintains certain inner concentrations by:

- restricting the entrances of potentially harmful chemicals from the blood

- allowing the entrance of essential nutrients

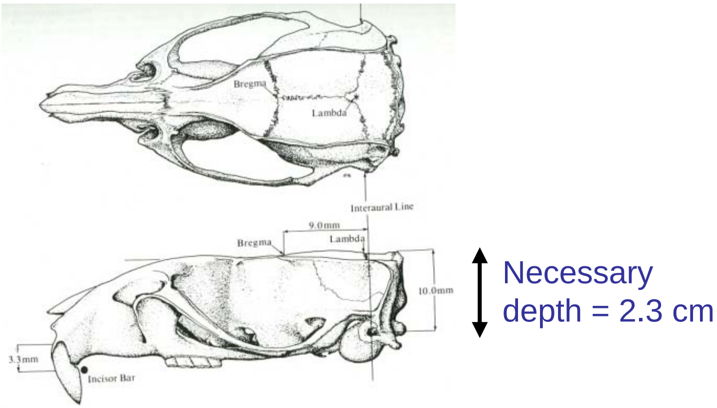
→ Protection of the brain

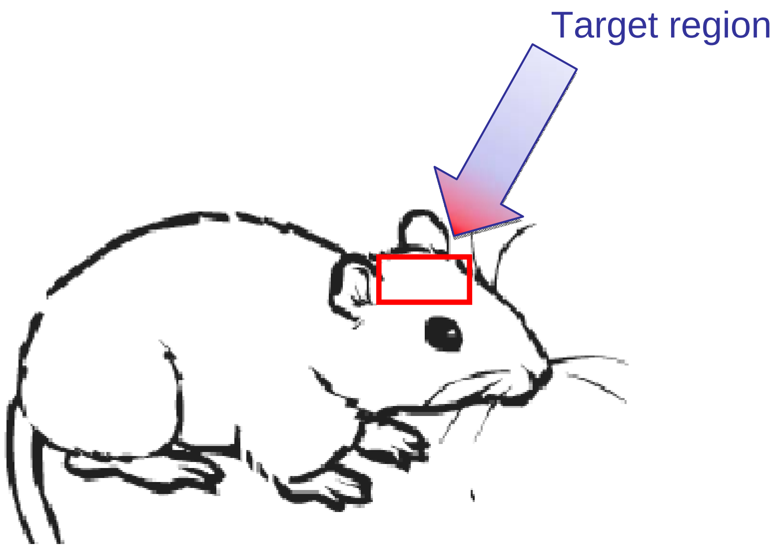


The approach

→ Our goal: introduce active agents into brain

→ Approach: overcome the blood brain barrier using external magnetic fields (high field gradients and a sufficient flux density)





Experiments, Literature →

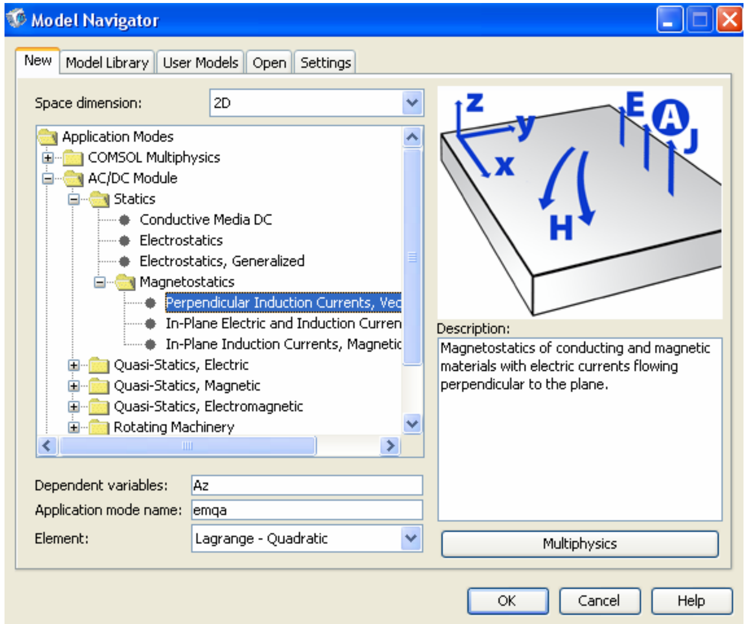
Magnetic Flux Density	B > 200 mT
Magnetic Field Gradient	dB/dx > 10 T/m

