

Capturing the elevation dependence of ITD using an extension of the spherical-head model

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3D3A Laboratory, Princeton University

This talk is based on the work by Sridhar and Choueiri, published under the same title as paper number 9447 in the proceedings of the AES 139th convention

Outline

- Introduction & motivation
- Background & previous work
- Spherical-head model for ITD estimation
- Proposed extension to spherical-head model
- Evaluation of models
- Conclusions

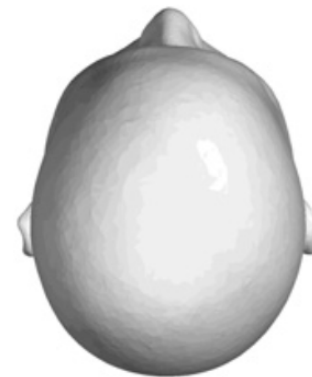
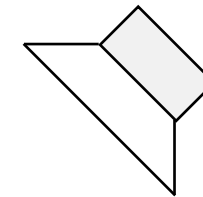
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Introduction & motivation

What is ITD?

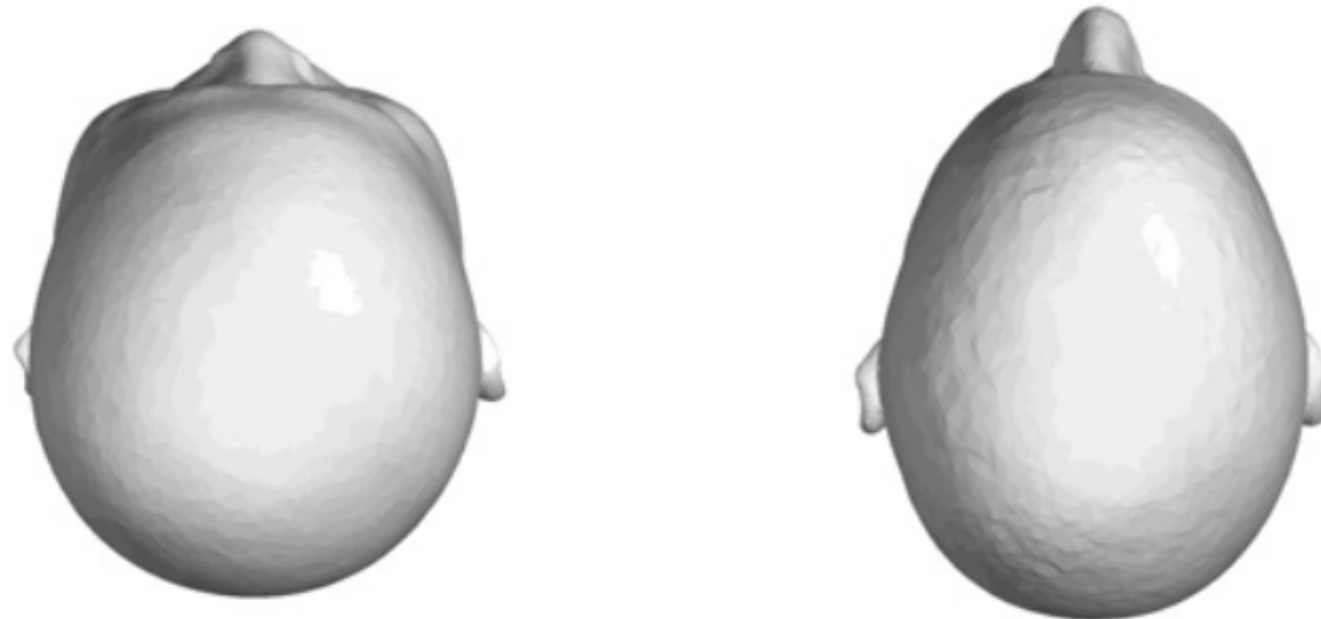
sound source



Top view of human head

Introduction & motivation

Why must it be individualized?



Top view of two different human heads showing variations in head shape and size

Images taken from Ball *et al.* "A comparison between Chinese and Caucasian head shapes," *Applied Ergonomics* 41 (2010) 832-839

Introduction & motivation

How should we individualize it?

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Background & Previous Work

Techniques for estimating individualized ITDs

From measured HRIRs^{3,5}

3D scan + acoustic ray tracing⁶

Anthropometry-based model based on simple geometric shape of head^{4,12}

Anthropometry-based model based on spatial variation of ITD⁷⁻¹⁰

Background & Previous Work

Techniques for estimating individualized ITDs

From measured HRIRs^{3,5}



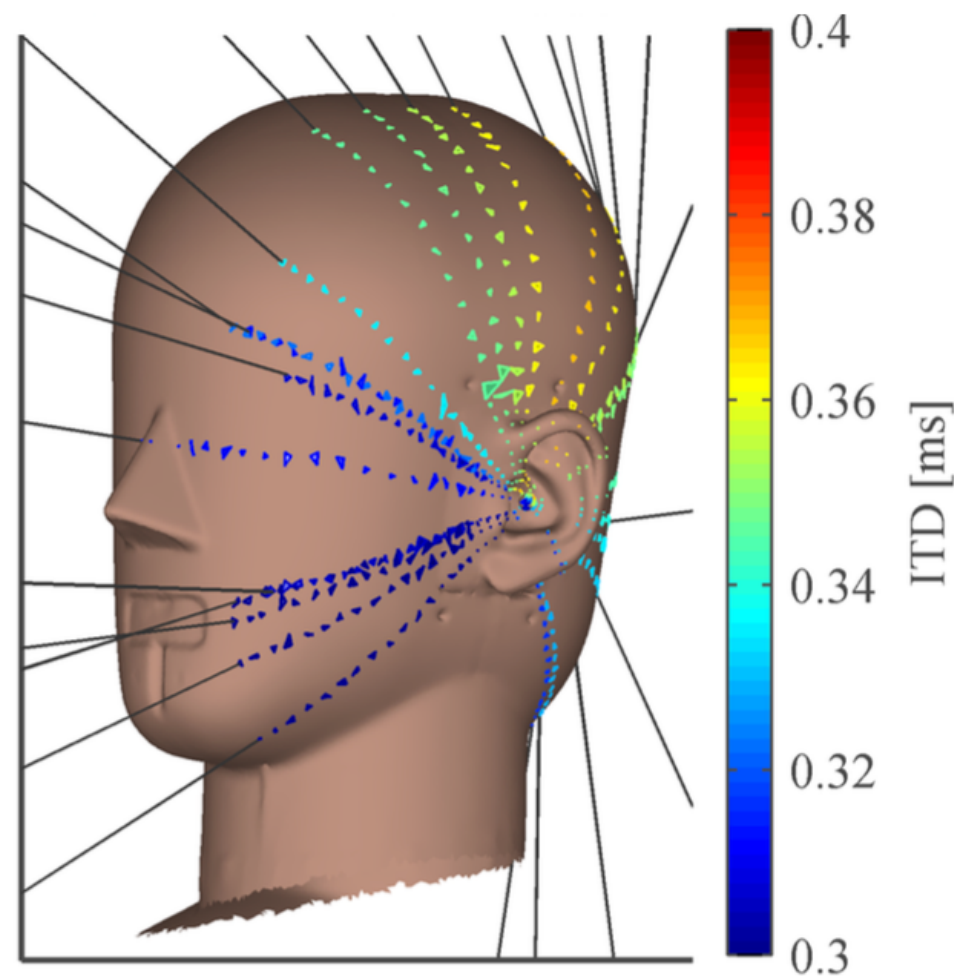
Sound localization facility at Wright Patterson Air Force Base in Dayton, Ohio

Image taken from Hartmann, W. M., "How We Localize Sound," *Physics Today*, pp. 24-29, 1999

Background & Previous Work

Techniques for estimating individualized ITDs

3D scan + acoustic ray tracing⁶



Propagation delay visualization. Sound source is 39 deg. to the right of the dummy head

Image take from Gamper, H. *et al.*, "Estimation of multi path propagation delays and interaural time differences from 3-D head scans," ICASSP 2015

Background & Previous Work

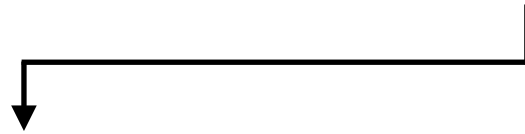
Techniques for estimating individualized ITDs

Anthropometry-based model based on simple geometric shape of head^{4,12}

Background & Previous Work

Techniques for estimating individualized ITDs

Anthropometry-based model based on simple geometric shape of head^{4,12}



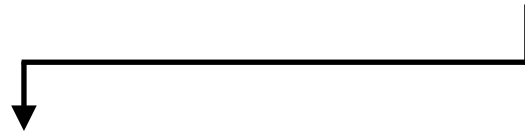
Ellipsoidal-head model⁴

fairly simple and accurate

Background & Previous Work

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Anthropometry-based model based on simple geometric shape of head^{4,12}



Ellipsoidal-head model⁴

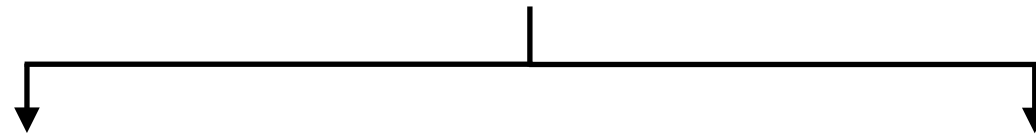
fairly simple and accurate

*tricky mapping to
anthropometric features*

Background & Previous Work

Techniques for estimating individualized ITDs

Anthropometry-based model based on simple geometric shape of head^{4,12}



Ellipsoidal-head model⁴

Spherical-head model¹²

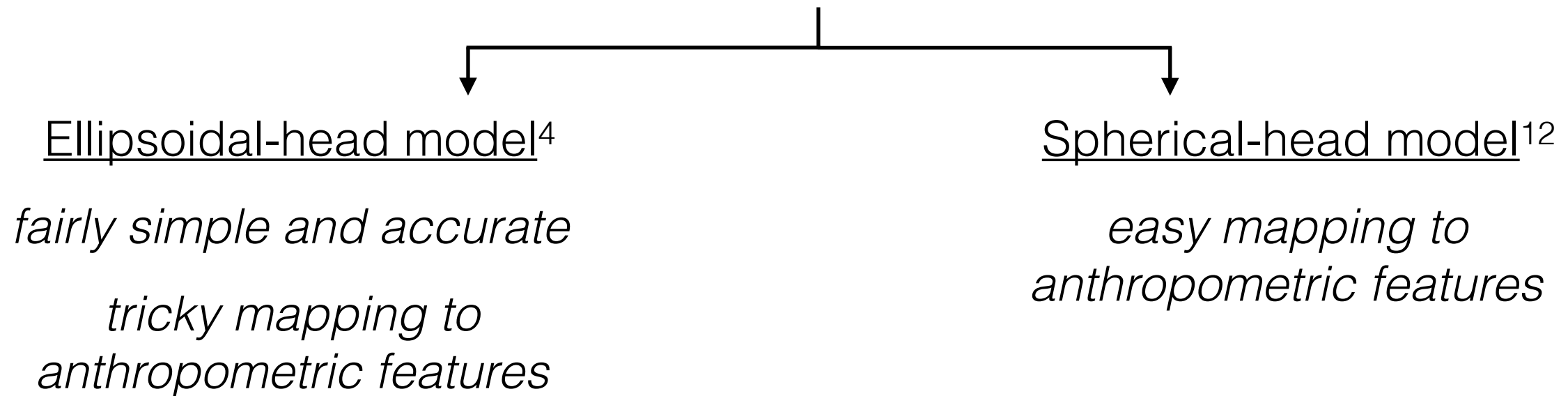
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Background & Previous Work

Techniques for estimating individualized ITDs

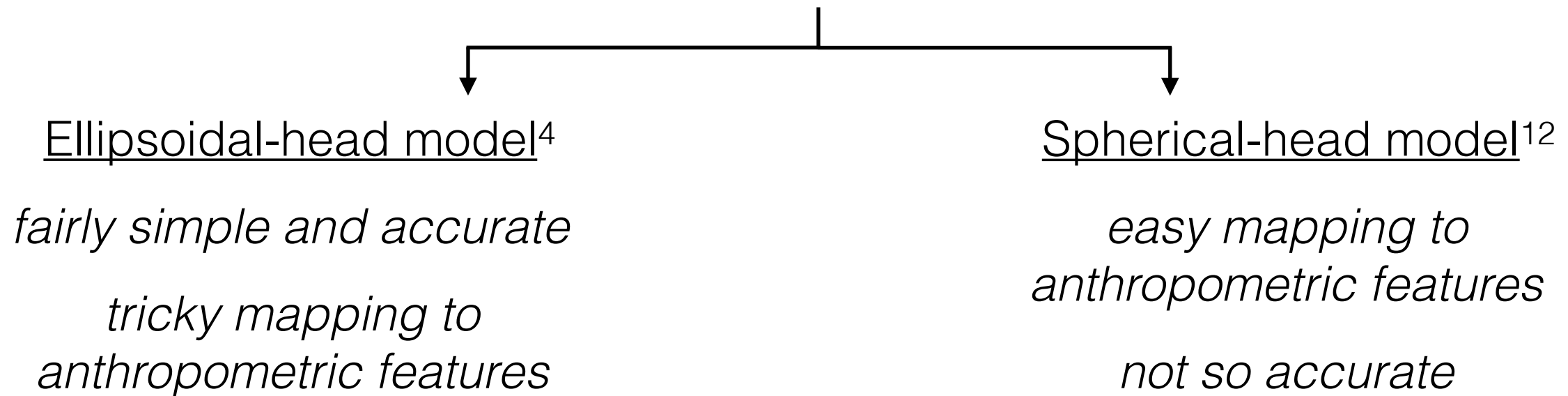
Anthropometry-based model based on simple geometric shape of head^{4,12}



