

# Finite element simulation of the ear canal wall vibrations

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**IHTA** Institute for  
Hearing Technology  
and Acoustics

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# Introduction

- Cause of occlusion effect: motion of ear canal wall
- Wall imposes volume velocity<sup>1,2</sup>
  - Open: radiated
  - Occluded: sound pressure increase
- This study:
  - Three-dimensional, frequency dependent ear canal motion
  - Quantify volume velocity in terms
    - Magnitude
    - Spatial distribution

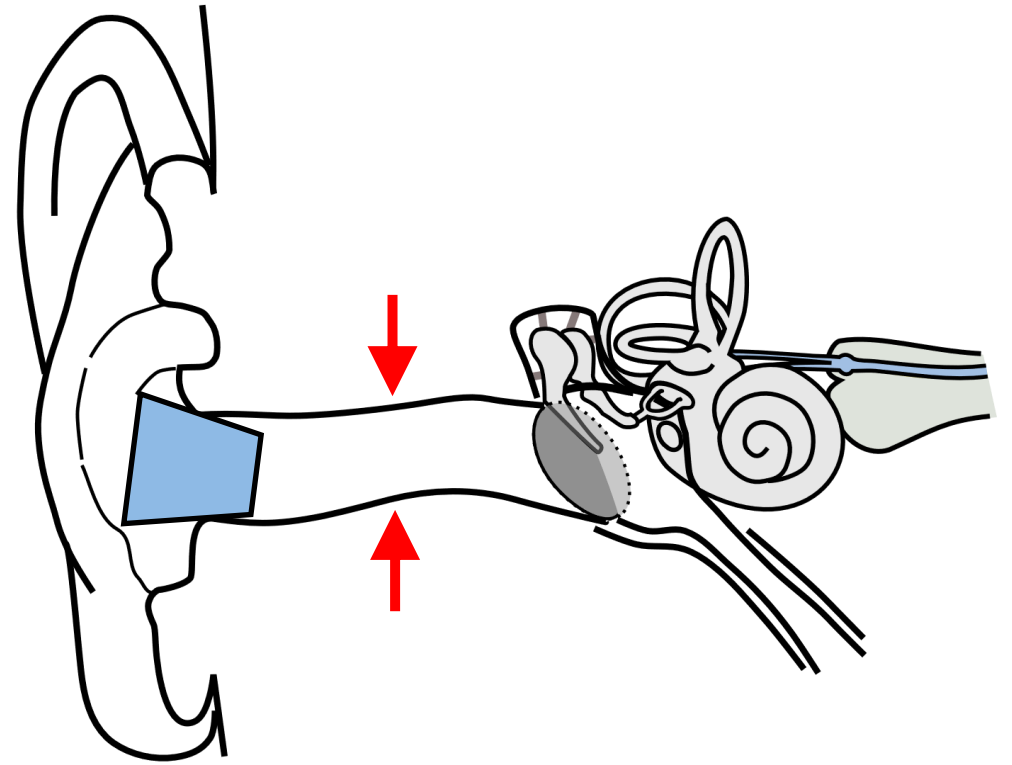


Figure adapted after Chittka, L., Brockmann, A., 2005. Perception Space—The Final Frontier.

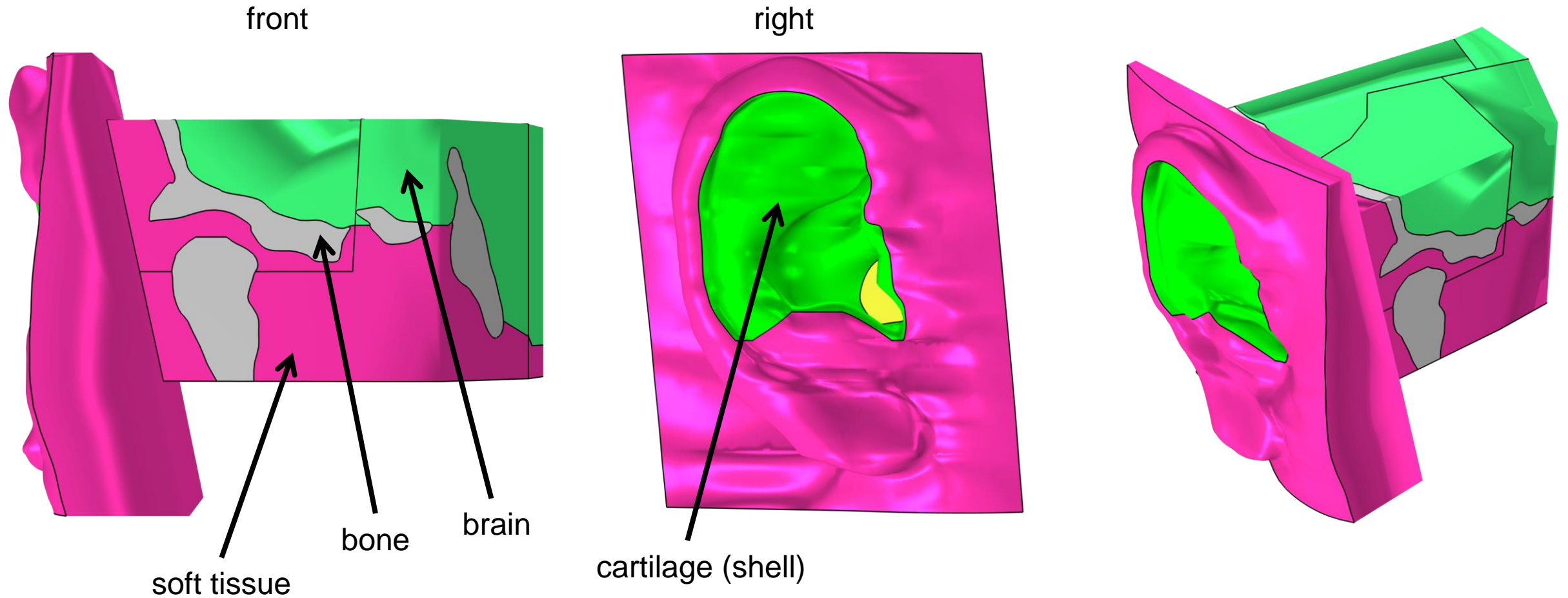
[1] Stenfelt, S., & Reinfeldt, S. (2007). A model of the occlusion effect with bone-conducted stimulation. *International Journal of Audiology*, 46(10), 595–608

[2] Carillo, K., Doutres, O., & Sgard, F. (2021b). On the removal of the open earcanal high-pass filter effect due to its occlusion: A bone-conduction occlusion effect theory. *Acta Acustica*, 5.