Using Comsol to solve the problem

Conception of an electromagnet with:

- needed field properties

- optimal design to allow experiments



2D → AC/DC Module

→ Statics

→ Magnetostatics

→ Perpendicular Induction Currents, Vector Potential

- involved Maxwell equations: ×H = J and B = 0

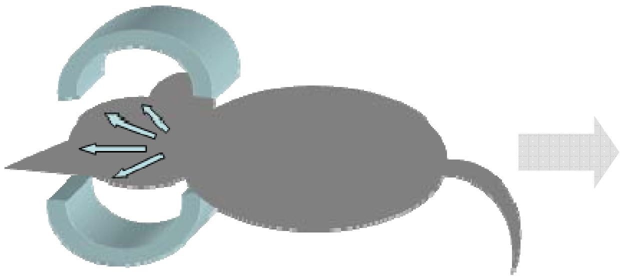
- constitutive relation $B = \mu_0 \mu_r H$

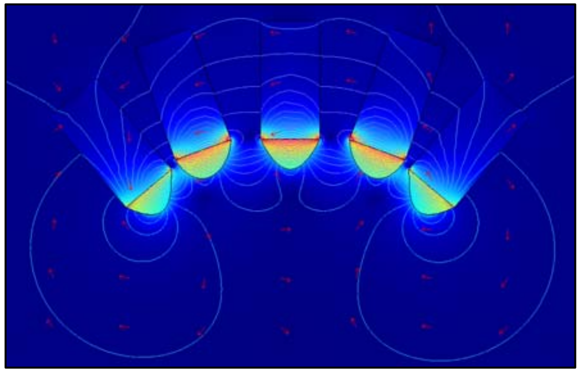
- governing equation of the Magnetostatics mode ×(μ-1 ×A - M) = J.

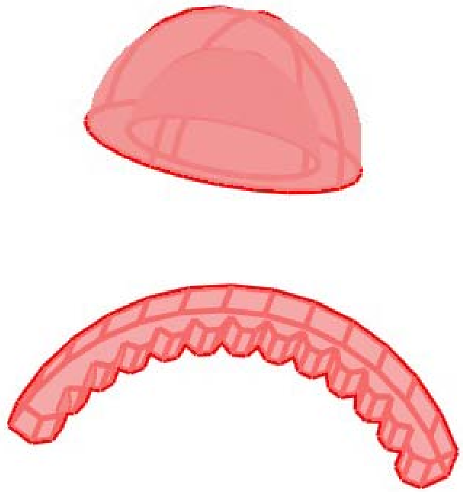
→ Input parameters: Relative permeability, external current density