Background & Previous Work

Techniques for estimating individualized ITDs

Anthropometry-based model based on simple geometric shape of head^{4,12}



Background & Previous Work

Techniques for estimating individualized ITDs

Anthropometry-based model based on spatial variation of ITD⁷⁻¹⁰

Background & Previous Work

Summary

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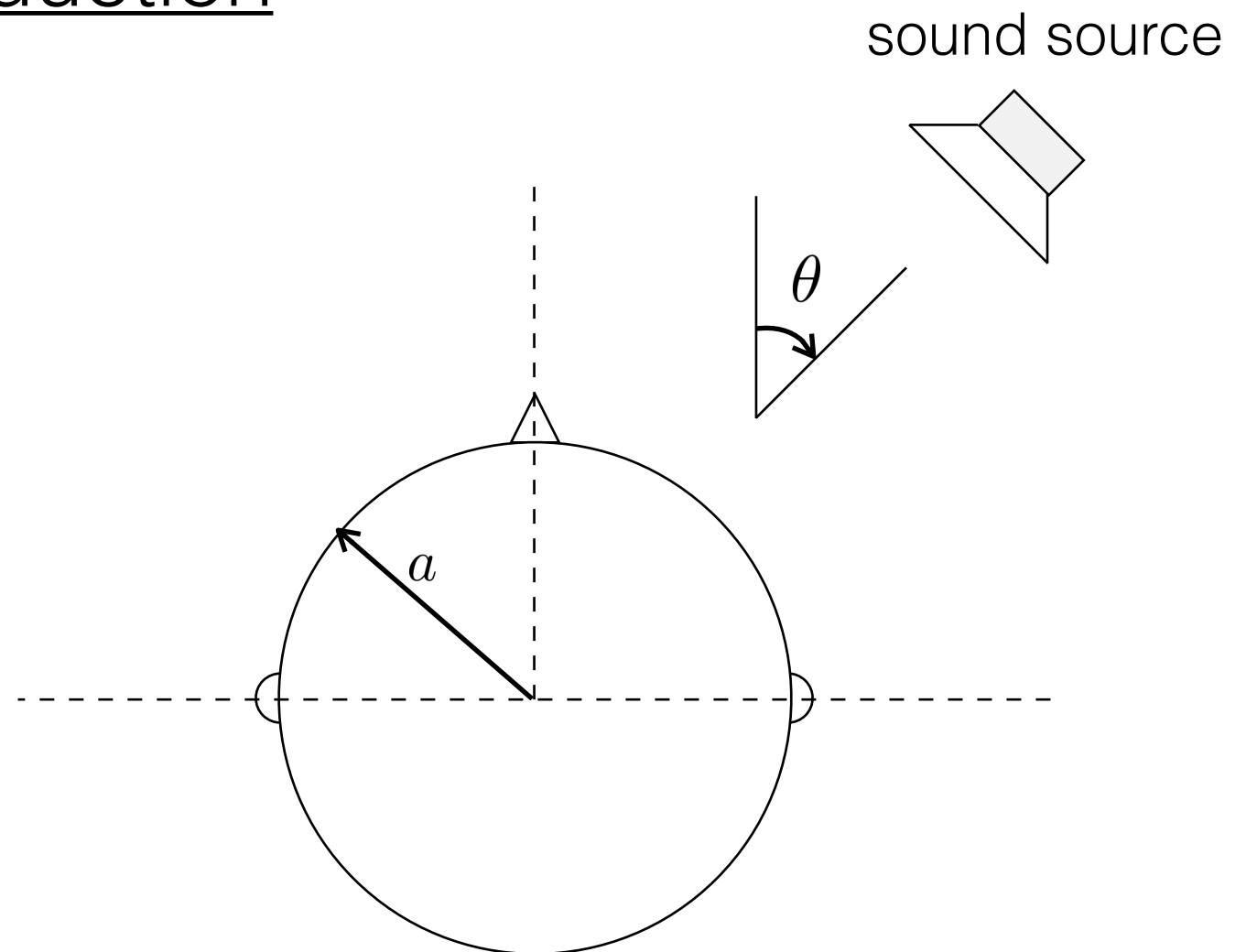
Spherical-head model for ITD estimation

Introduction

Woodworth & Schlosberg
formula¹¹

$$\tau_{W\&S} = \frac{a (\sin \theta + \theta)}{c}$$

c is speed of sound



Spherical-head (Top View)

