Angle-dependent light scattering in the case of thin bone layers for the application of optical cochlear implants

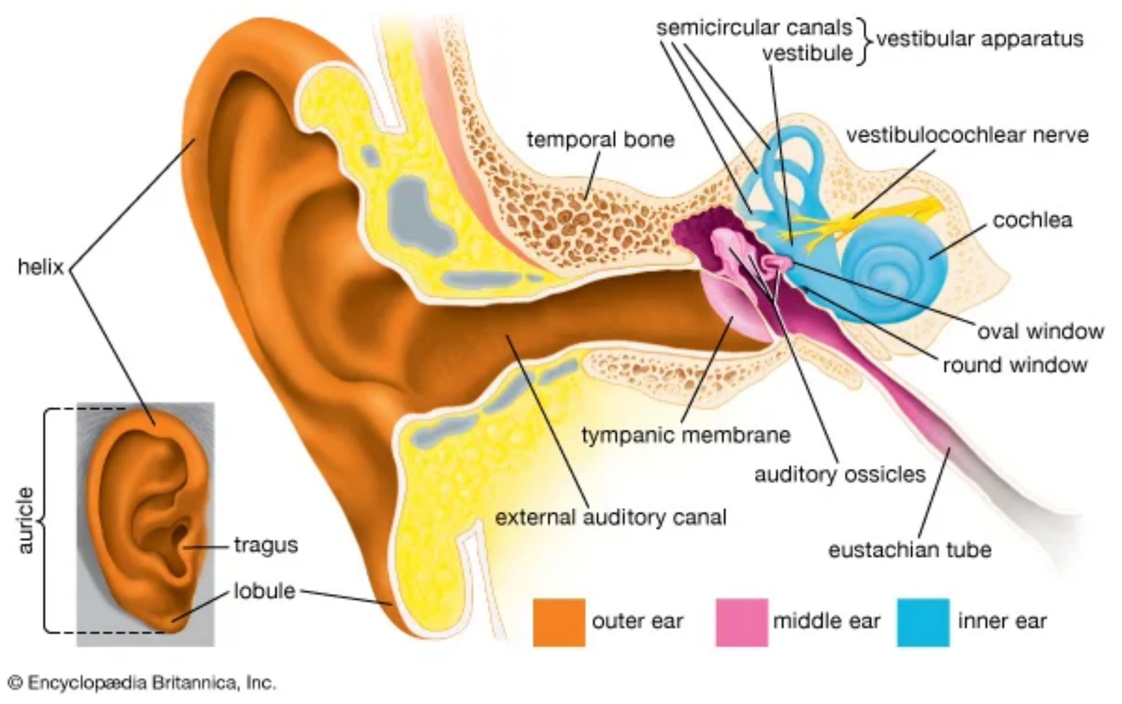
TECHNISCHE UNIVERSITÄT CHEMNITZ

Tom Witke, Fabian Teichert, Angela Thränhardt

Institute of Physics, Chemnitz University of Technology, Chemnitz

Light scattering for optical cochlear implants

- Implant uses waveguide and photodiodes instead of electrode array
- Precise light stimulation of neurons
- Understanding how light is scattered in human cochlea
- Use of phantom tissue layers
- Simulative and analytical approaches



Phase functions and single scattering

- Aim: Finding a phase function which is as exact as a calculated scattering distribution and at the same time meets:
- the condition of normalisation