Using Comsol to solve the problem

Initial concept

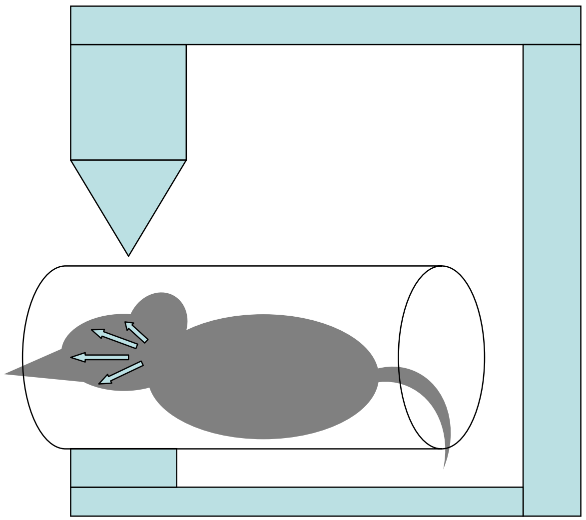






→ Intuitively conceived magnet forms lead to a very weak field

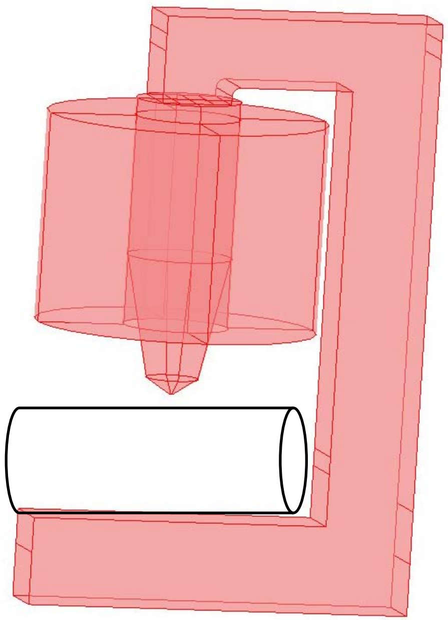
Final concept →

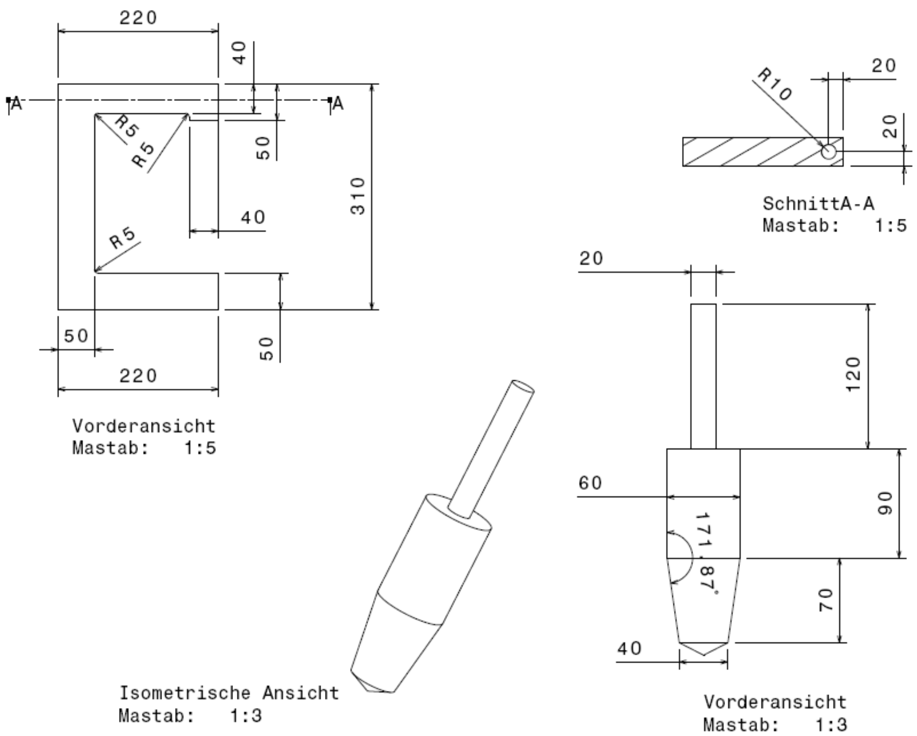


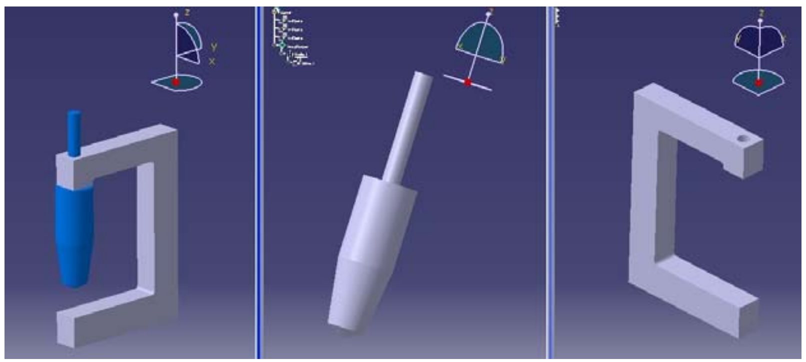
→ The final concept was achieved through several trials and optimization changes