Spherical-head model for ITD estimation

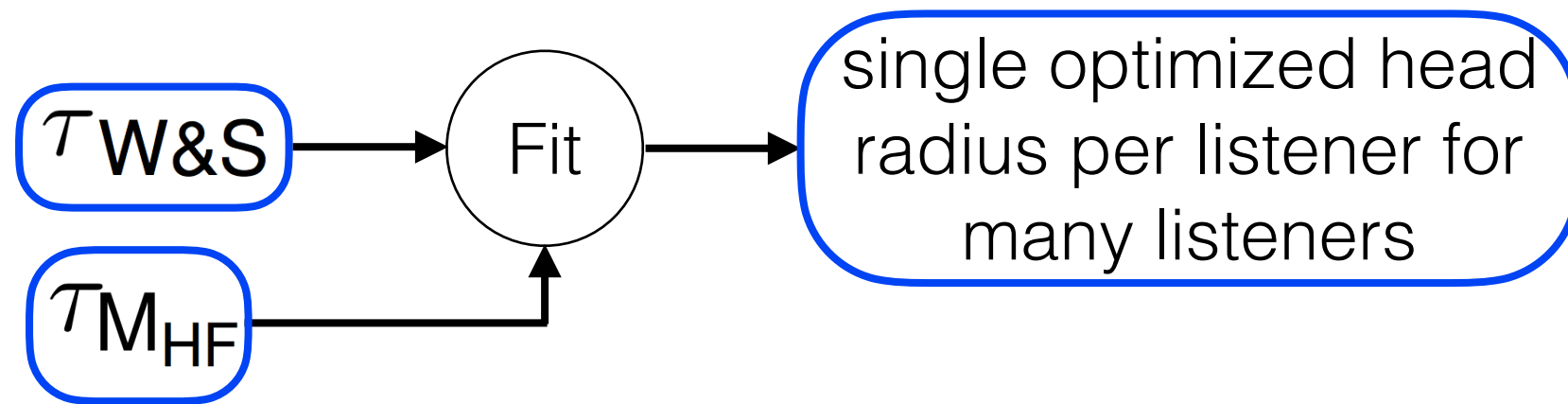
Model formulation

$\tau_{W\&S}$

$\tau_{M_{HF}}$

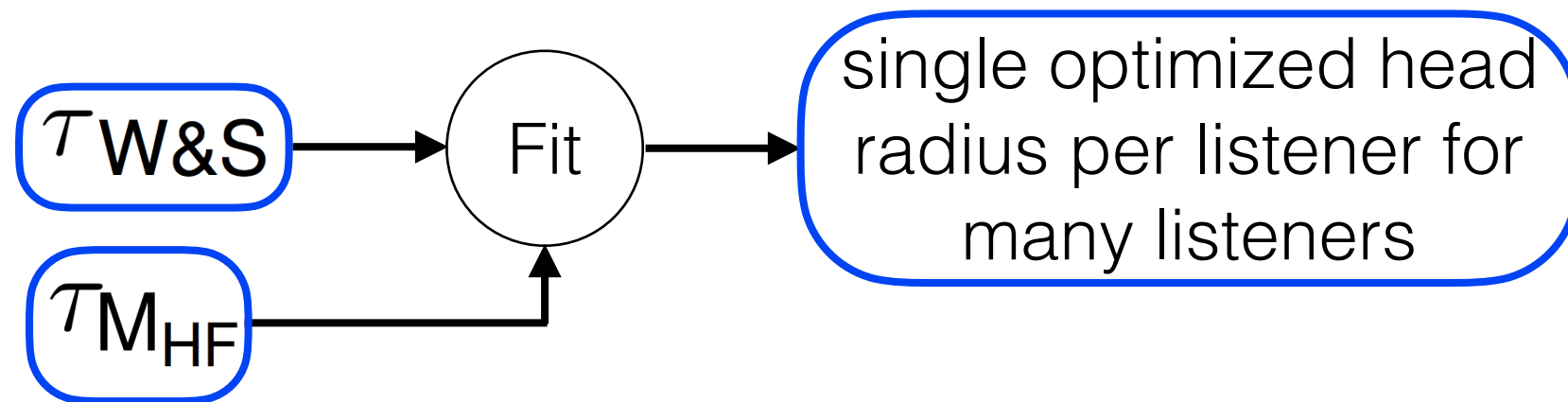
Spherical-head model for ITD estimation

Model formulation



Spherical-head model for ITD estimation

Model formulation

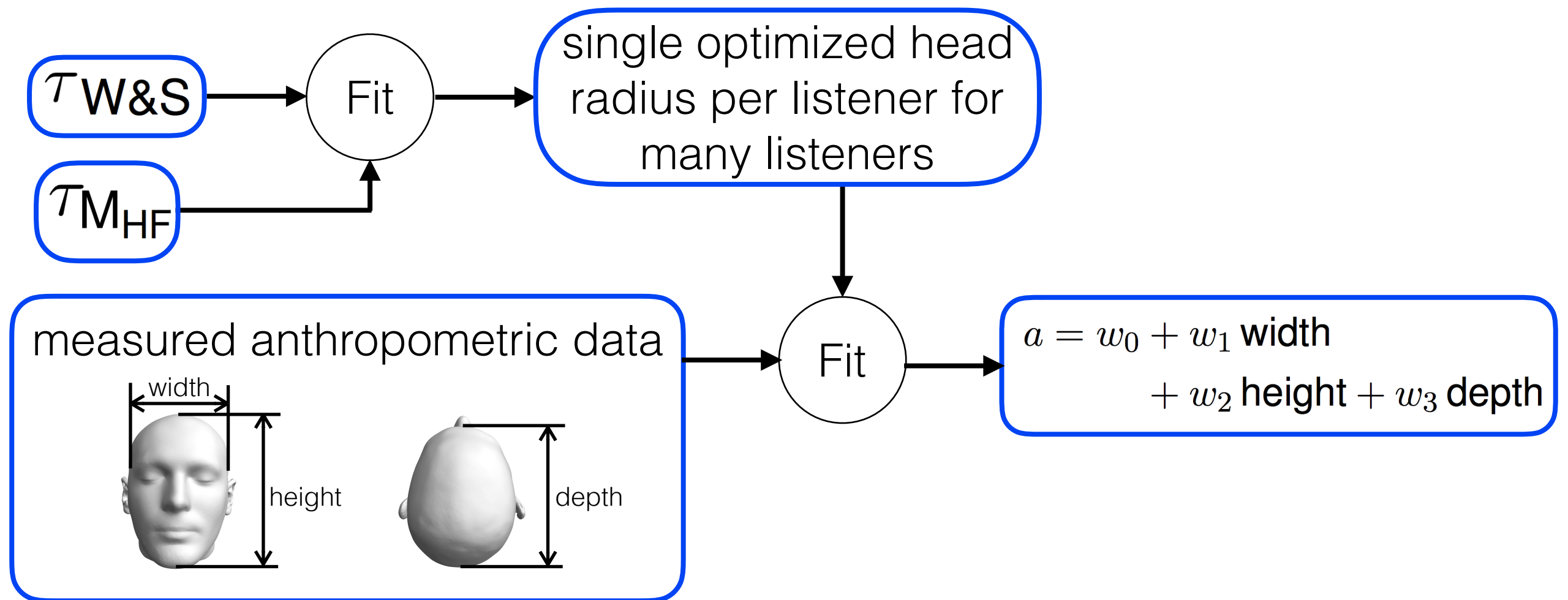


measured anthropometric data



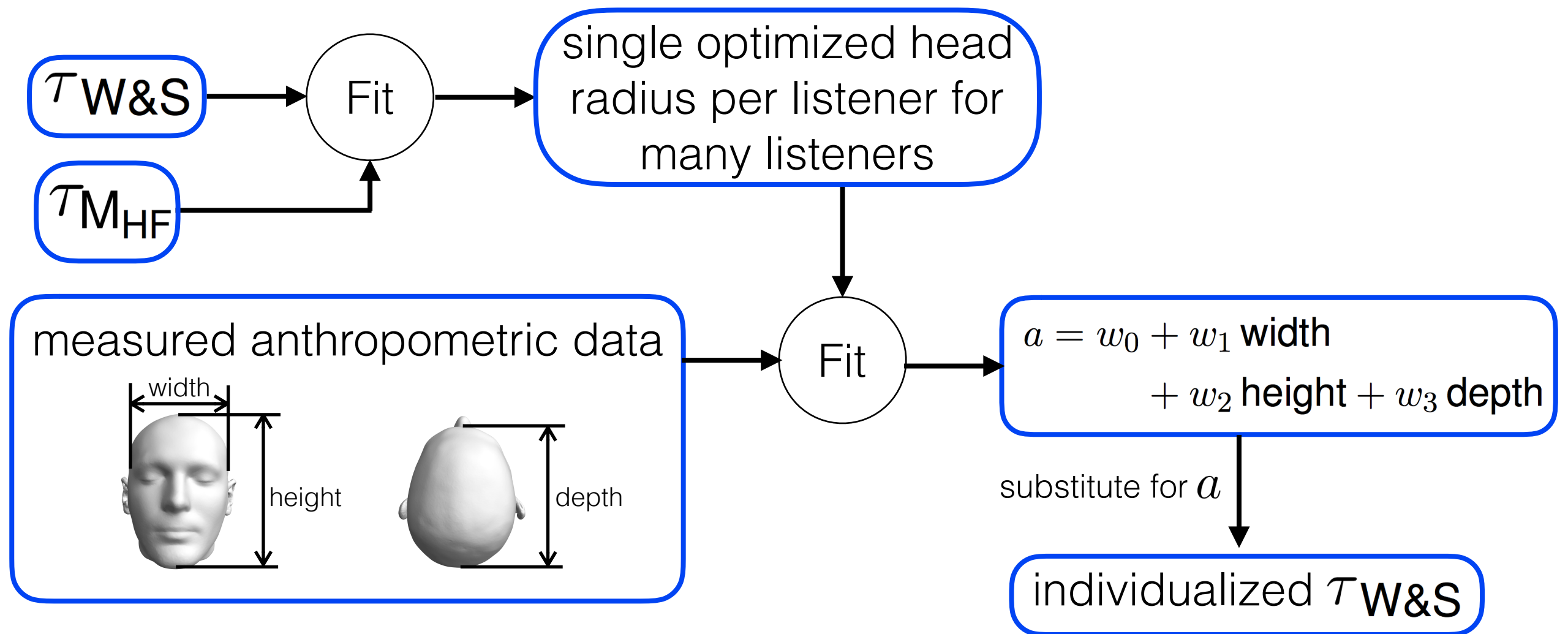
Spherical-head model for ITD estimation

Model formulation



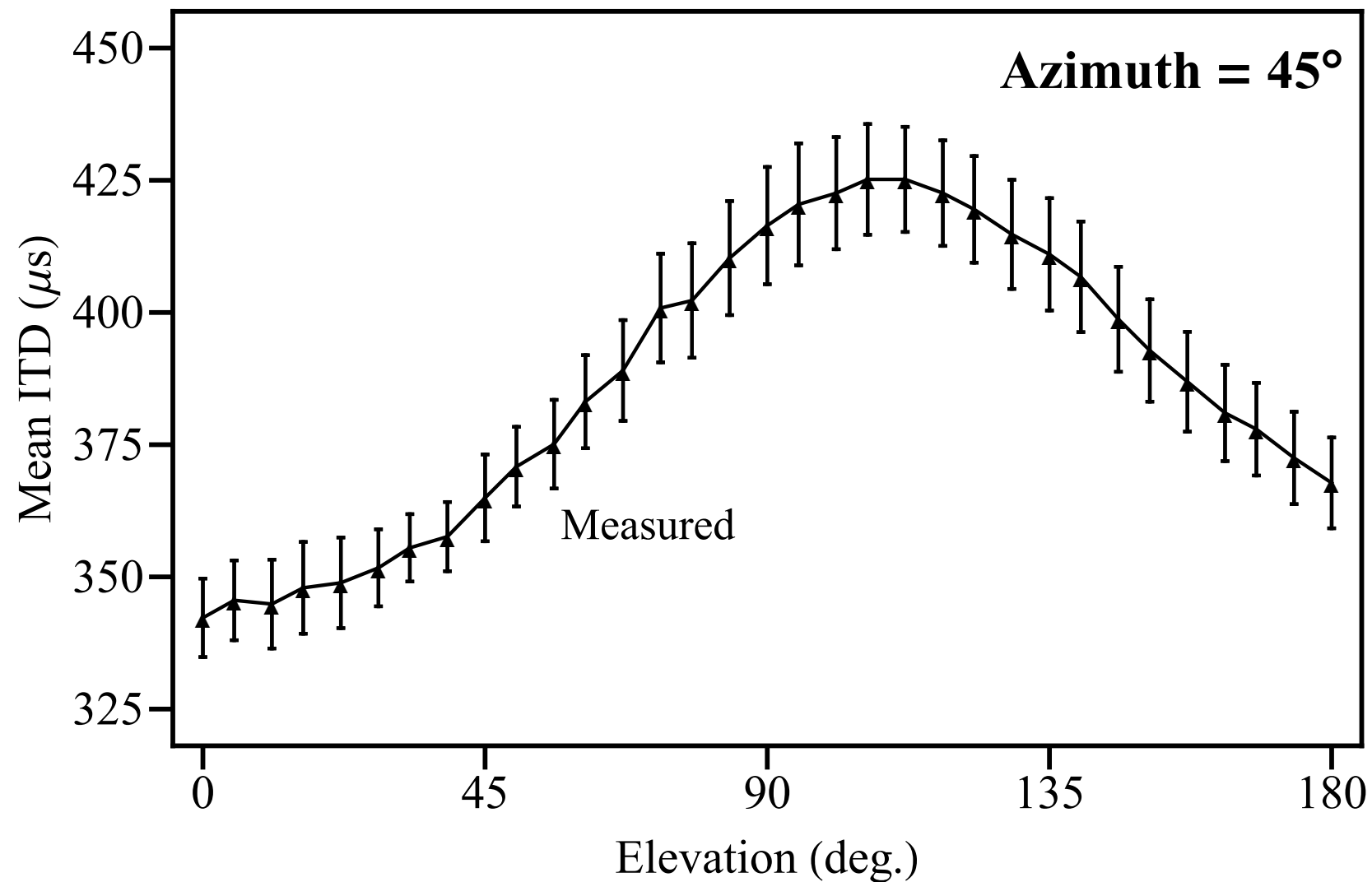
Spherical-head model for ITD estimation

Model formulation



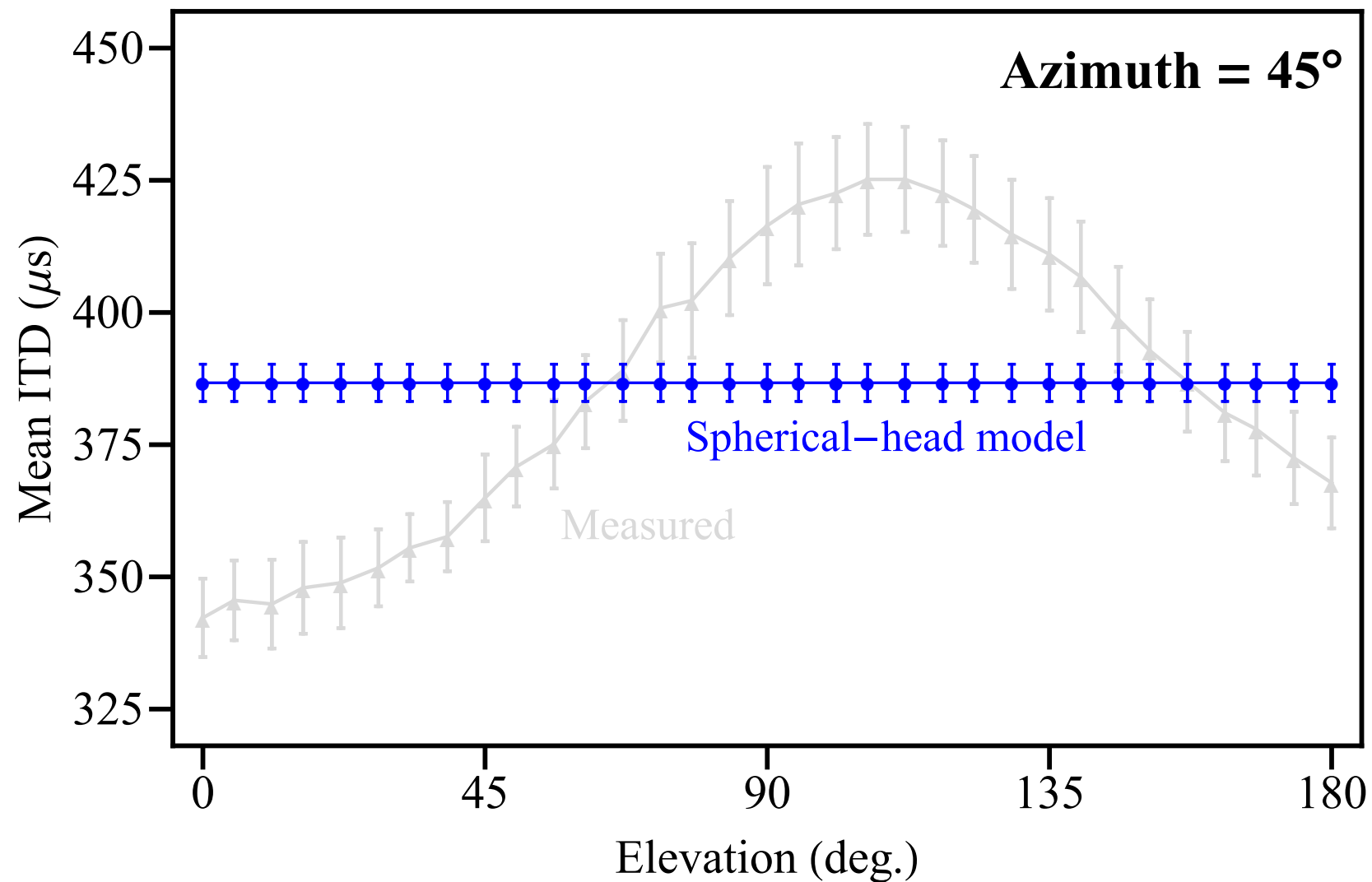
Spherical-head model for ITD estimation

Limitations



Spherical-head model for ITD estimation

Limitations



Spherical-head model for ITD estimation

Limitations

$$\tau_{LF} = 1.5 \times \tau_{W\&S}$$

Outline

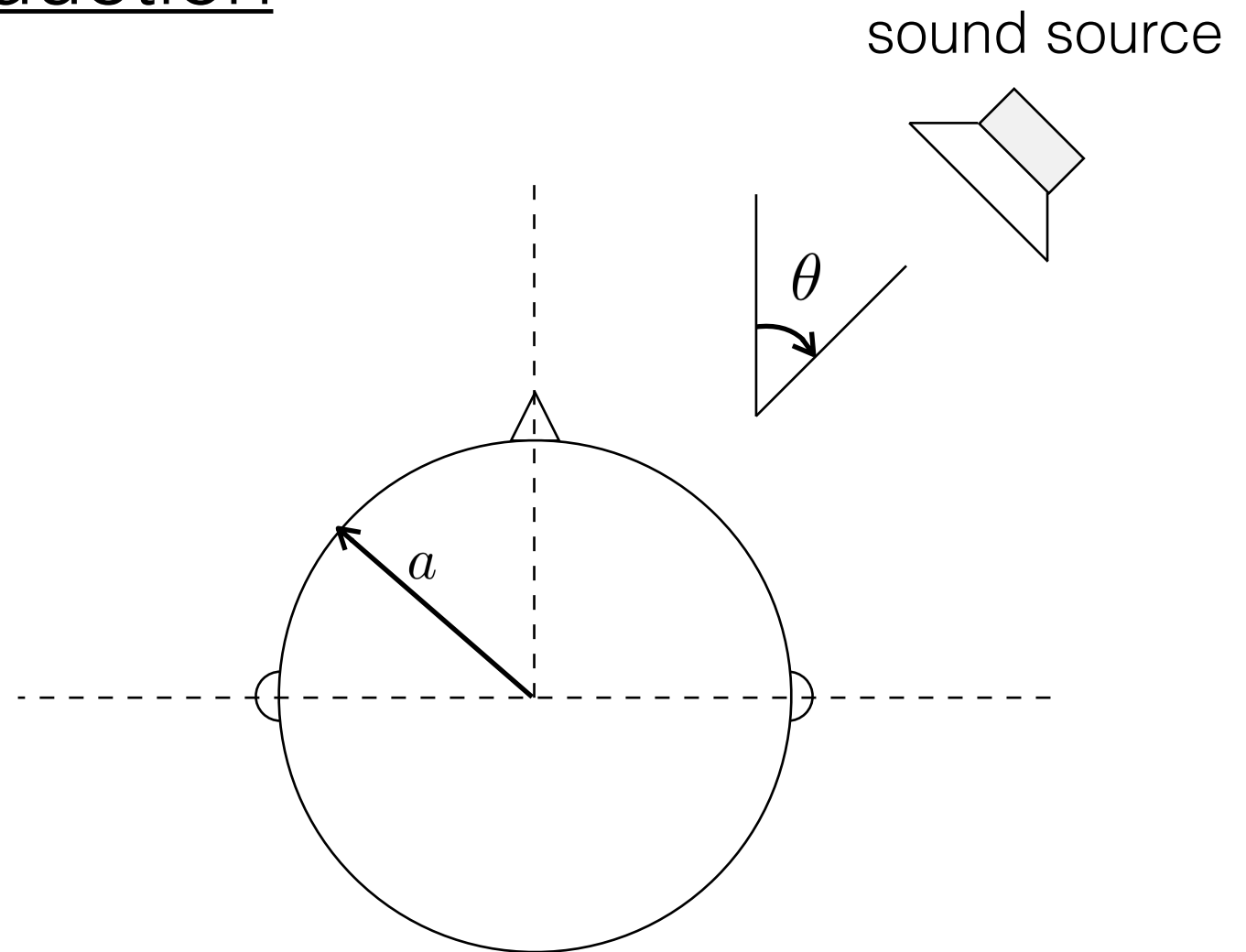
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Proposed extension to spherical-head model