$$2\pi \int_0^{\pi} p(\theta) \sin\theta \, \mathrm{d}\theta = 1$$

- and anisotropy

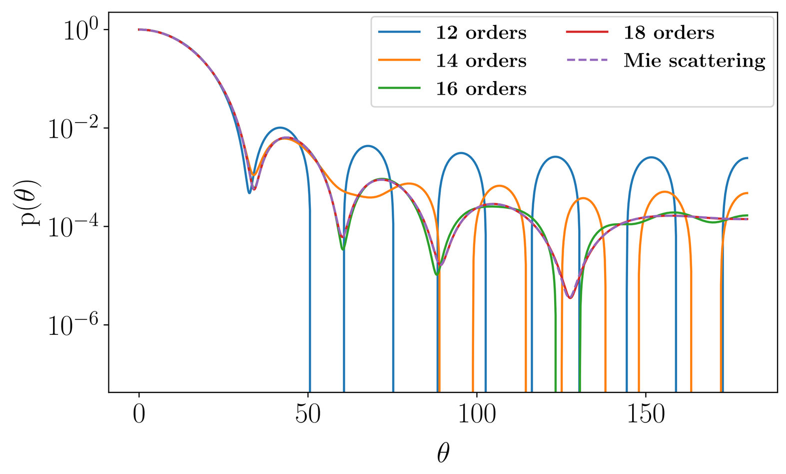
$$2\pi \int_0^{\pi} p(\theta) \cos\theta \sin\theta \, \mathrm{d}\theta = g$$

- Out of the Mie derivation for any scattering event

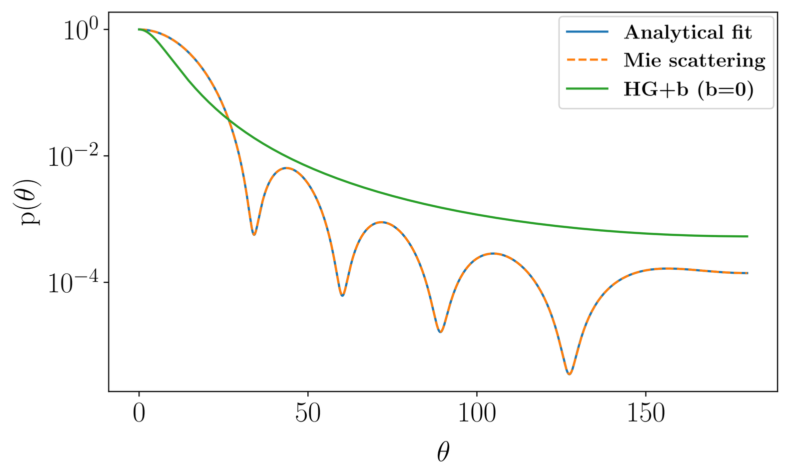
$$p(\theta) = \sum_{l=0}^{2n_{\max}} \tilde{g}_l \cos l\theta .$$

- With $2n_{\max}$ fit parameters $\tilde{g}_l$, we can write an analytical fit to any calculated Mie distribution as

$$p_1(\theta) = \sum_{l=0}^{2m} \tilde{g}_l \cos(l\theta) + \tilde{g}_{2m+1} \cos((2m+1)\theta) + \tilde{g}_{2m+2} \cos((2m+2)\theta)$$



Order of fit parameters



Phase functions

Multiple scattering

- Analytical calculation of multiple scattering in a tissue layer
- Calculation of second scattering event out of $p_1(\theta)$

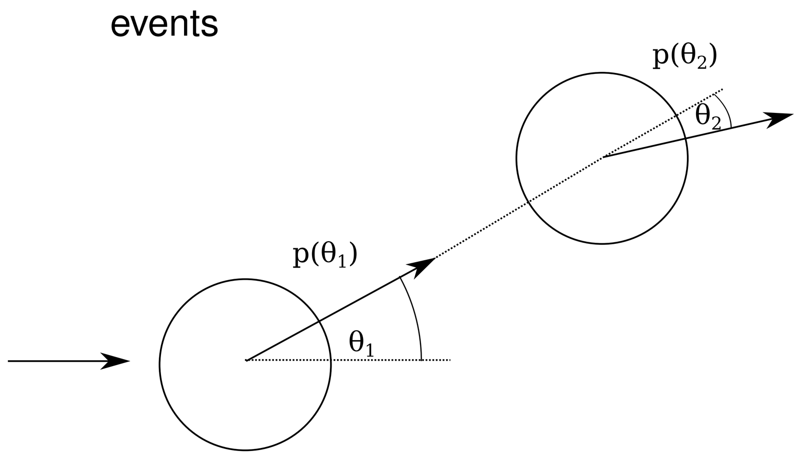
$$p_2(\theta) = \int_{-\pi}^{\pi} p_1(\theta_1) p(\theta_2) \, \mathrm{d}\theta_1$$