Using Comsol to solve the problem

Dimensioning the electromagnet





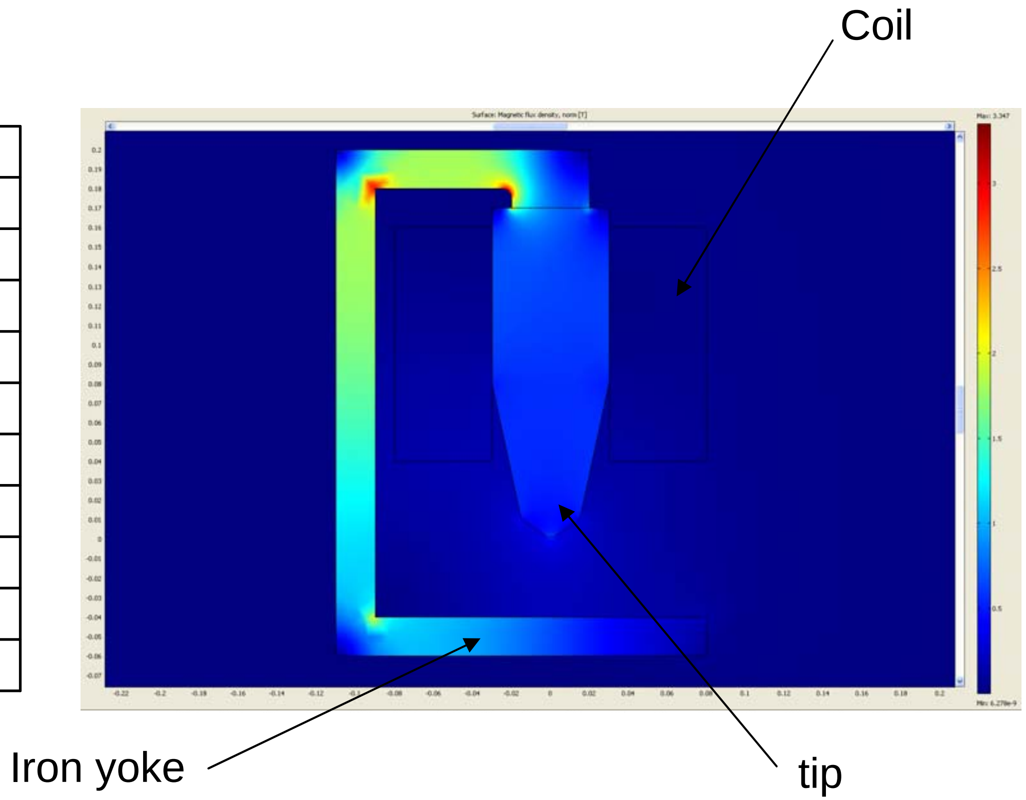


- modular assembly
- variable air gap
- adaptable tip

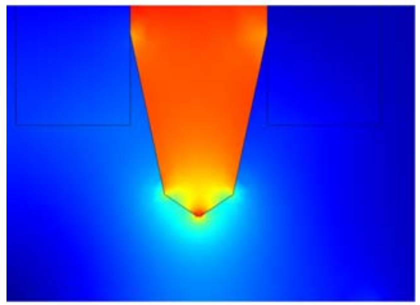
Using Comsol to solve the problem

Parameters of the coil

Diameter of the copper wire	d = 1.2 mm
Cross-section of the wire	A_L = 1.13 mm^2
Average length of the winding	l_m = 34.56 cm
Number of windings	N = 3714
Length of the coil	l = 1283.56 m
Mass of the coil	m = 12.95 kg
External current density	J = 1.79e6 A/m^2
Output voltage	U = 41.12 V
Output current	I = 2.04 A
Power loss	P = 83.71 W
Adiabatic heating	$\Delta\theta$ = 40.3 K



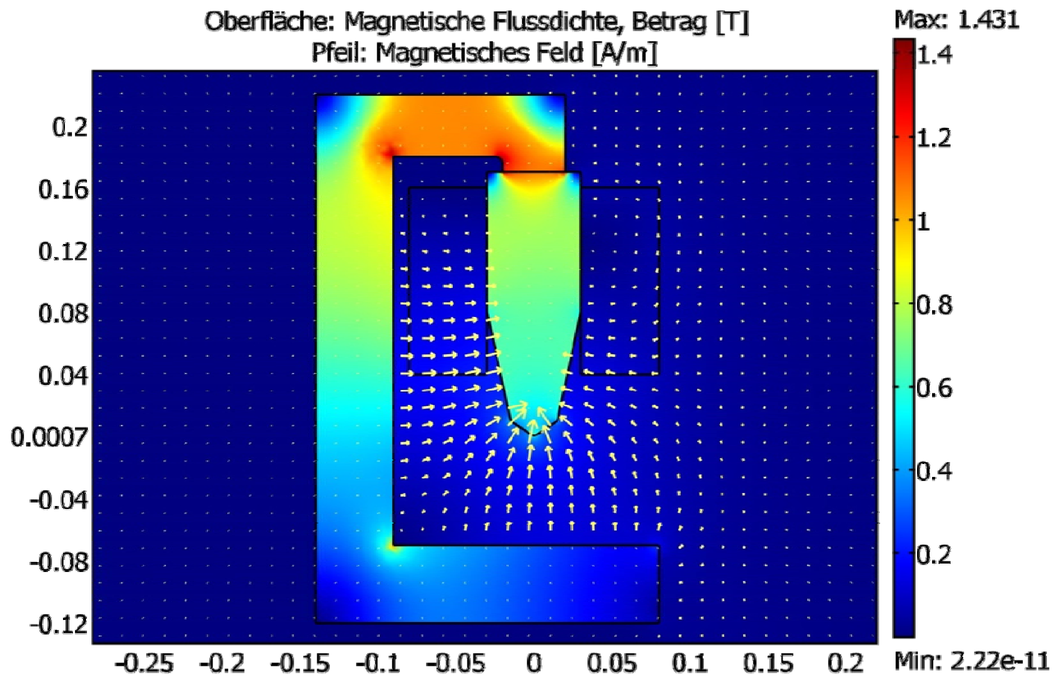
Optimizing the form of the magnet tip is necessary to obtain best field properties