# Finite element model

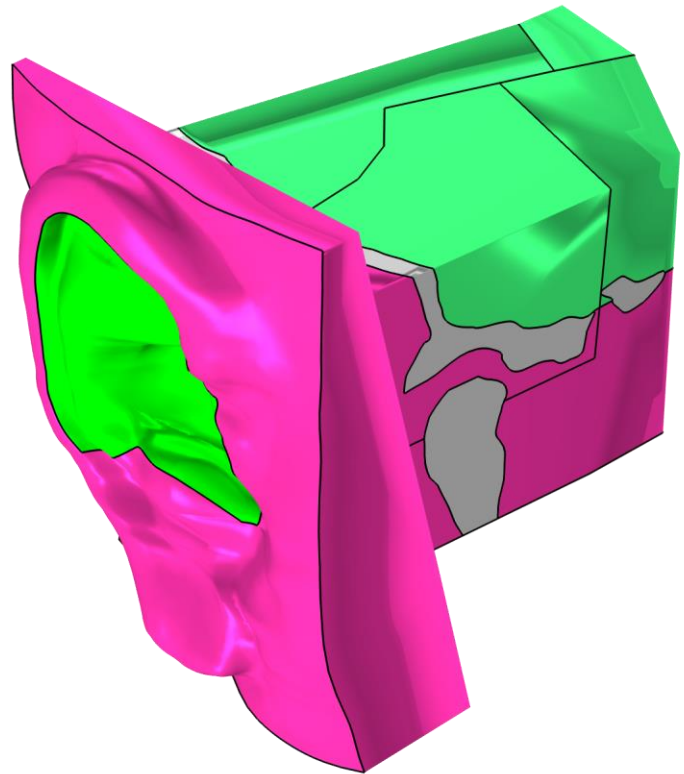


# Model geometry

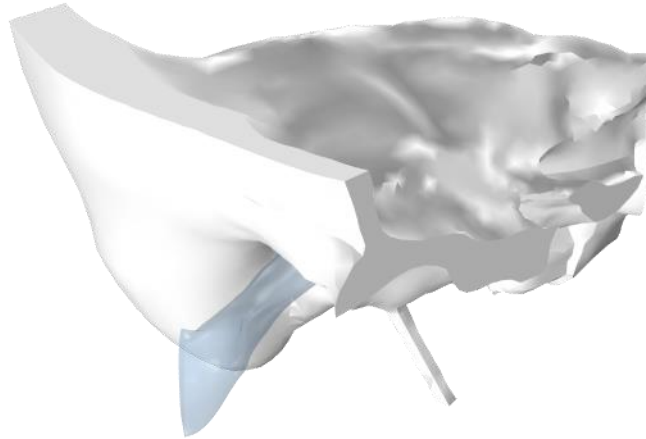


cf. Taschke, H. (2005). *Mechanismen der Knochenschalleitung (Mechanisms of bone-conducted sound)* [Ph.D. Dissertation]. Ruhr University Bochum.