- with correction terms

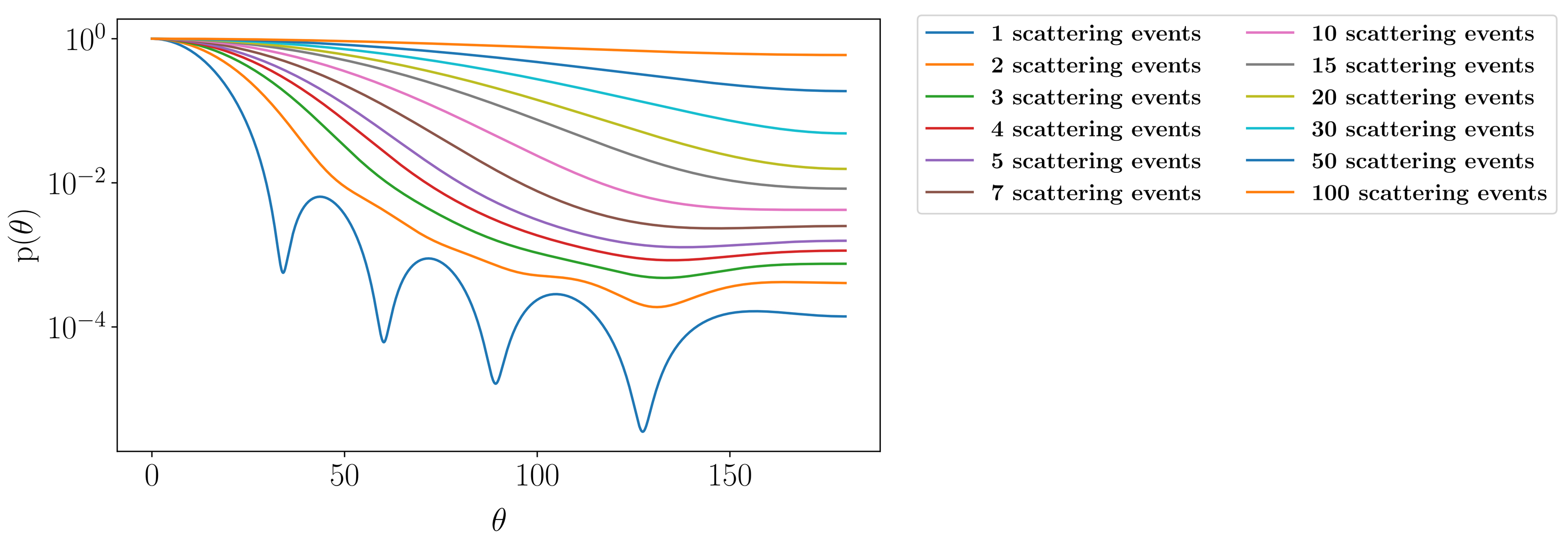
$$\int_{-\pi}^{-\pi+\theta} p_1(\theta_1) p(\theta - \theta_1 - 2\pi) \, \mathrm{d}\theta_1$$

$$\int_{\pi+\theta}^{\pi} p_1(\theta_1) p(\theta - \theta_1 + 2\pi) \, \mathrm{d}\theta_1$$

- Convolute every scattering angle back into the desired interval $[-\pi, \pi]$
- Angle distribution for $n+1$ scattering events



$$p_{n+1} = \begin{cases} \int_{-\pi+\theta}^{\theta} p_n(\theta_n) p(\theta - \theta_n) \, \mathrm{d}\theta_n + \int_{-\pi}^{-\pi+\theta} p(\theta_n) p(\theta - \theta_n - 2\pi) \, \mathrm{d}\theta_n : & 0 \le \theta \le \pi . \\ \int_{-\pi}^{\pi+\theta} p_n(\theta_n) p(\theta - \theta_n) \, \mathrm{d}\theta_n + \int_{\pi+\theta}^{\pi} p_n(\theta_n) p(\theta - \theta_n + 2\pi) \, \mathrm{d}\theta_n : & -\pi \le \theta \le 0 \end{cases}$$