Introduction

Woodworth & Schlosberg
formula¹¹

$$\tau_{W\&S} = \frac{a (\sin \theta + \theta)}{c}$$



Spherical-head (Top View)

Proposed extension to spherical-head model

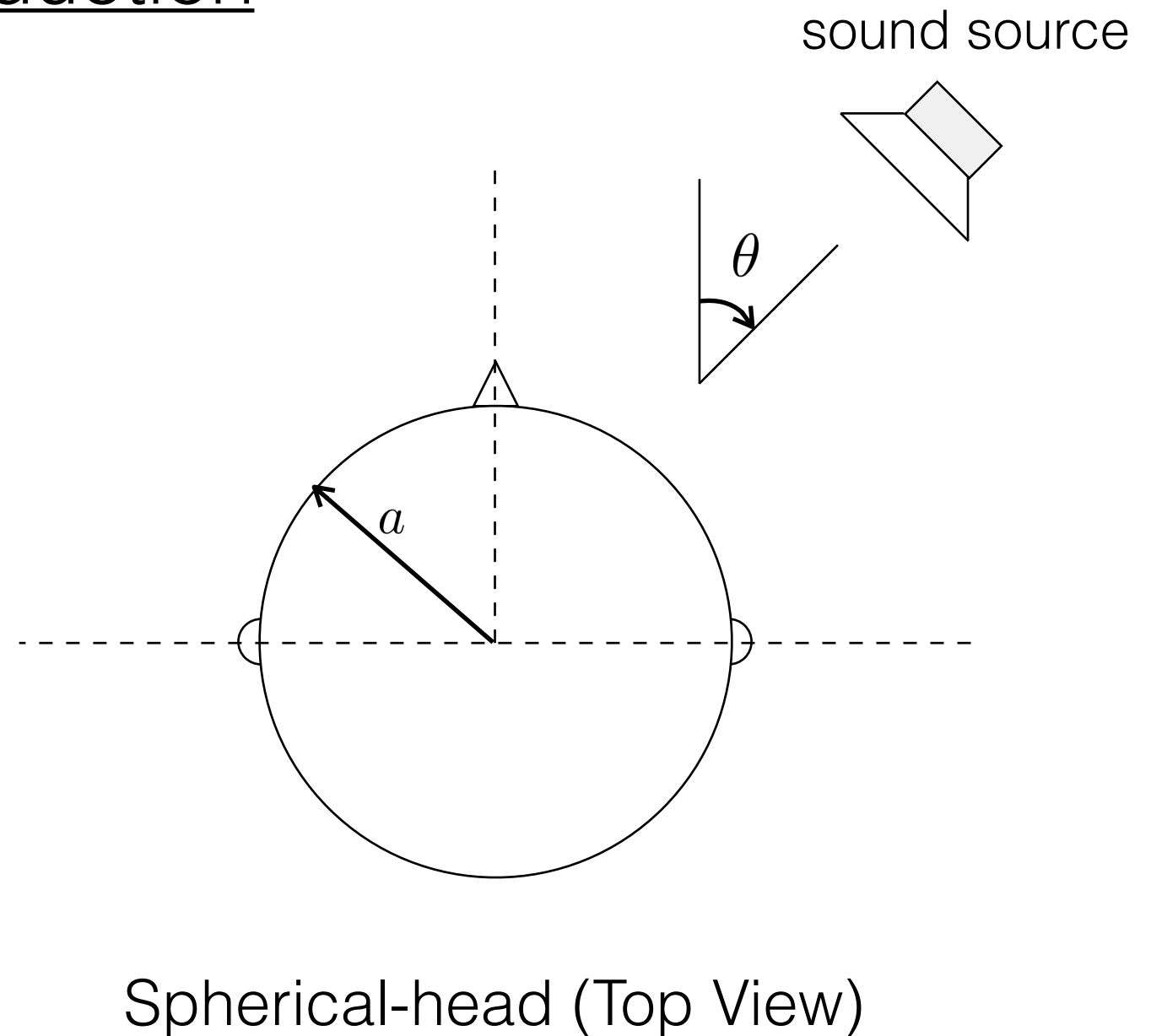
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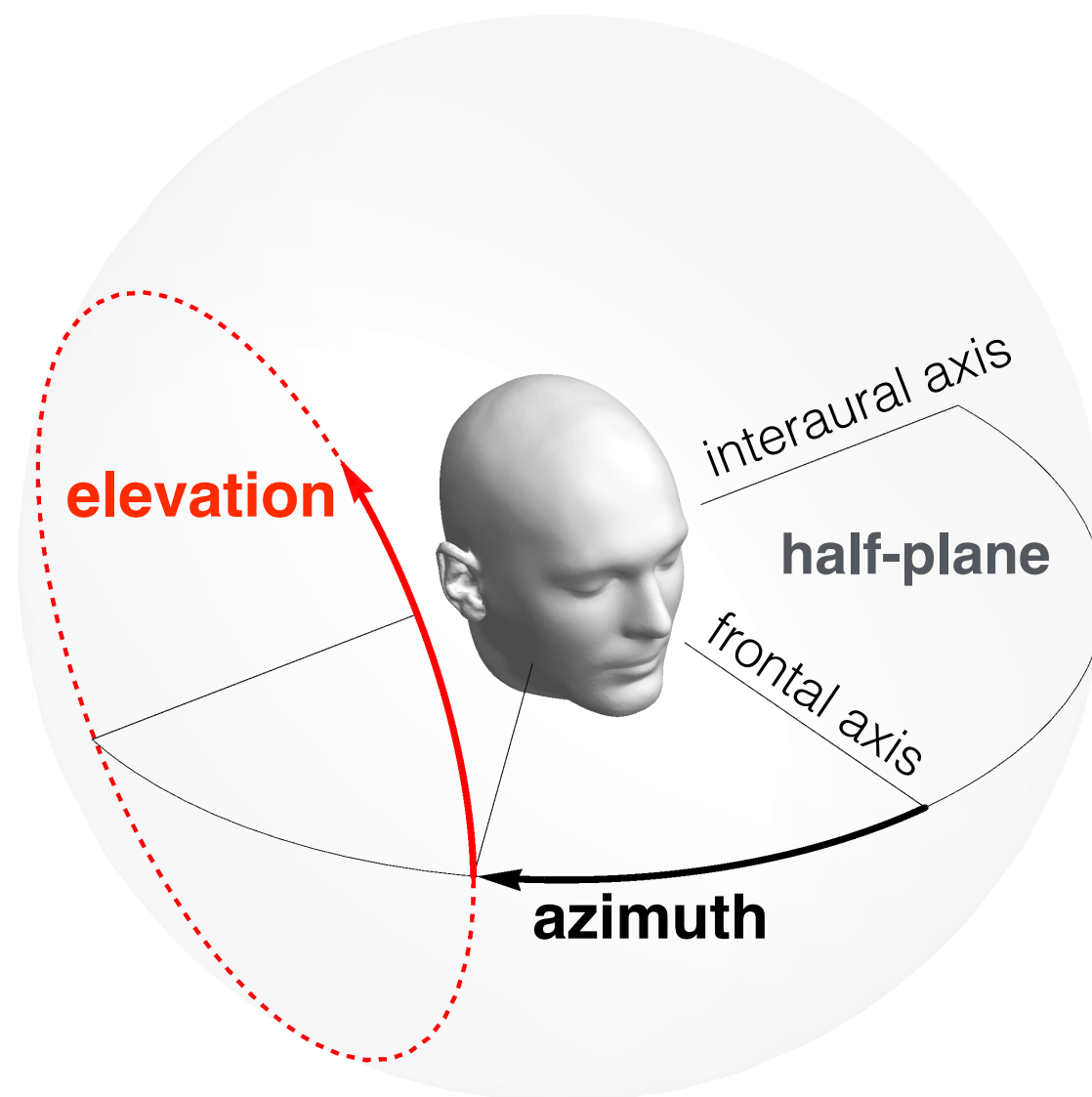
Formula for estimating
low-frequency ITD¹

$$\tau_{LF} = \frac{3 a \sin \theta}{c}$$



Proposed extension to spherical-head model

Introduction



Interaural coordinate system

Proposed extension to spherical-head model

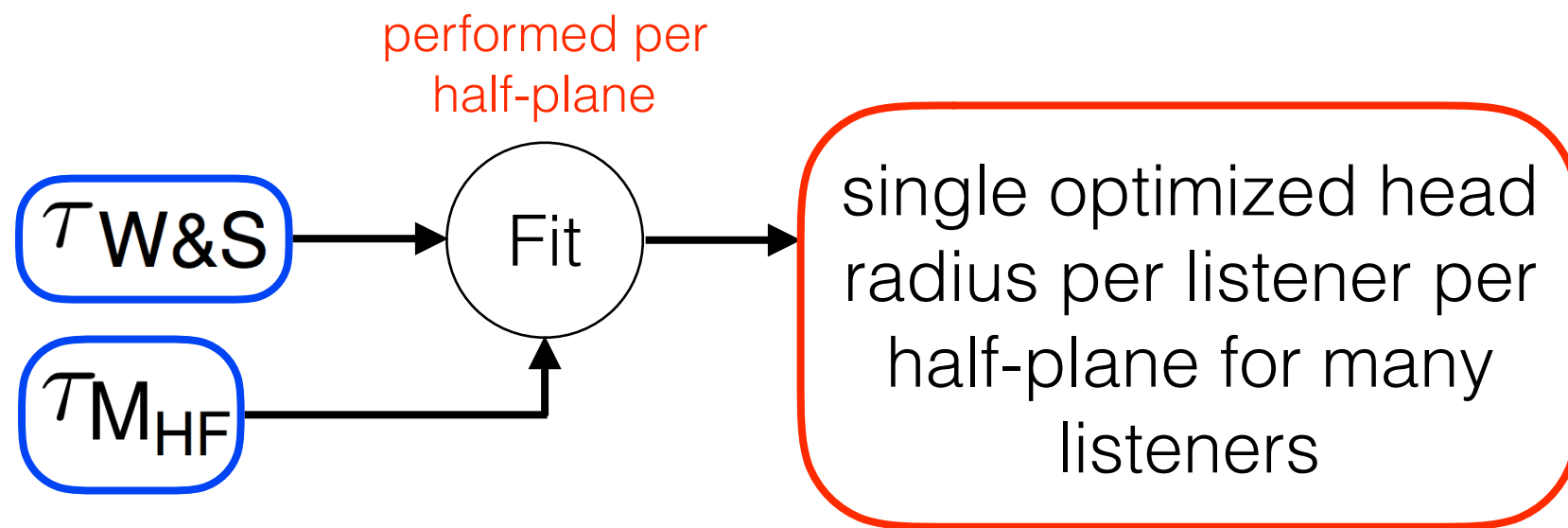
Model formulation

$\tau_{W\&S}$

$\tau_{M_{HF}}$

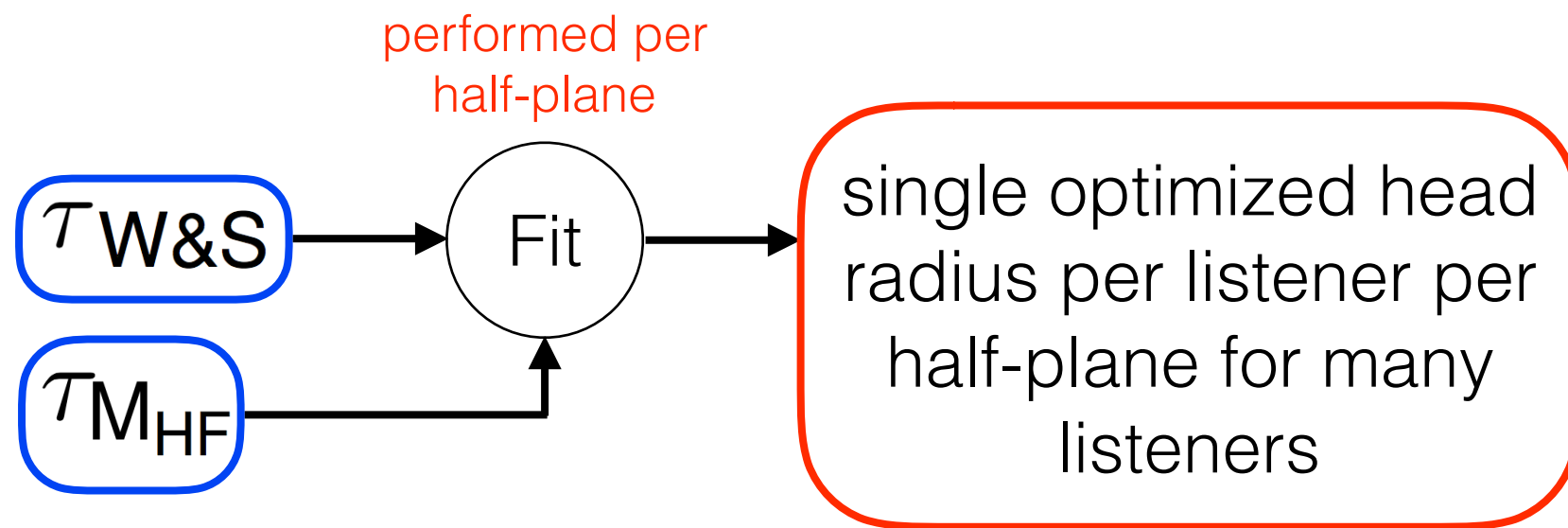
Proposed extension to spherical-head model