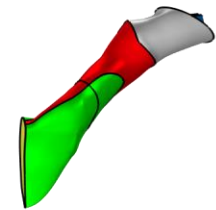
# Model geometry



temporal bone

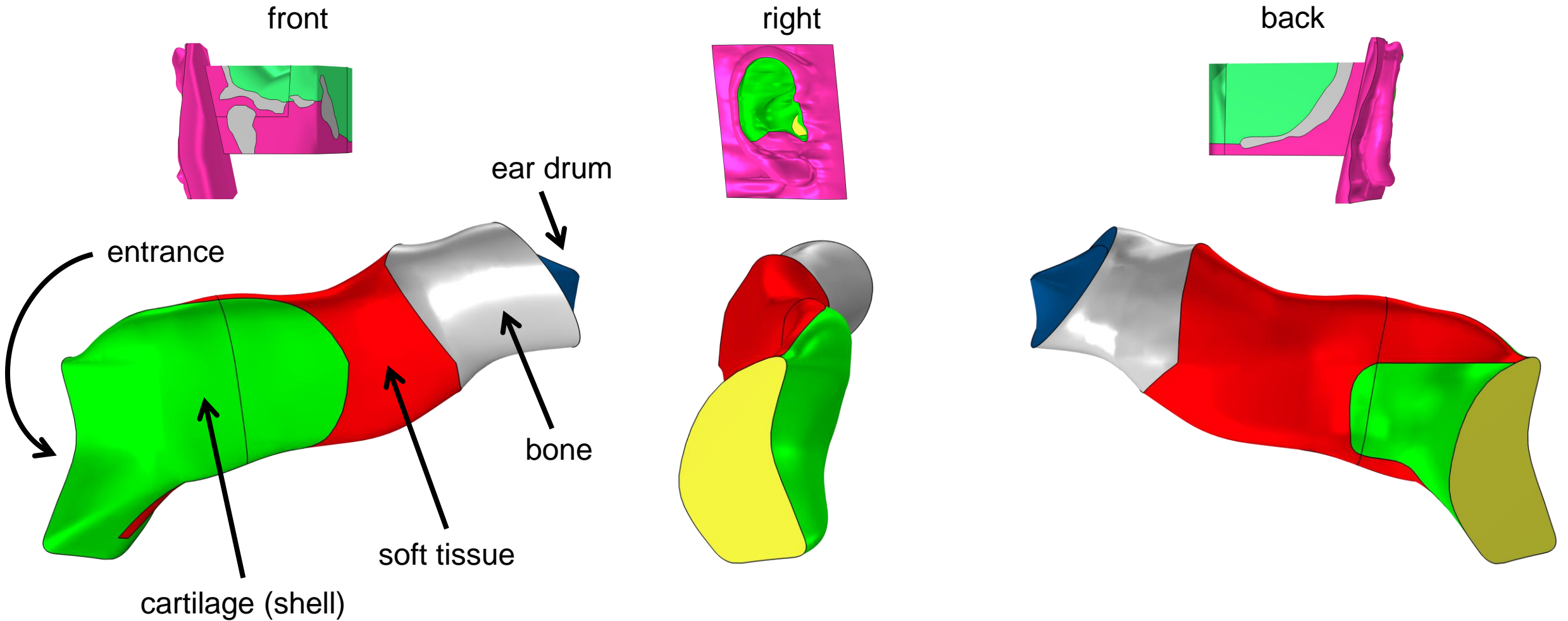


ear canal



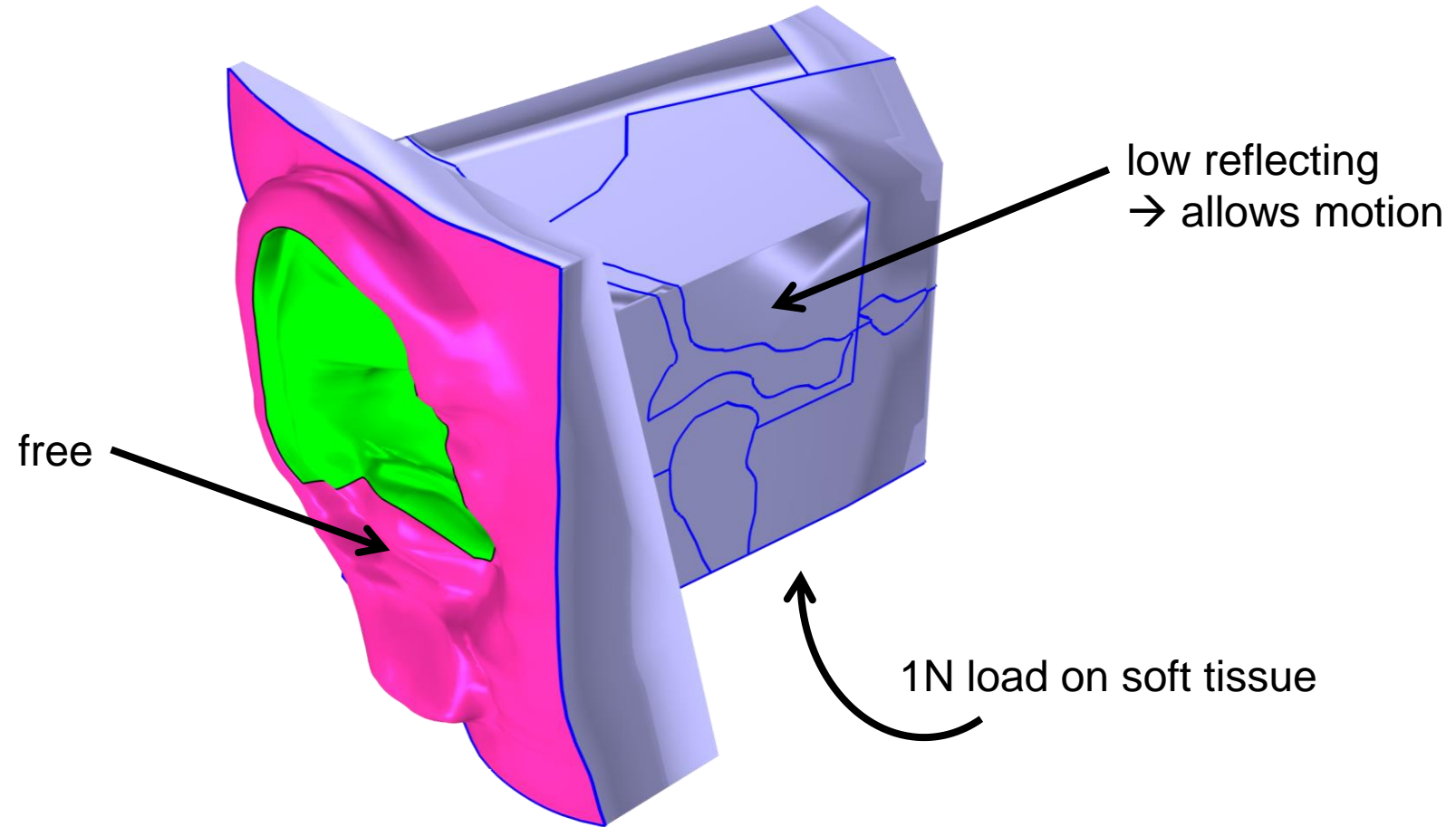
cf. Taschke, H. (2005). *Mechanismen der Knochenschallleitung (Mechanisms of bone-conducted sound)* [Ph.D. Dissertation]. Ruhr University Bochum.

# Ear canal geometry



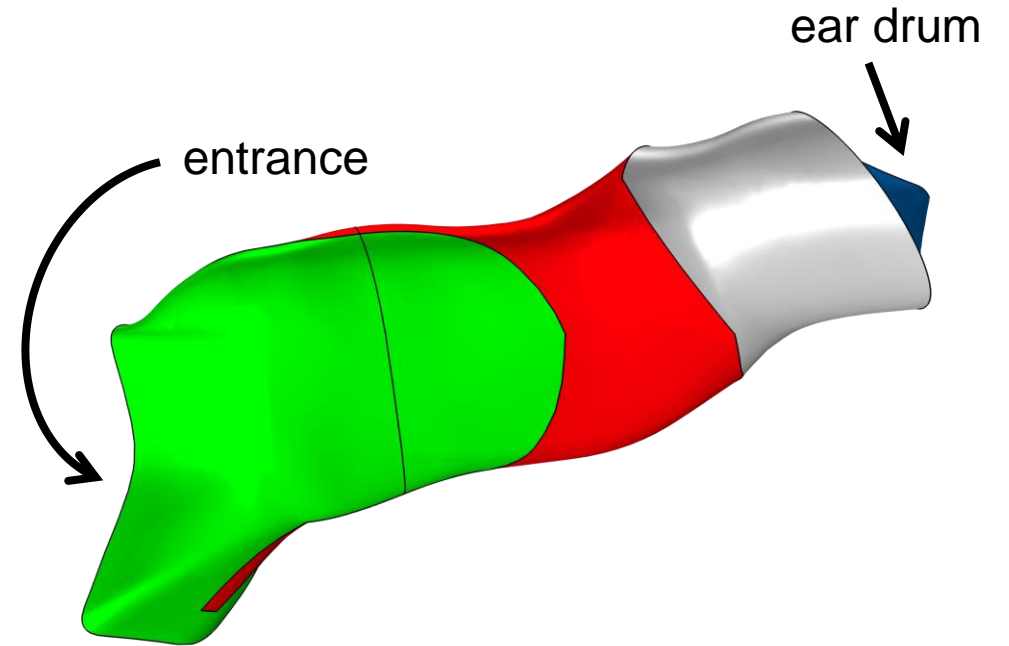
cf. Taschke, H. (2005). *Mechanismen der Knochenschallleitung (Mechanisms of bone-conducted sound)* [Ph.D. Dissertation]. Ruhr University Bochum.