Multiple scattering events

Monte Carlo Simulation and Experiment

- Calculation of an angle dependent intensity distribution and scattering efficiency for a single scatterer

$$S_{\mathrm{U}}(\theta) = \frac{1}{2}(S_{\perp} + S_{\parallel})$$

$$Q_{\mathrm{sca}} = \frac{2}{z^2} \sum_{n=1}^{\infty} (2n+1)|a_n|^2 + |b_n|^2$$

- Calculation of the scattering parameters

$$l_s = \frac{1}{\mu_s} = \frac{1}{\rho\sigma} = \frac{4\pi R^3}{3\sigma\eta}$$

$$g = \frac{\int_0^{\pi} S_{\mathrm{U}}(\theta) \sin\theta \cos\theta \, \mathrm{d}\theta}{\int_0^{\pi} S_{\mathrm{U}}(\theta) \sin\theta \, \mathrm{d}\theta}$$

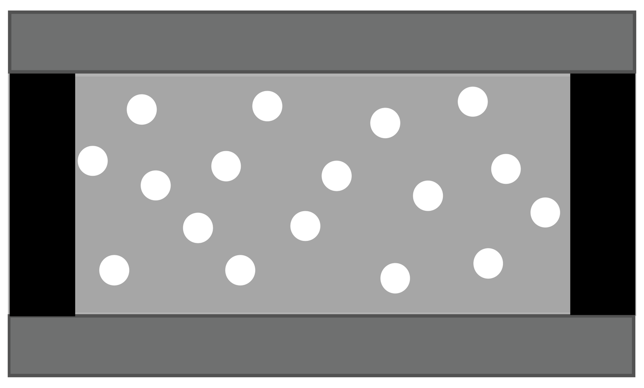
- Defining the phase function as calculated angle distribution

$$p(\theta) = S_{\mathrm{U}}(\theta) = \frac{1}{2}(S_{\perp} + S_{\parallel})$$

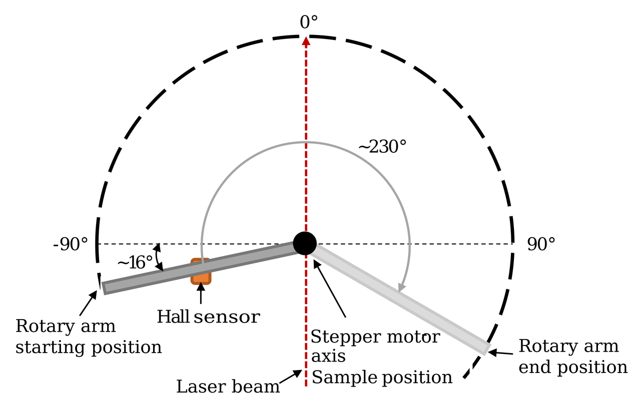
- Henyey-Greenstein as phase function

$$p(\theta) = \frac{1}{4\pi} \left[b + (1-b) \frac{1-g^2}{(1+g^2-2g\cos\theta)^{\frac{3}{2}}} \right] .$$

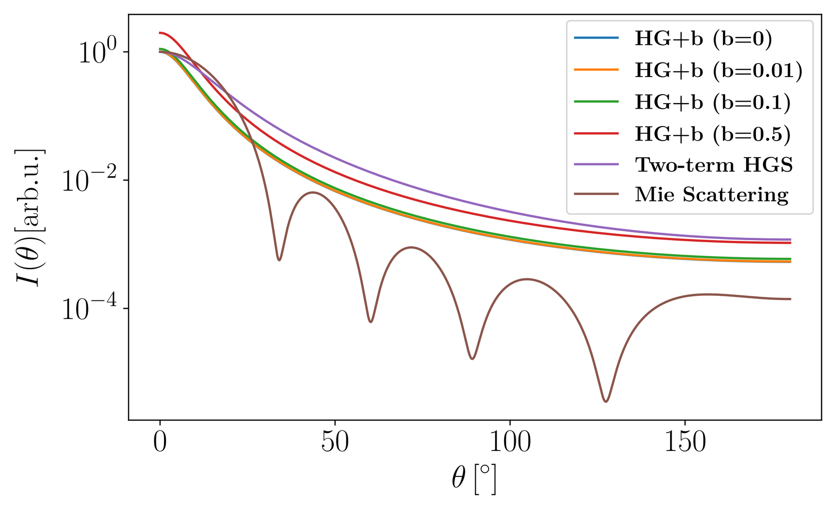
- Simulation/Measurement of light scattering through thin layers
- Phantom materials which mimic thin layers of human tissue
- Epoxy matrix with polymer spheres as scatteres