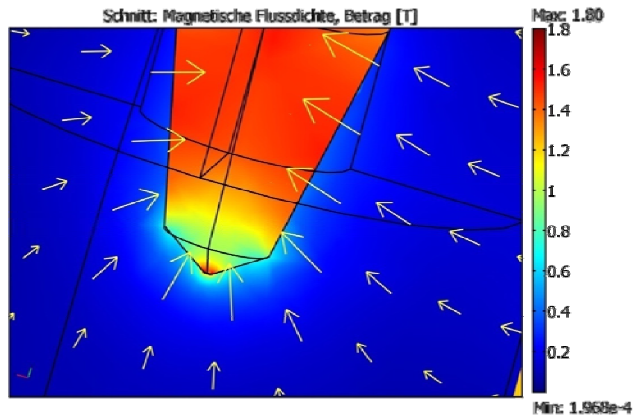
Using Comsol to solve the problem

Achieved Results

Characteristics	
Flux density directly under magnet tip	> 500 mT
Flux density at 20 mm	> 200 mT
Field gradient at 20 mm	> 10 T/m
Field-Field gradient product	> 2,1 T²/m

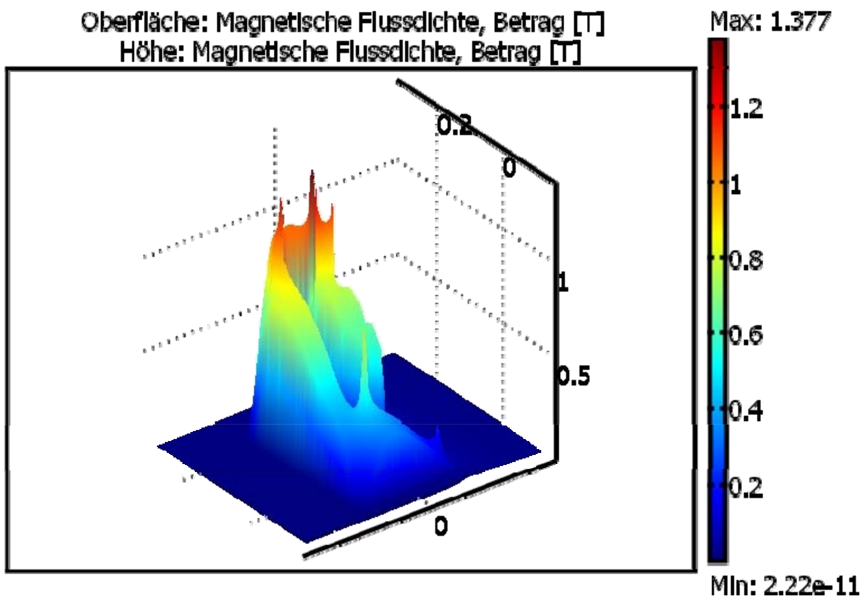


→ The needed magnetic flux and field gradient to eventually overcome the blood brain barrier are reached in an active volume of 2 x 2 x 2 cm³