Model formulation

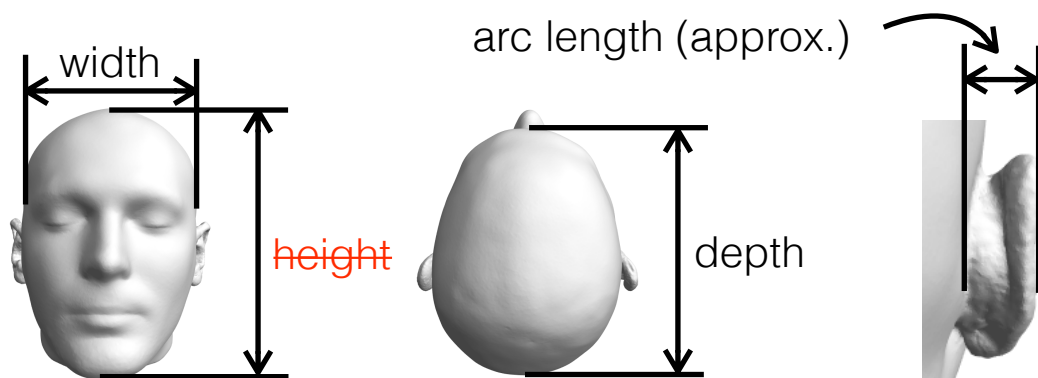


Proposed extension to spherical-head model

Model formulation

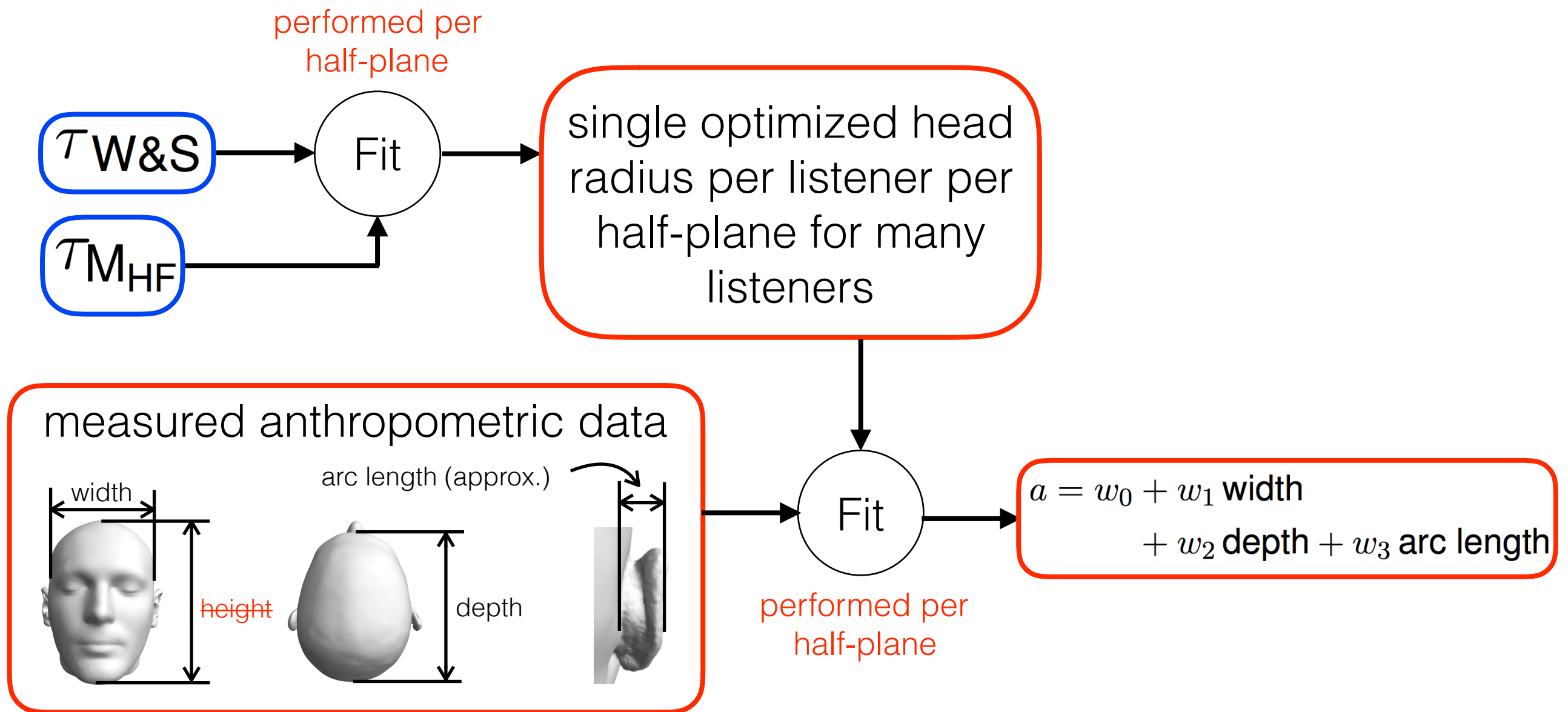


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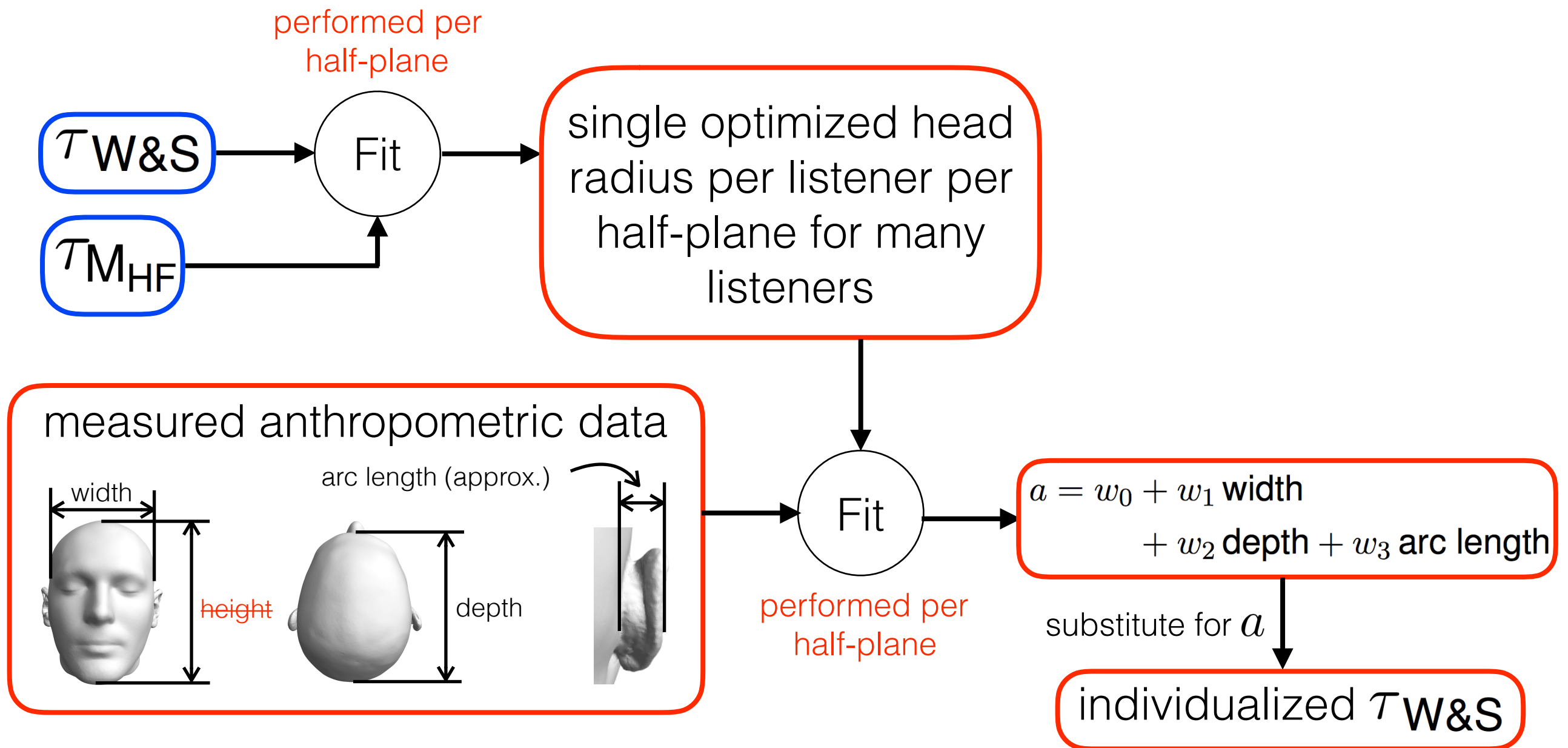
Proposed extension to spherical-head model

Model formulation



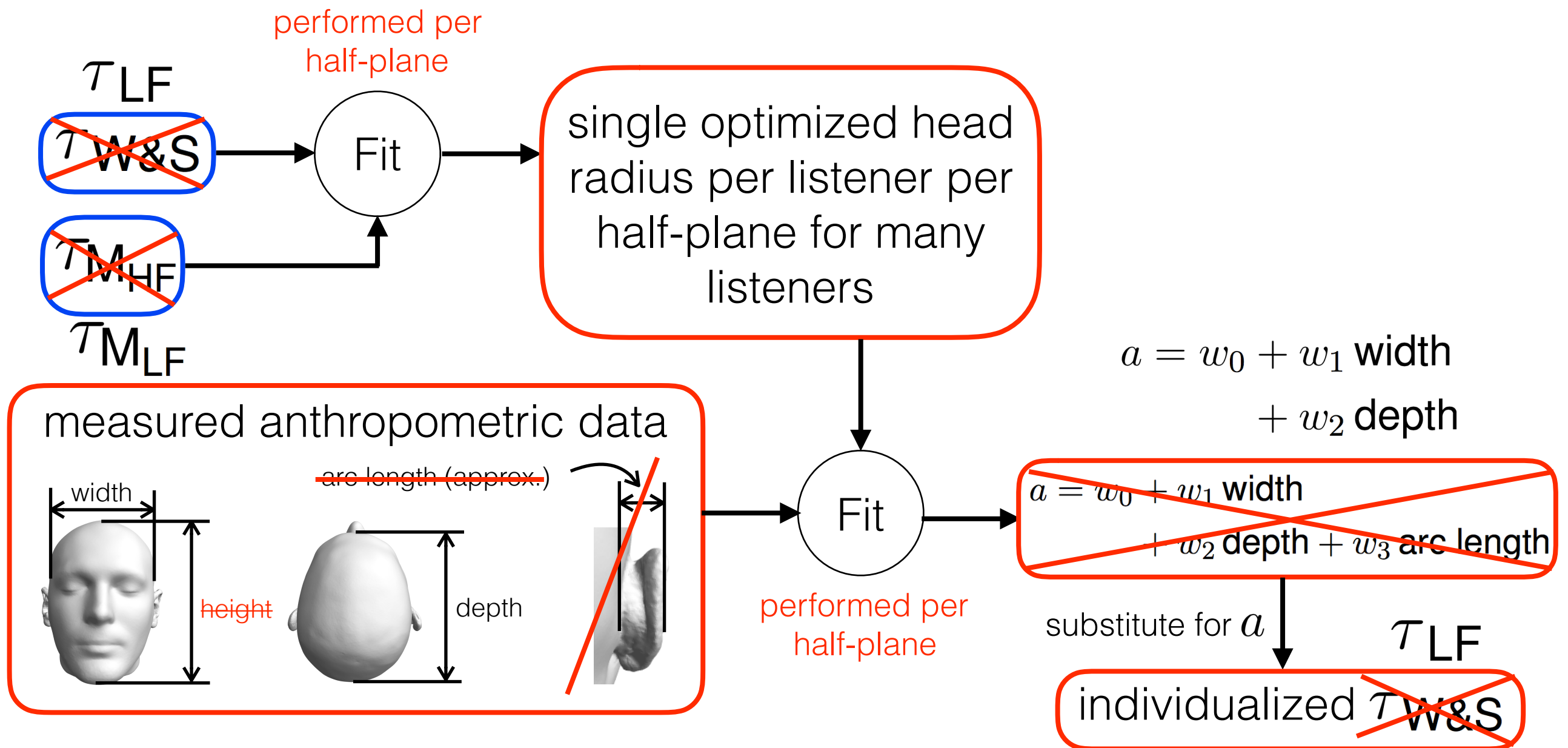
Proposed extension to spherical-head model