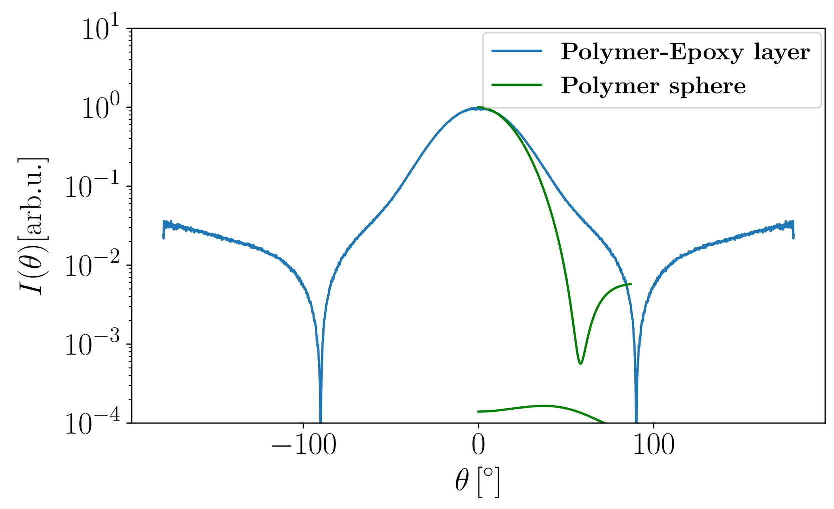
Phantom Layer



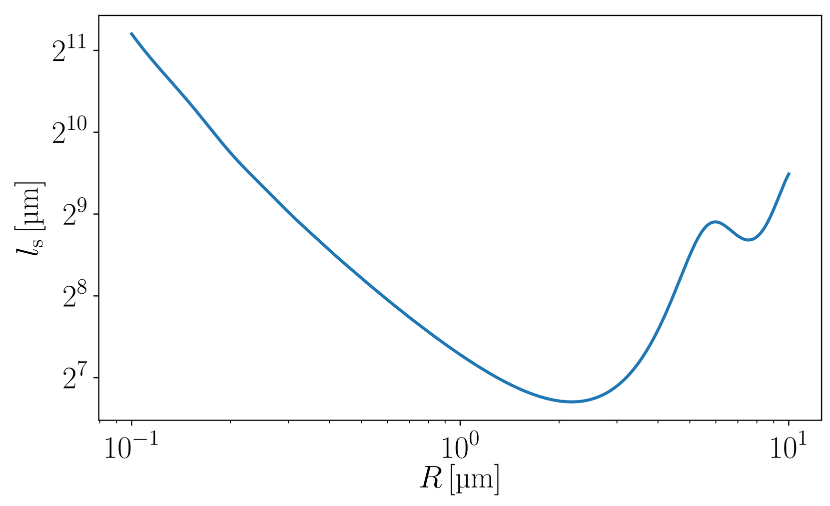
Experimental Setup



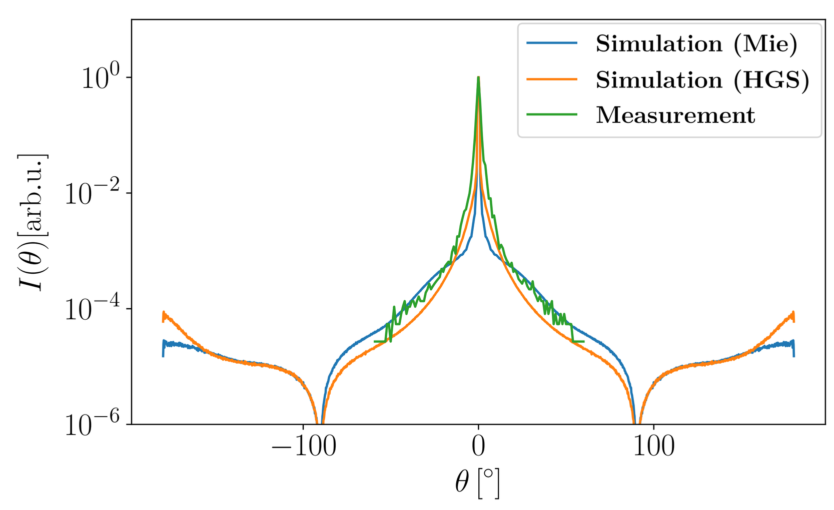
Henyey-Greenstein as phase function



Multiple scattering in MCS



Mean free path length

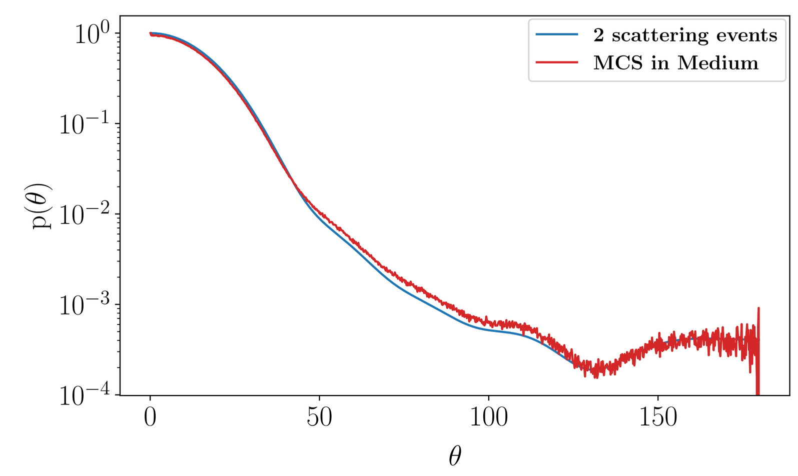


Measurement and Simulations

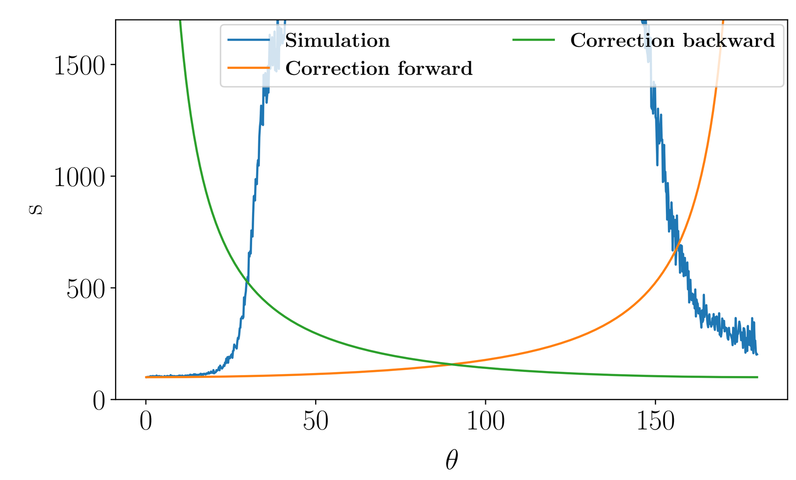
Outlook for realizing an analytical model

- Calculating angle distributions for tissue layers
- Including material transitions
- Fresnel correction in the analytic model
- Finding exact number of scattering events in simulation
- Different distances traveled by photons
- Calculating transmission for multiple scattering
- Multiple media layers with corresponding scattering functions

$$T_n = \int_{\frac{\pi}{2}}^{-\frac{\pi}{2}} p_n(\theta) \, \mathrm{d}\theta$$



Predetermined scattering events in simulation



Distance traveled in model and simulation

tom.witke@physik.tu-chemnitz.de