# Boundary conditions



# Impedances

- Physiological impedance models<sup>1</sup>
  - Ear drum
  - Ear canal entrance
    - Open: radiation
    - Occluded: rigid, without ear plug
  - Structural motion of surrounding tissue considered<sup>2</sup>



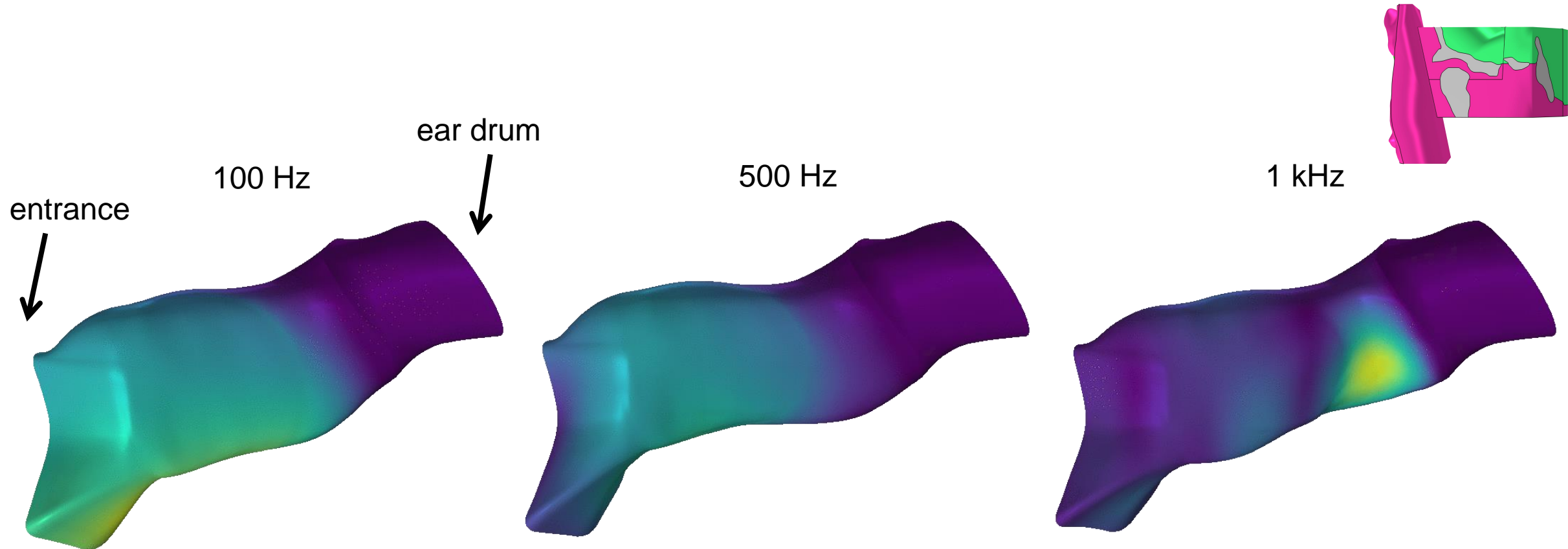
[1] Hudde, H., & Engel, A. (1998). Measuring and Modeling Basic Properties of the Human Middle Ear and Ear Canal. Part III: Eardrum Impedances, Transfer Functions and Model Calculations. *Acta Acustica United with Acustica*, 84(6), 1091–1108.

[2] Kersten, S. & Vorländer, M. (in review). Impact of the ear canal motion on the impedance boundaries for simulating the occlusion effect.