Model formulation



Proposed extension to spherical-head model

Model formulation (low-frequency ITD)

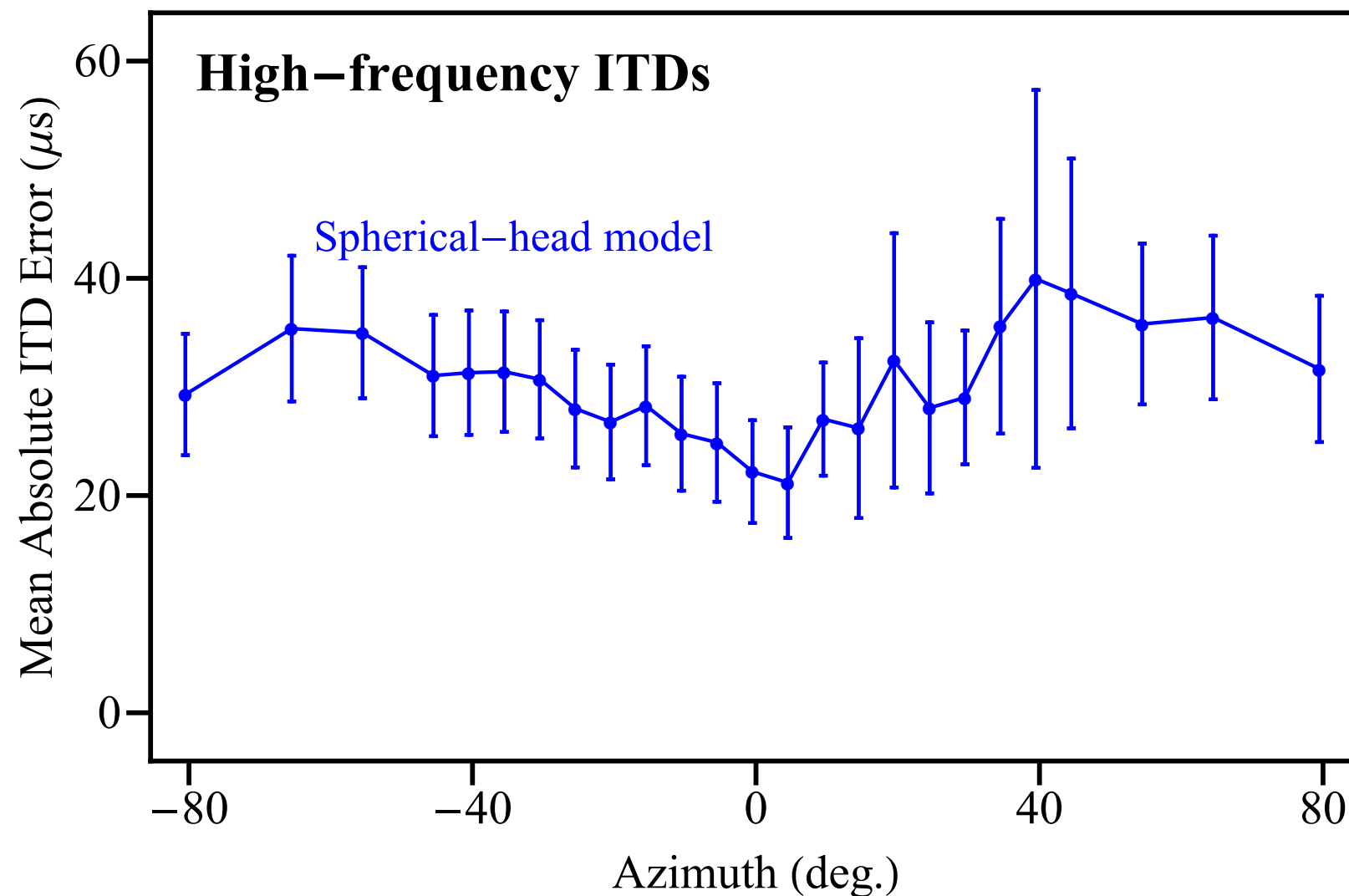


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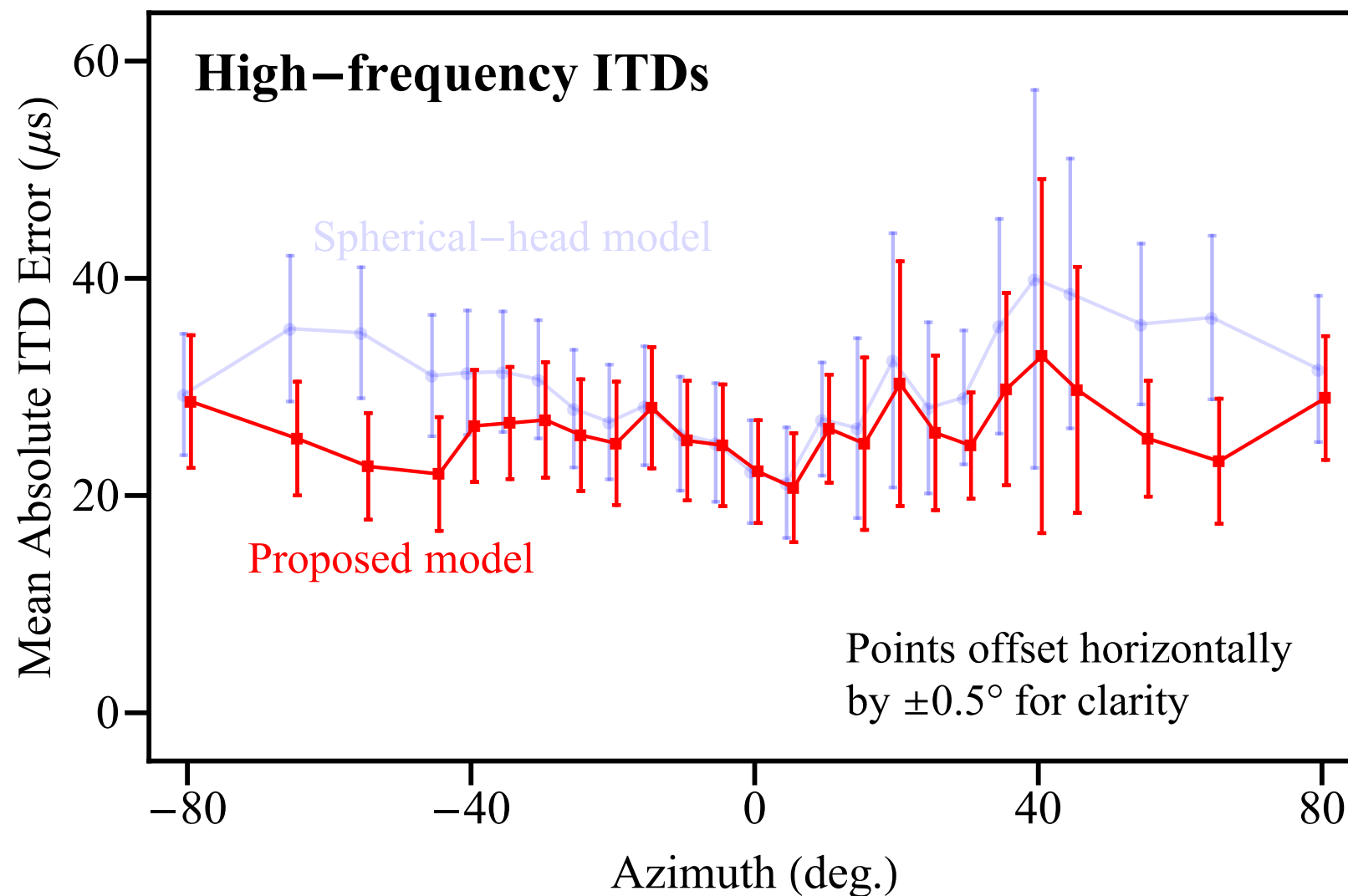
Evaluation of models

High-frequency ITD estimation accuracy



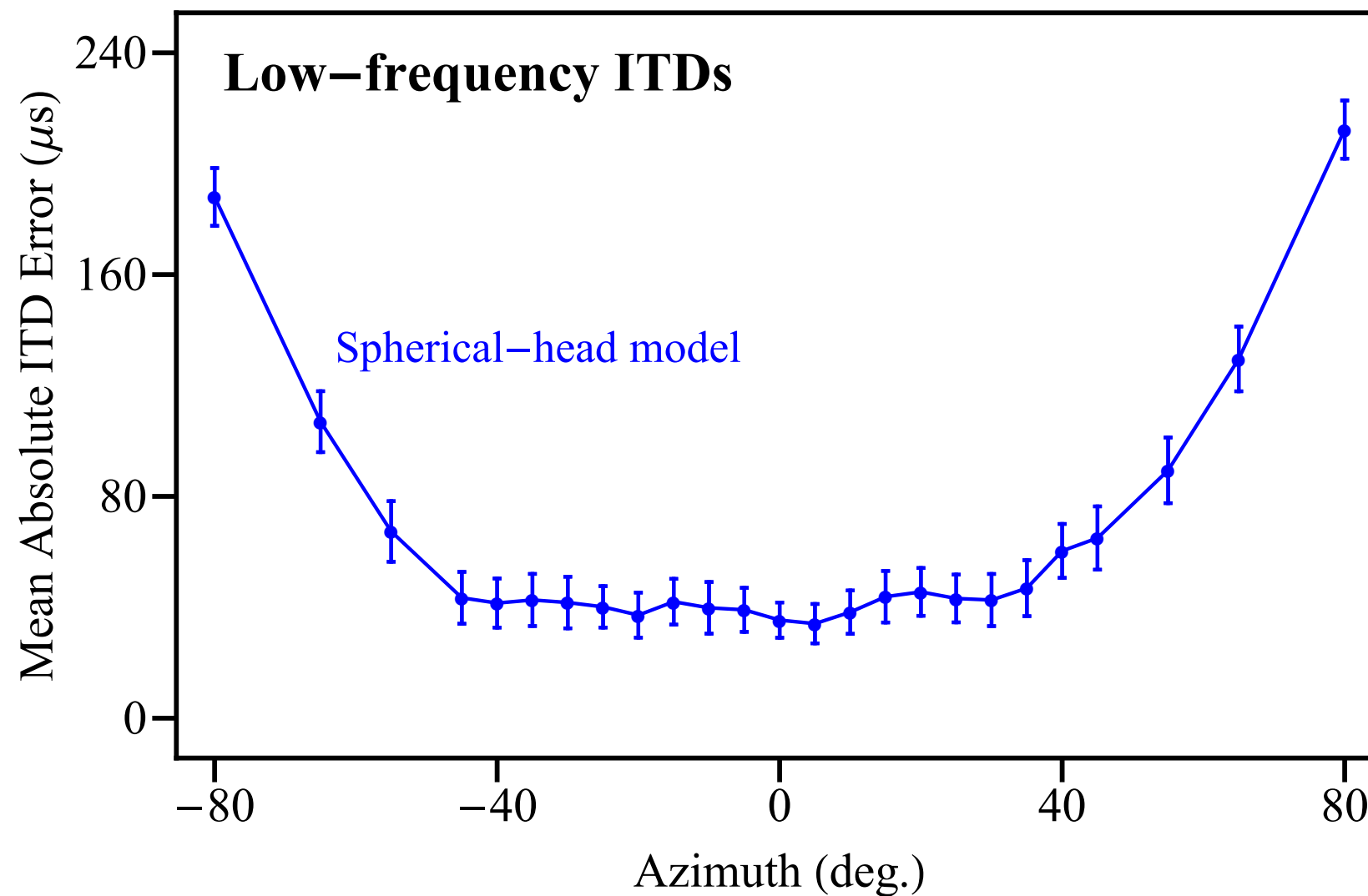
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High-frequency ITD estimation accuracy