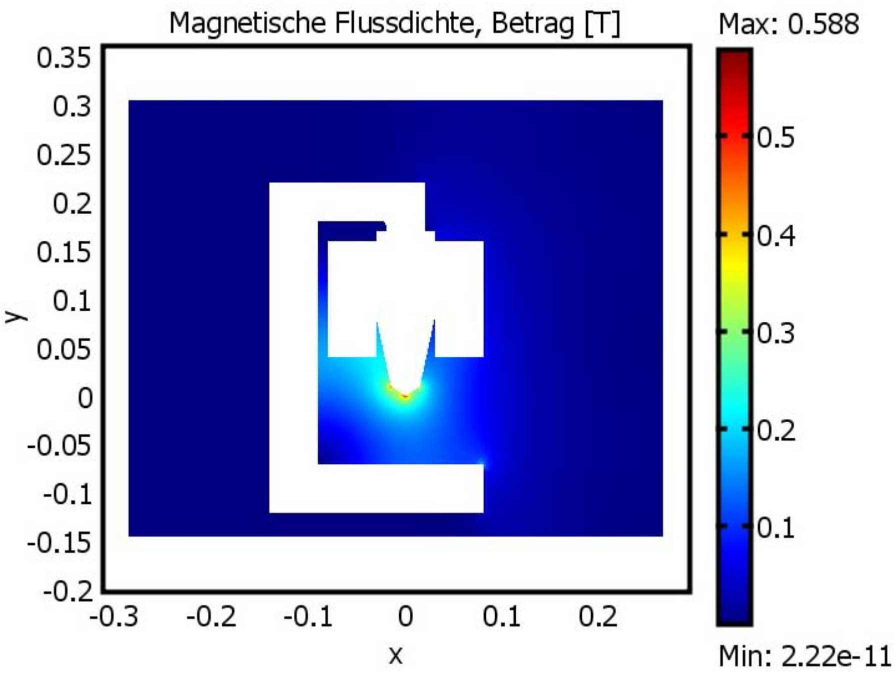


Using Comsol to solve the problem

Using the post processing options to evaluate the solution



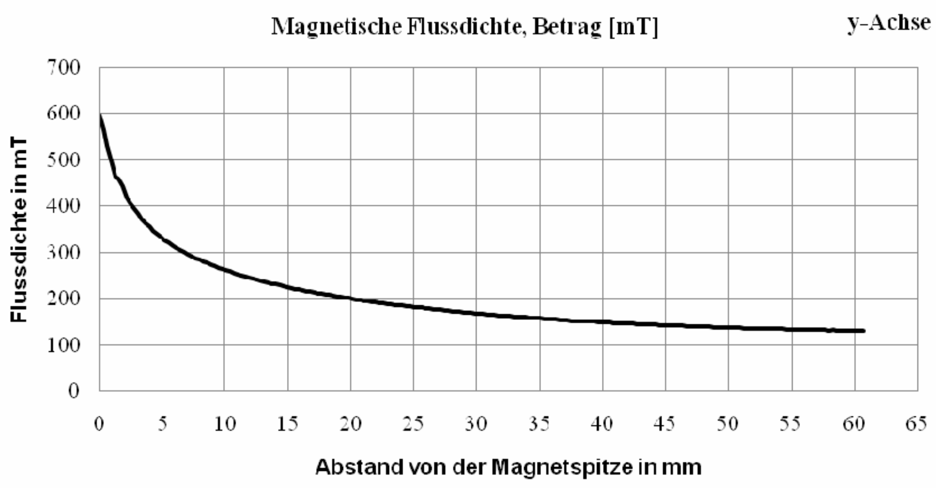
→ Height data around the magnet show concentration near tip



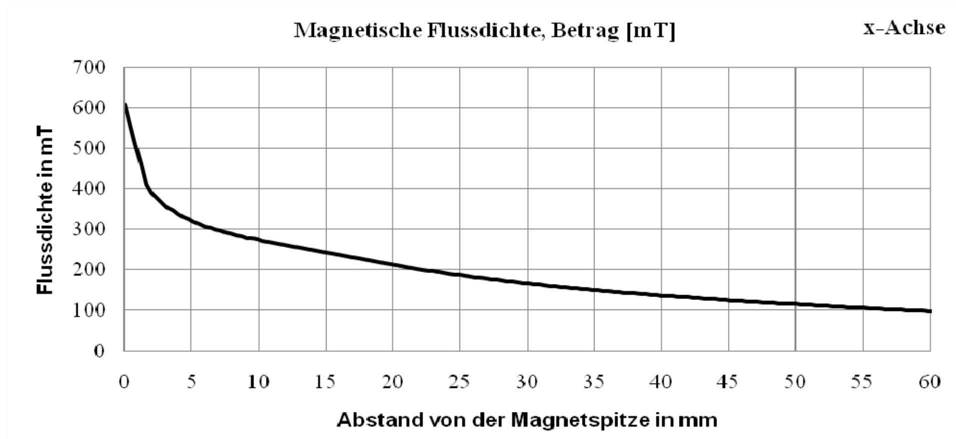
→ the needed field characteristics are reached in the volume around the tip