# Results



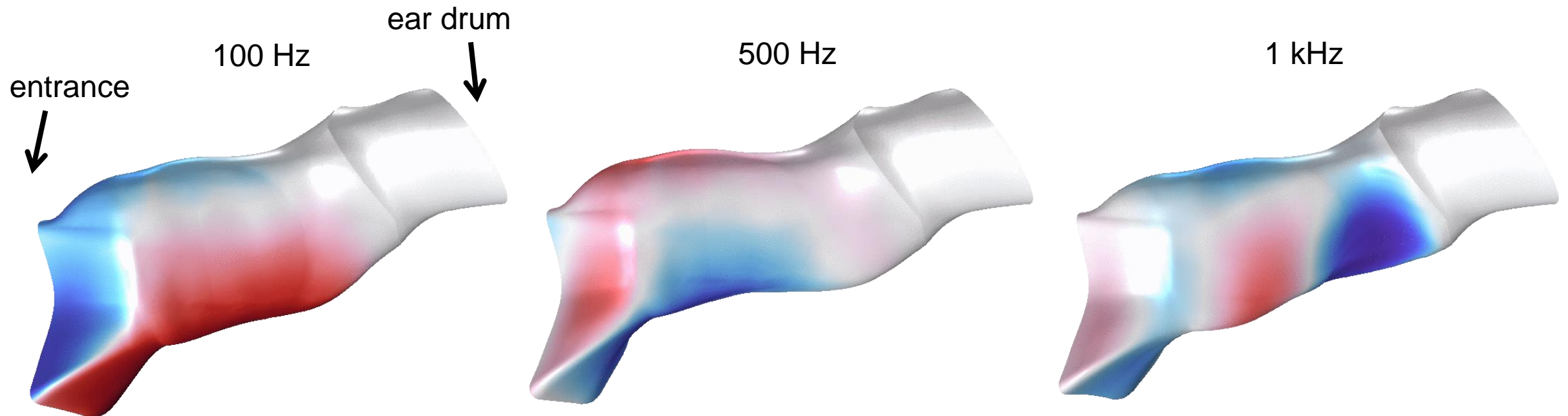
# Ear canal displacement



# Volume velocity

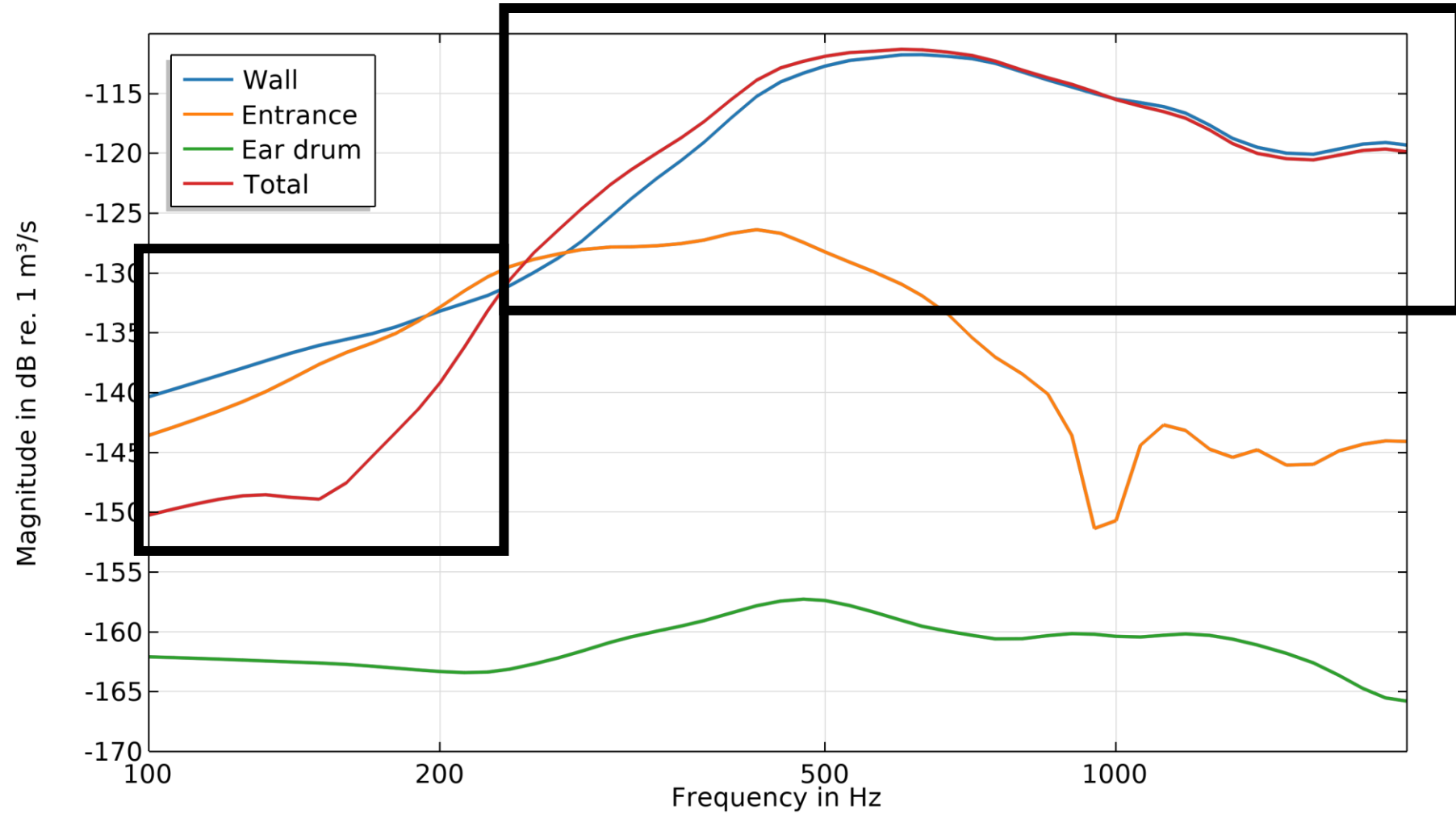
$$q_{\text{wall}} = \iint_{S_{\text{wall}}} v_n \, dS$$

ear canal wall      normal velocity (complex)