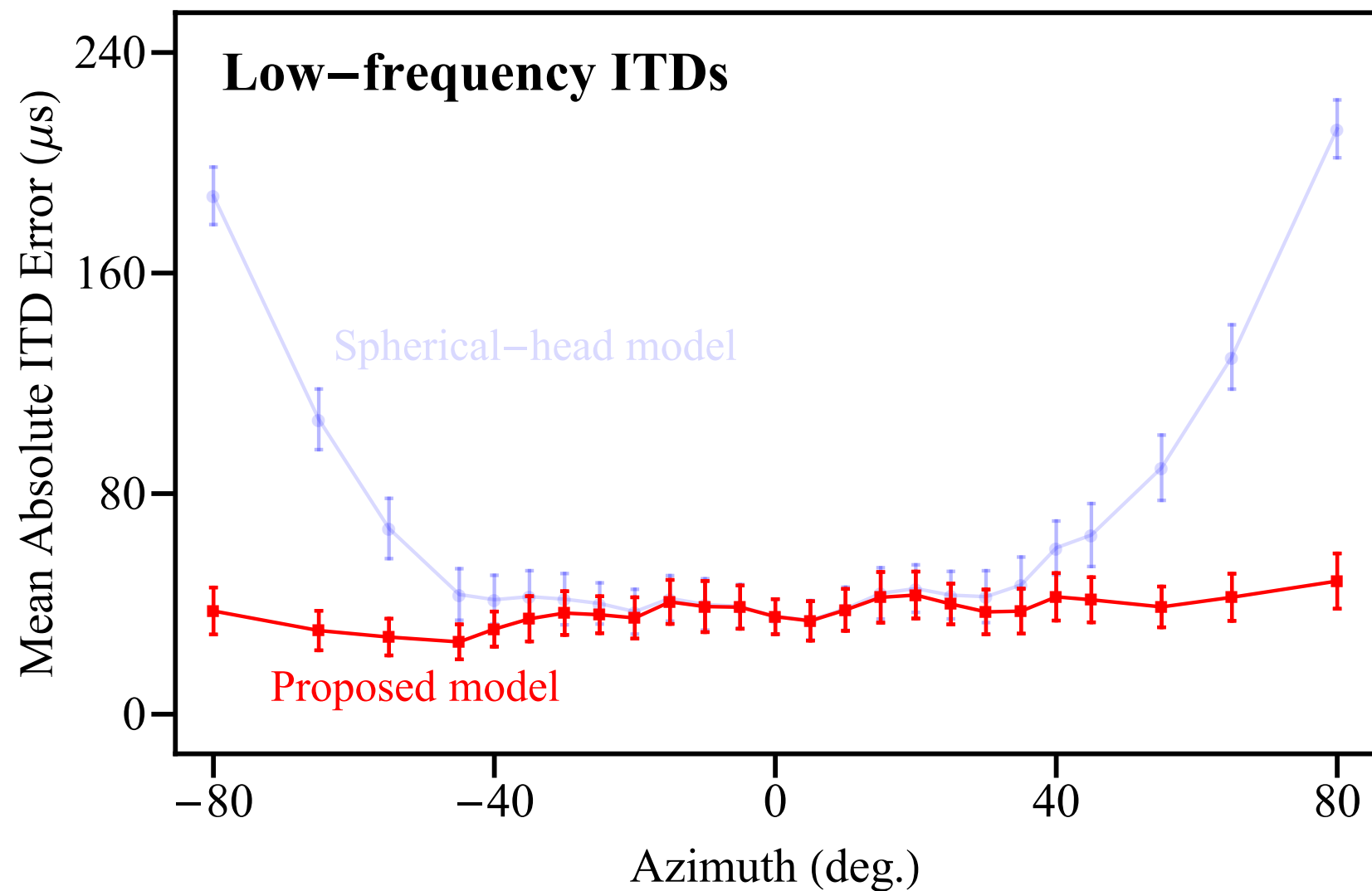
Evaluation of models

Low-frequency ITD estimation accuracy



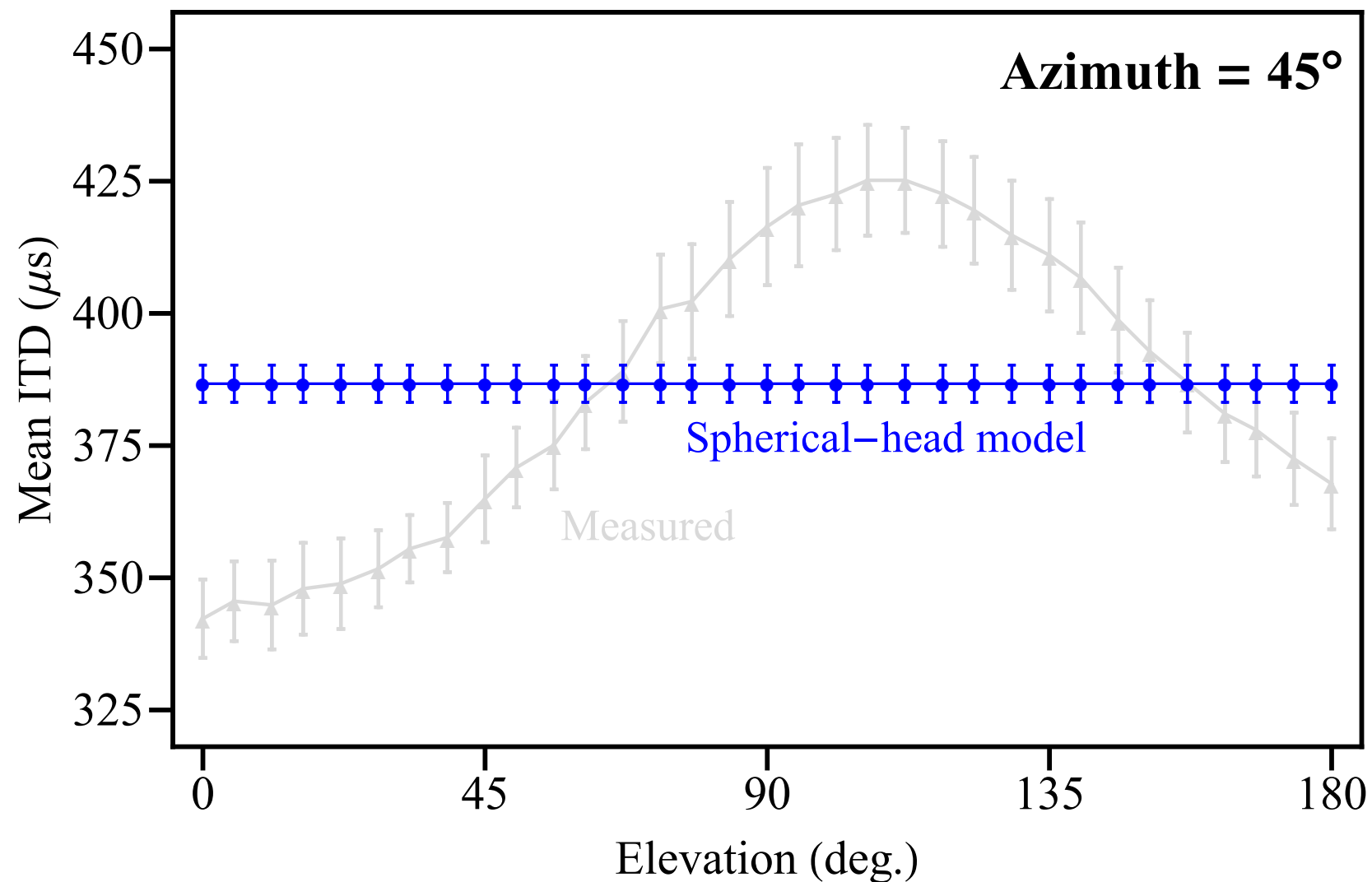
Evaluation of models

Low-frequency ITD estimation accuracy



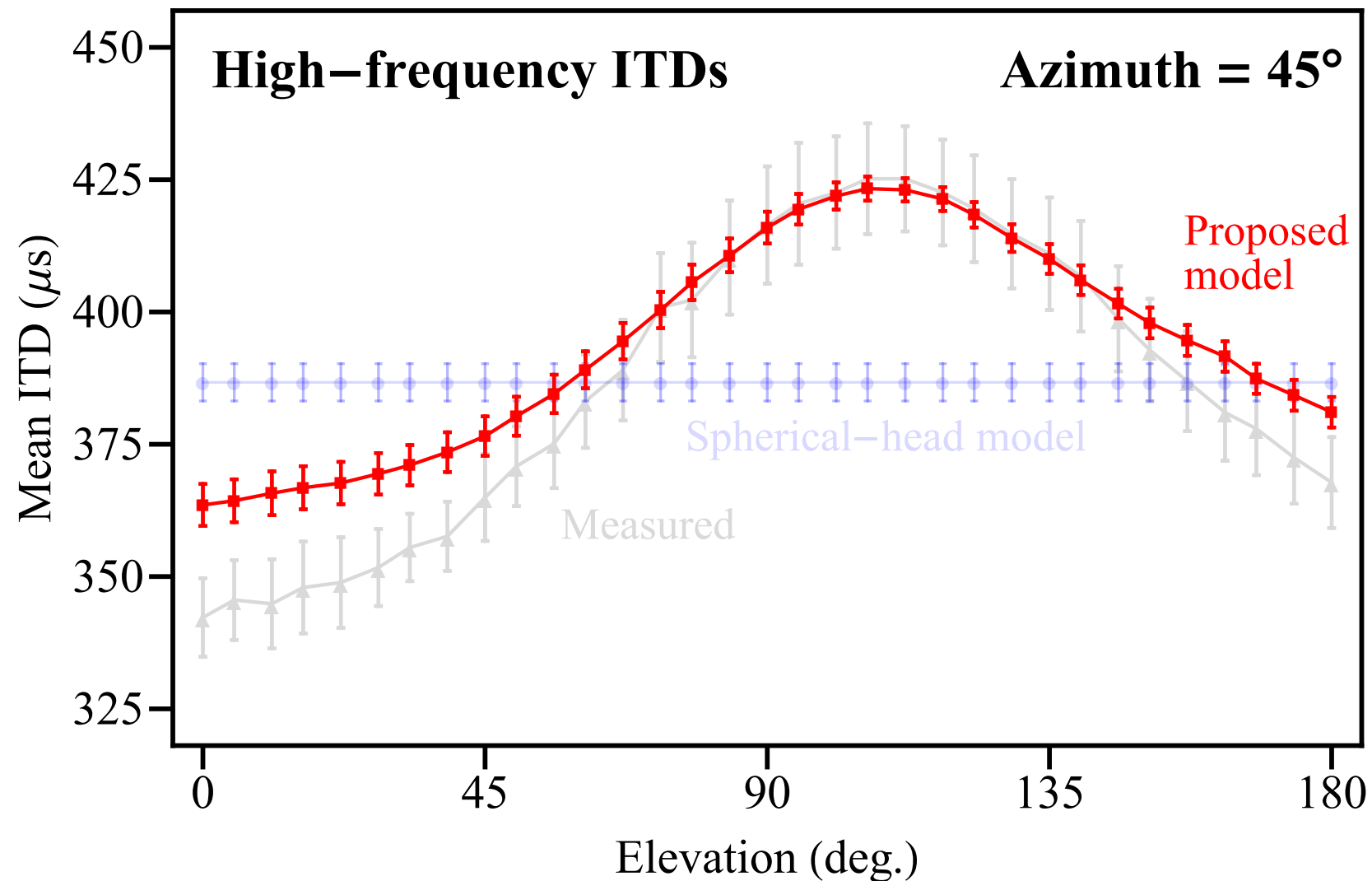
Evaluation of models

Ability of proposed model to capture elevation dependence of measured ITDs



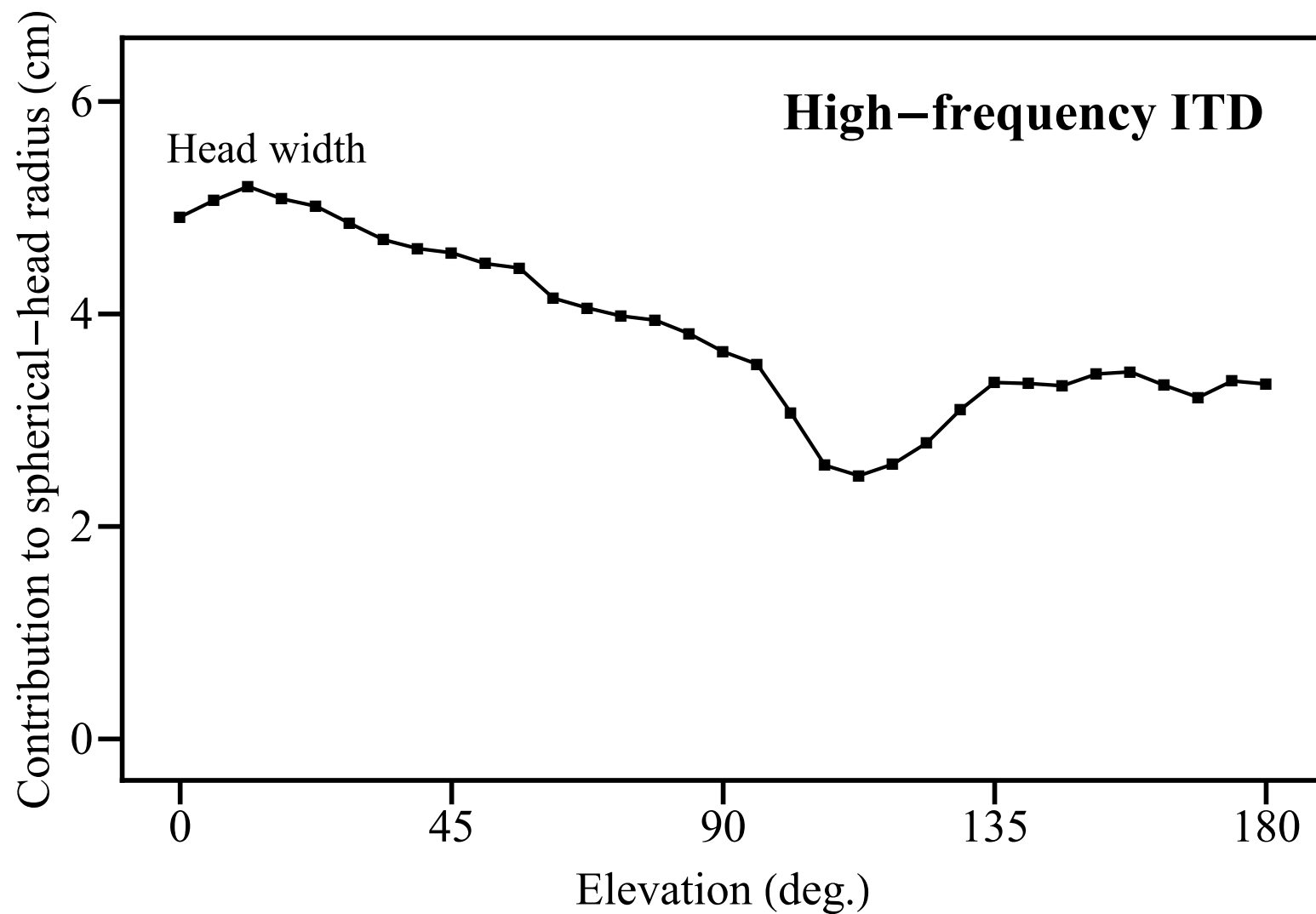
Evaluation of models

Ability of proposed model to capture elevation dependence of measured ITDs