Using Comsol to solve the problem

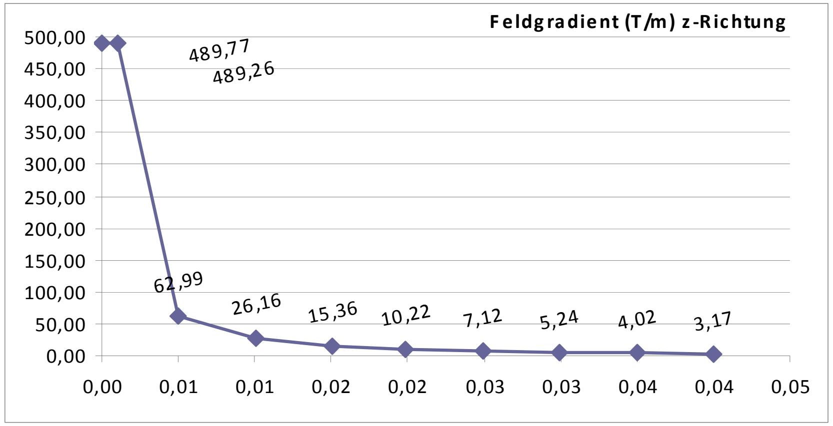
Extracting data after processing to assess the simulation result