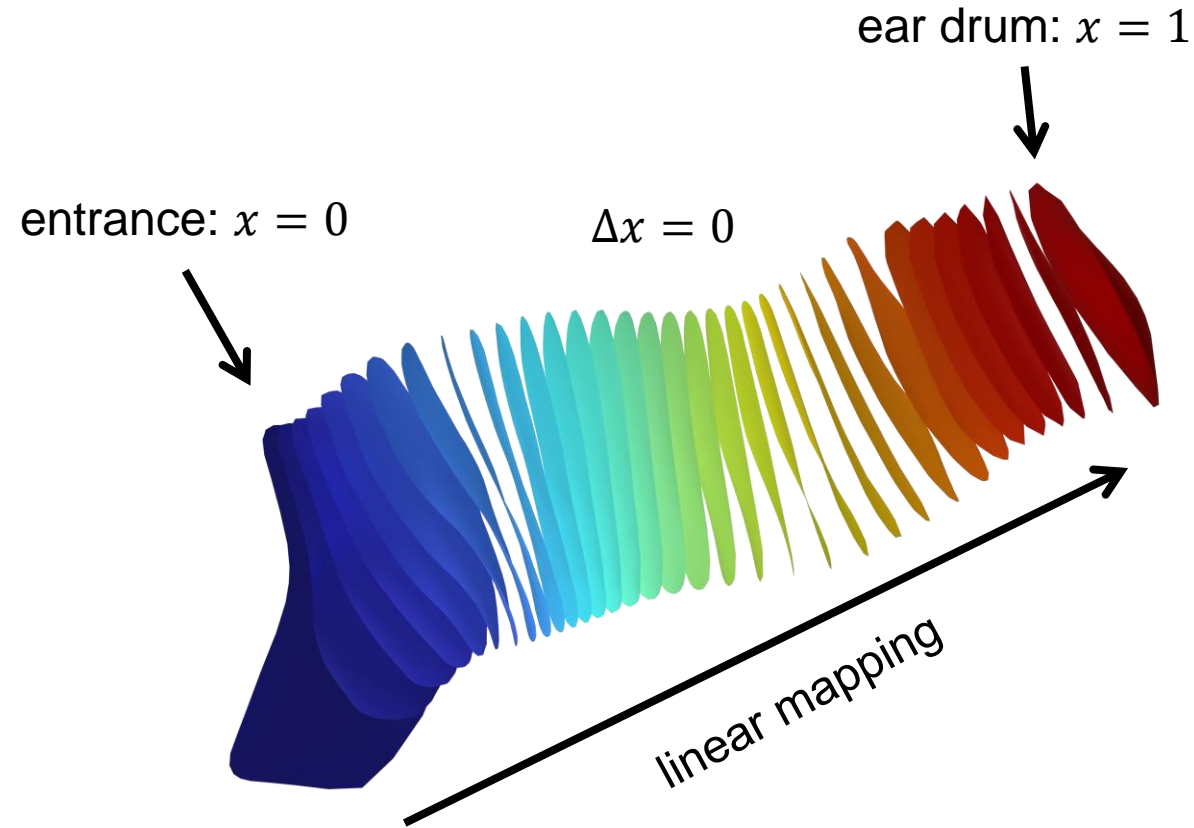


cf., e.g., Carillo, K., Doutres, O., & Sgard, F. (2020). Theoretical investigation of the low frequency fundamental mechanism of the objective occlusion effect induced by bone-conducted stimulation. *The Journal of the Acoustical Society of America*, 147(5), 3476–3489.

# Volume velocity contributions

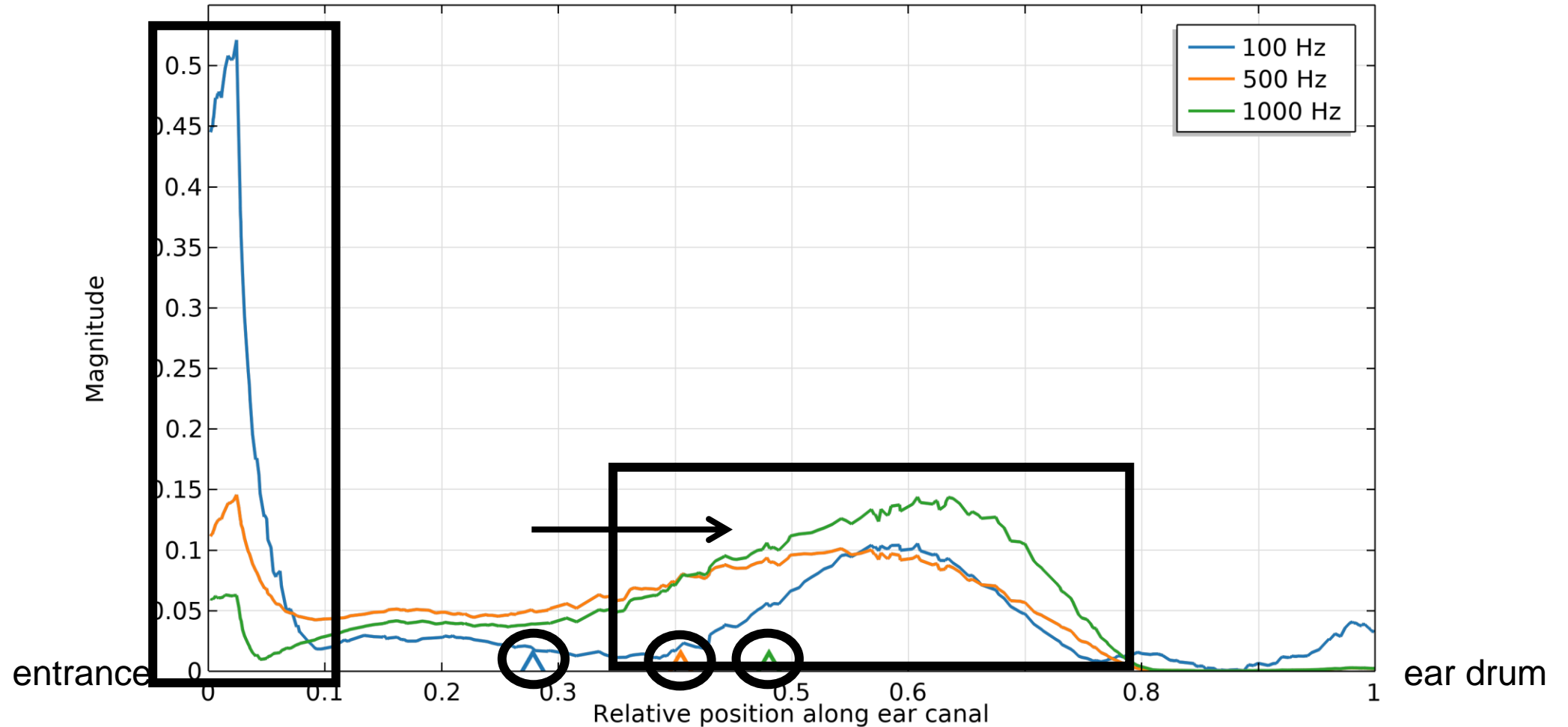


# Ear canal coordinate



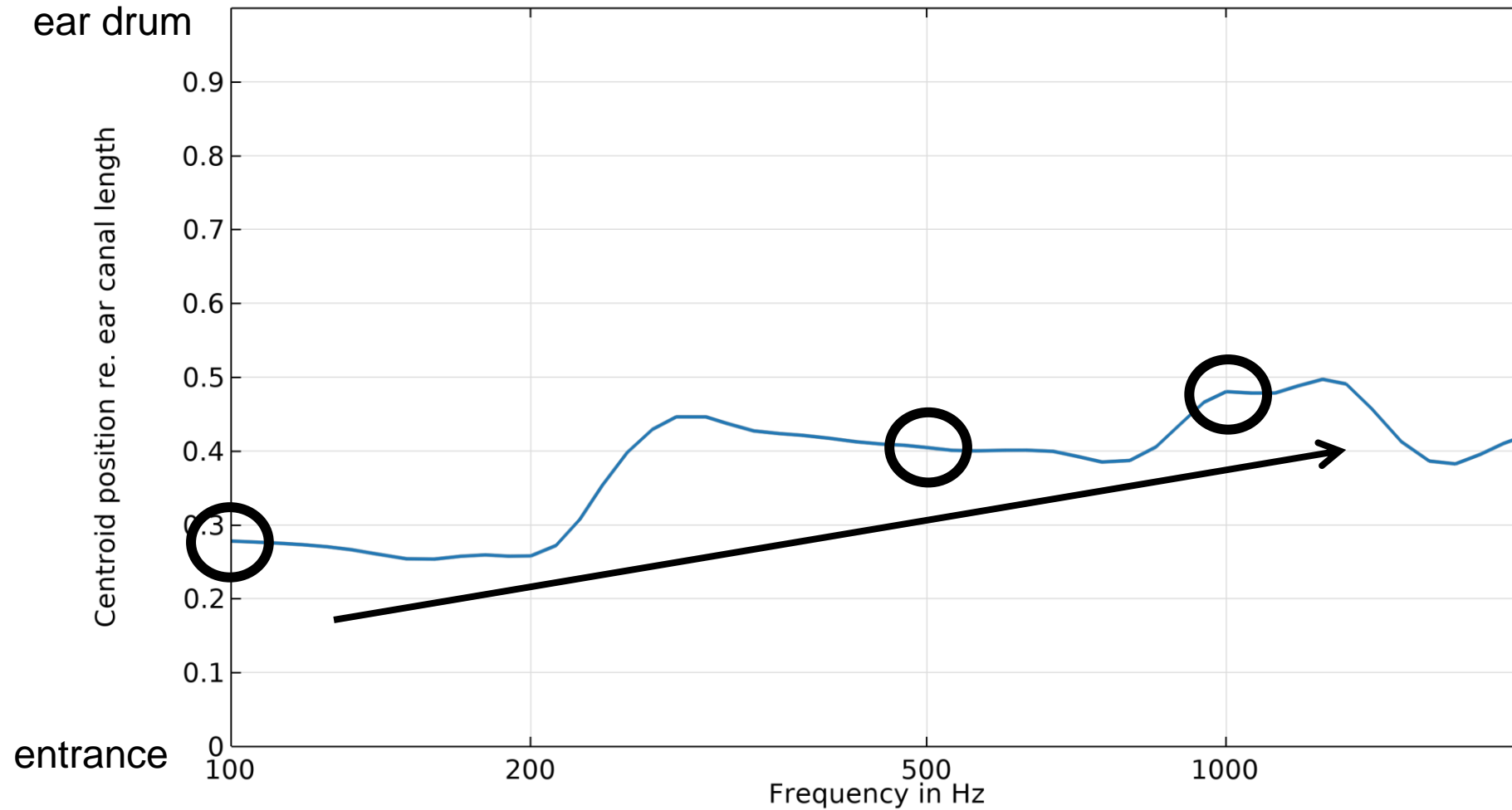
similar: Stinson, M. R., & Lawton, B. W. (1989). Specification of the geometry of the human ear canal for the prediction of sound-pressure level distribution. *The Journal of the Acoustical Society of America*, 85(6), 2492–2503.

# Volume velocity distribution



centroid position: cf. Carillo, K., Doutres, O., & Sgard, F. (2020). Theoretical investigation of the low frequency fundamental mechanism of the objective occlusion effect induced by bone-conducted stimulation. *The Journal of the Acoustical Society of America*, 147(5), 3476–3489.

# Centroid position



cf. Carillo, K., Doutres, O., & Sgard, F. (2020). Theoretical investigation of the low frequency fundamental mechanism of the objective occlusion effect induced by bone-conducted stimulation. *The Journal of the Acoustical Society of America*, 147(5), 3476–3489.

# Conclusion and outlook

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# Conclusion and outlook

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- Ear canal wall vibrations
  - Complex, frequency dependent distribution
- Study limitations
  - Truncated geometry
  - Load and boundary conditions
  - Sound radiation into ear canal<sup>1</sup>
- Outlook
  - Variation of centroid position
  - Apply approach in full head model<sup>1,2</sup>
  - Measurements<sup>3</sup> of velocity distributions (?)

[1] Xu, H., Sgard, F., Carillo, K., Wagnac, É., & de Guise, J. (2021). Simulation of the objective occlusion effect induced by bone-conducted stimulation using a three-dimensional finite-element model of a human head. *The Journal of the Acoustical Society of America*, 150(5), 4018–4030.

[2] Taschke, H. (2005). *Mechanismen der Knochenschallleitung (Mechanisms of bone-conducted sound)* [Ph.D. Dissertation]. Ruhr University Bochum

[3] Carillo, K., Doutres, O., & Sgard, F. (2021c). Principle of an acoustical method for estimating the centroid position of the earcanal wall normal velocity induced by bone-conducted stimulation: Numerical evaluation. *Applied Acoustics*, 182, 108245.