Cross section line plots showing sufficient flux density in x and y directions



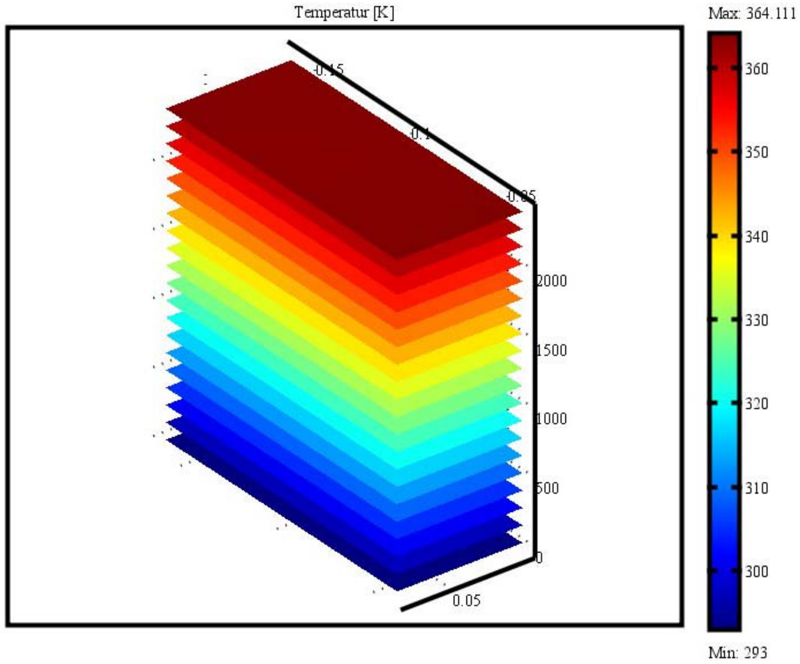
Field gradient

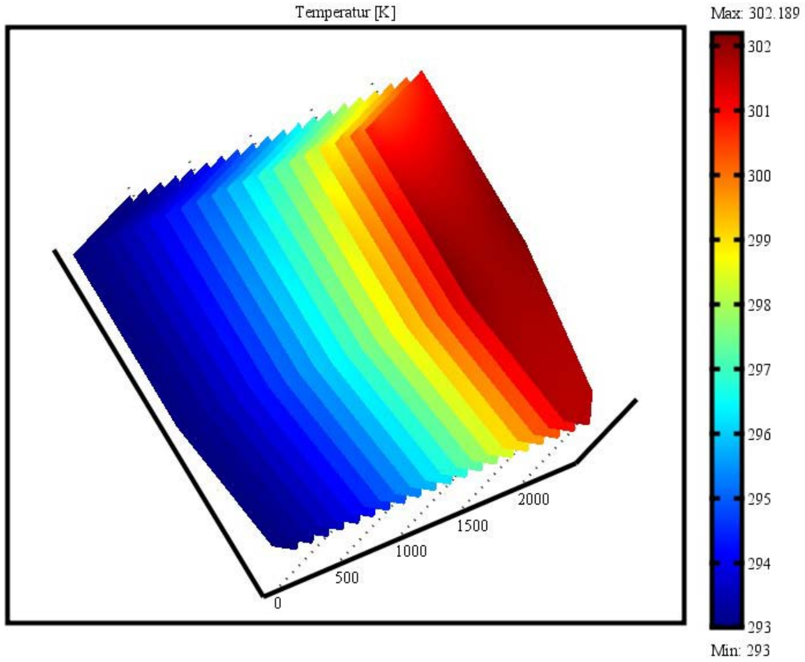


Exported plot data is processed in external software to show the field gradient necessary to exert a magnetic force on the nanoparticles is reached in the active volume

Using Comsol to solve the problem

Combining the field simulation with a thermal analysis



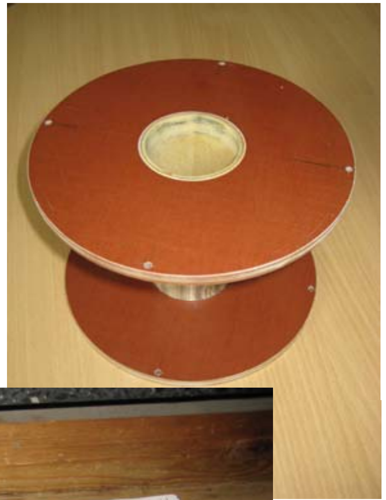


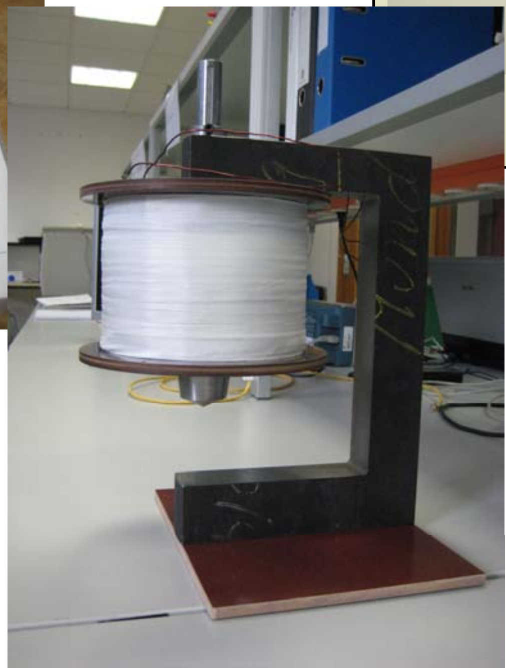
AC/DC Module → Electro-thermal interactions → Transient analysis

→ Reached temperature of 364 Kelvin (ca. 90°C) in 40 minutes

- Non consideration of the filling factor (0.5 to 0.6 in best cases)
- Necessity of an active cooling system for longer experiments

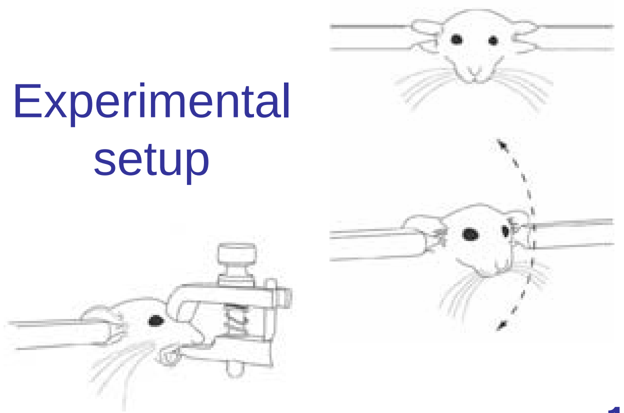
Construction and experimental setup





Testing in progress

Experimental setup



Thank you for your attention!

Back Up

Magnetostatics Equations	Value
Magnetic Insulation	$A_\varphi = 0$
Continuity	$n \times (H_1 - H_2) = 0$
Relative Permeability	Isotropic in each subdomain