# Thank you for your attention

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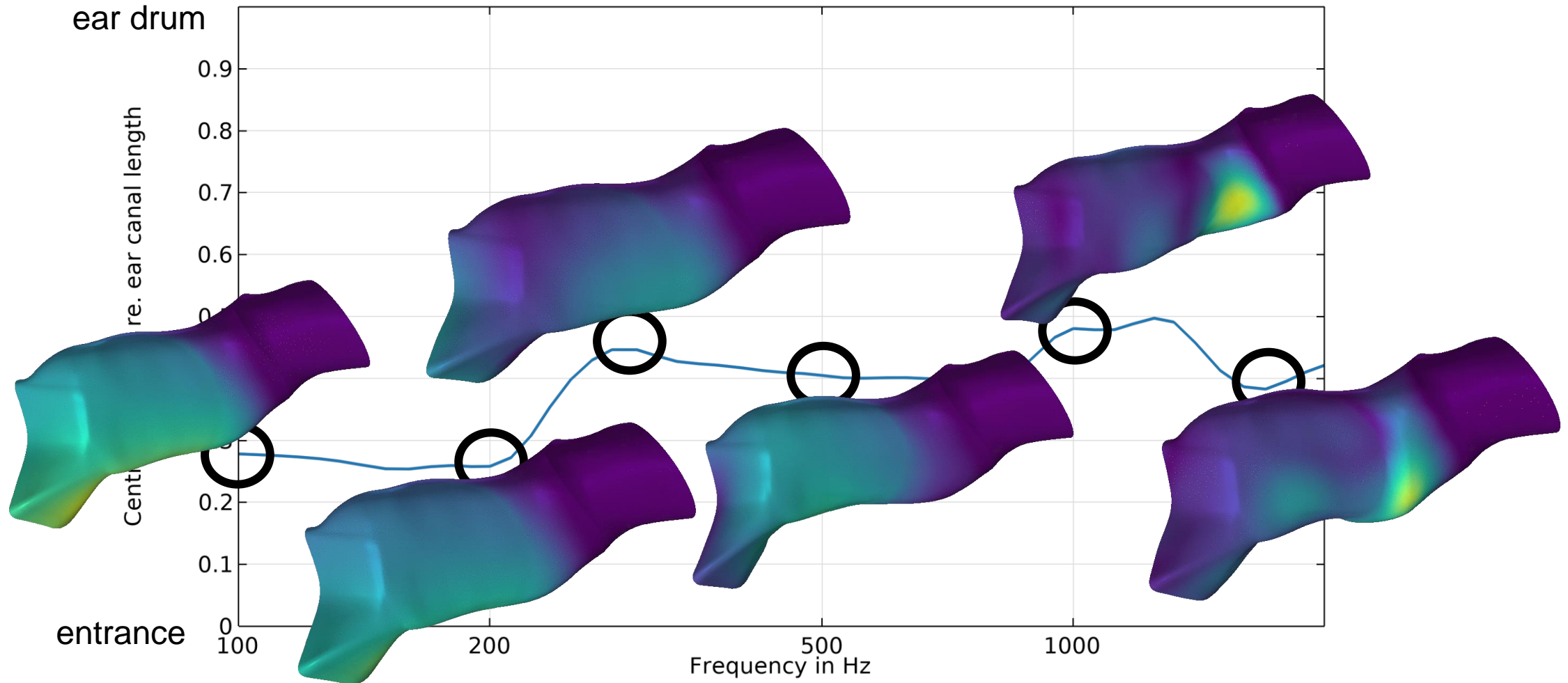
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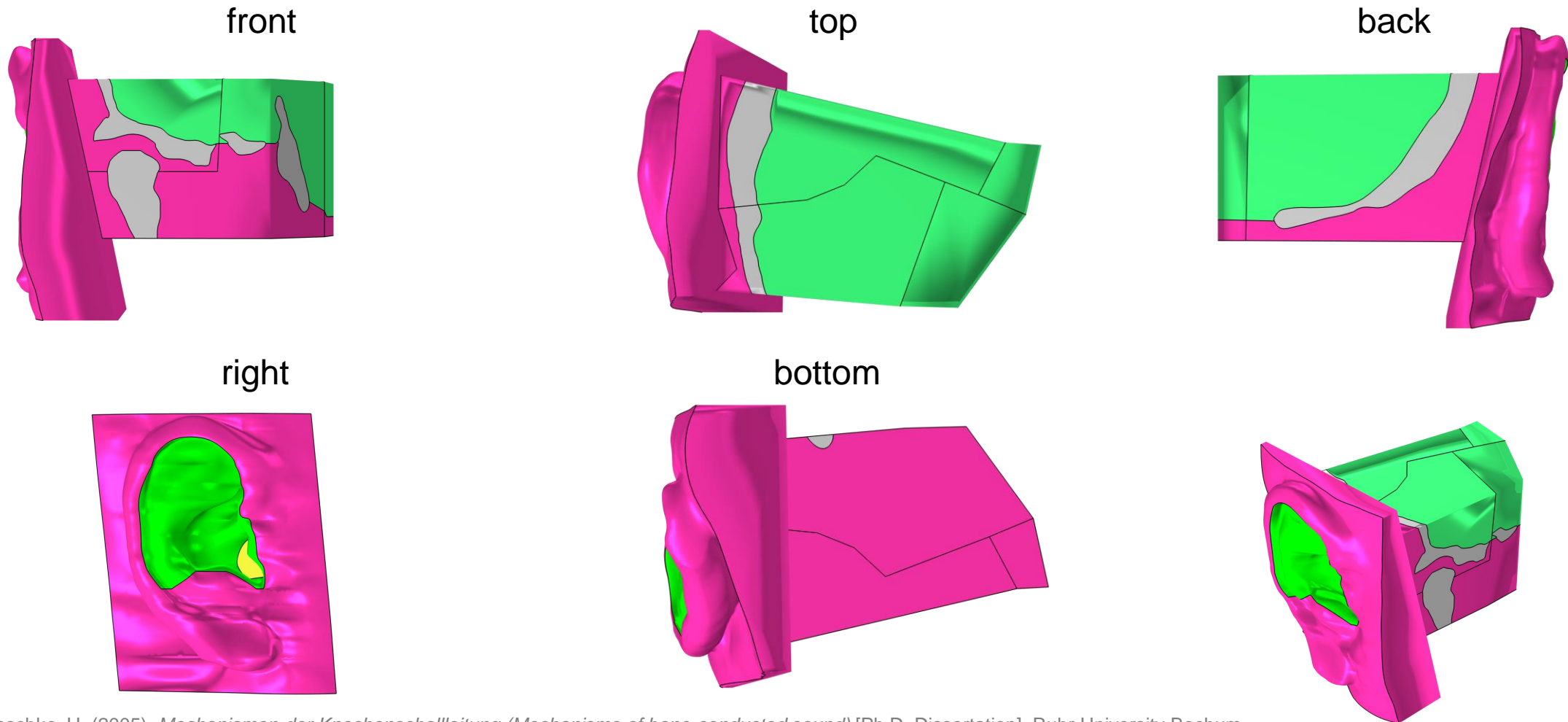


# Centroid position



cf. Carillo, K., Doutres, O., & Sgard, F. (2020). Theoretical investigation of the low frequency fundamental mechanism of the objective occlusion effect induced by bone-conducted stimulation. *The Journal of the Acoustical Society of America*, 147(5), 3476–3489.

# Geometry



cf. Taschke, H. (2005). *Mechanismen der Knochenschalleitung (Mechanisms of bone-conducted sound)* [Ph.D. Dissertation]. Ruhr University Bochum.