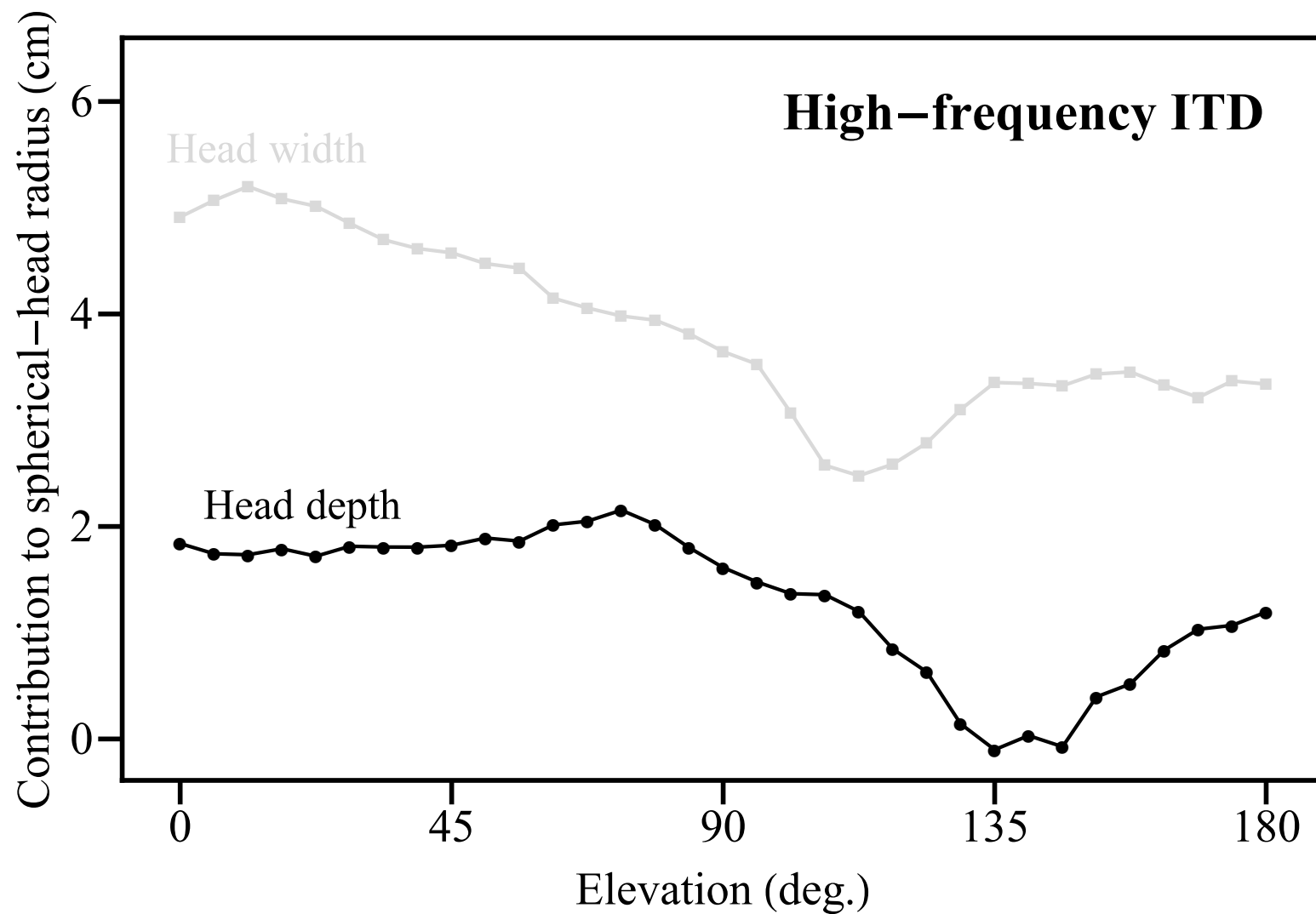
Proposed extension to spherical-head model

Contribution of anthropometric features to head radius



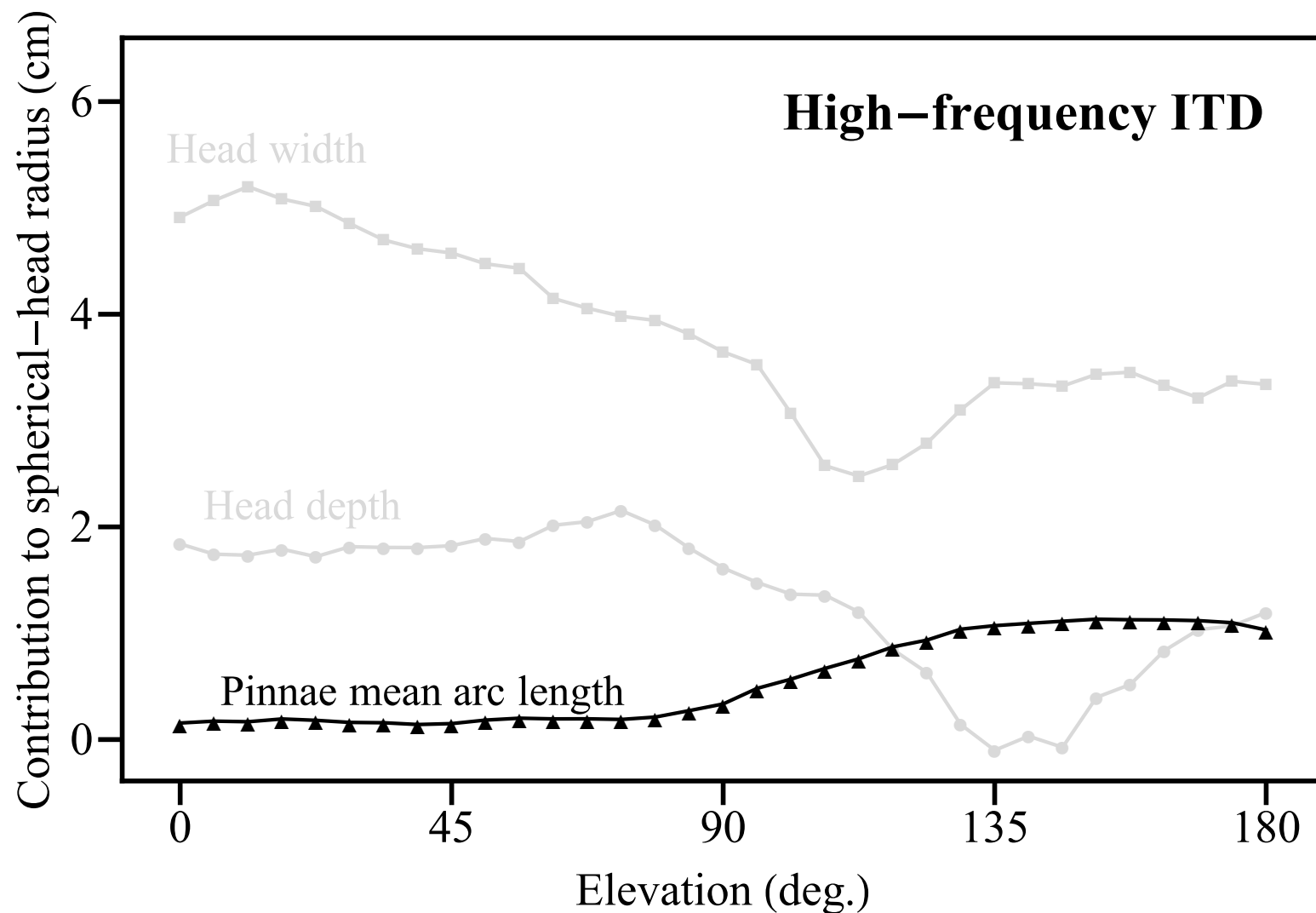
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Contribution of anthropometric features to head radius



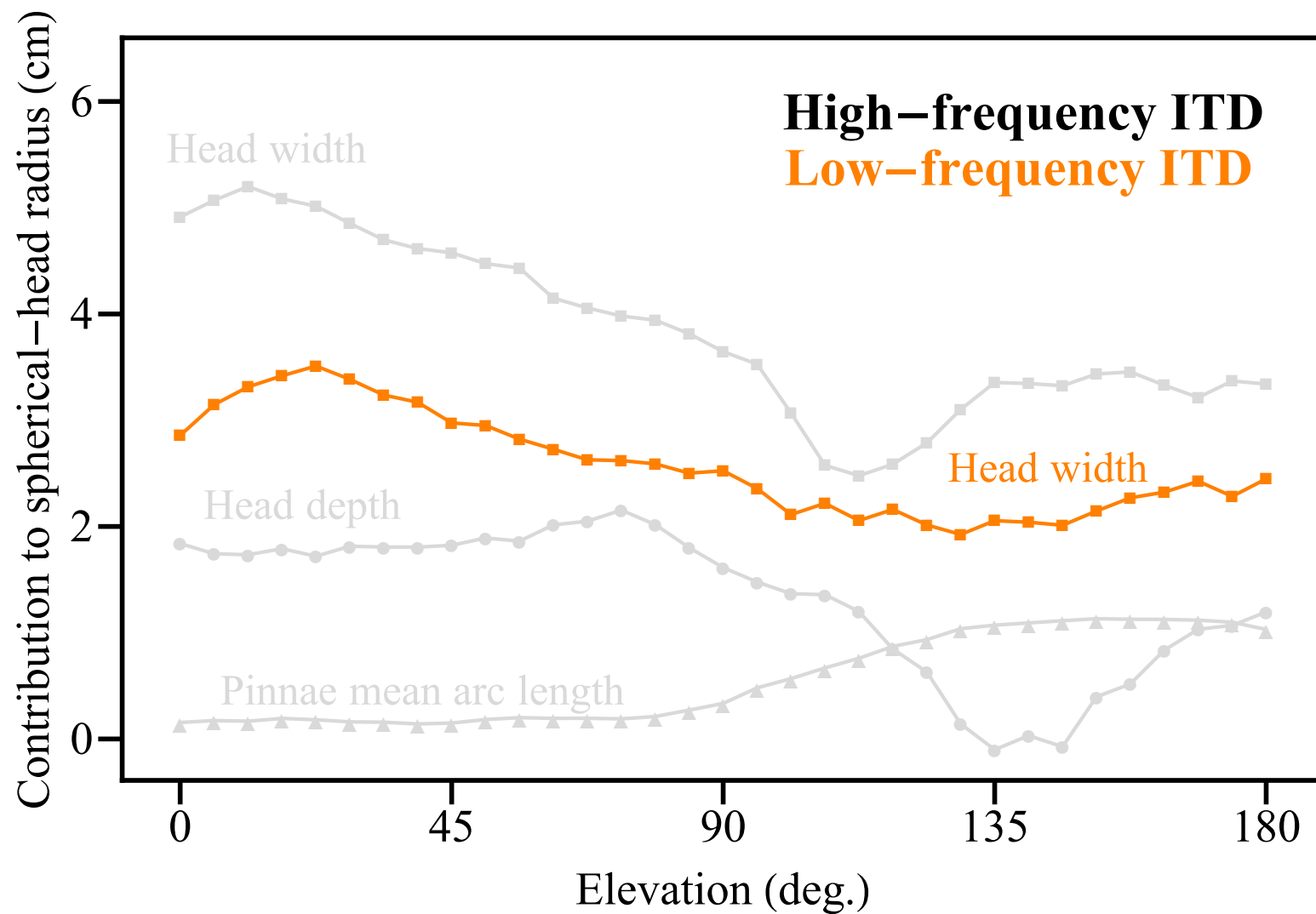
Proposed extension to spherical-head model

Contribution of anthropometric features to head radius



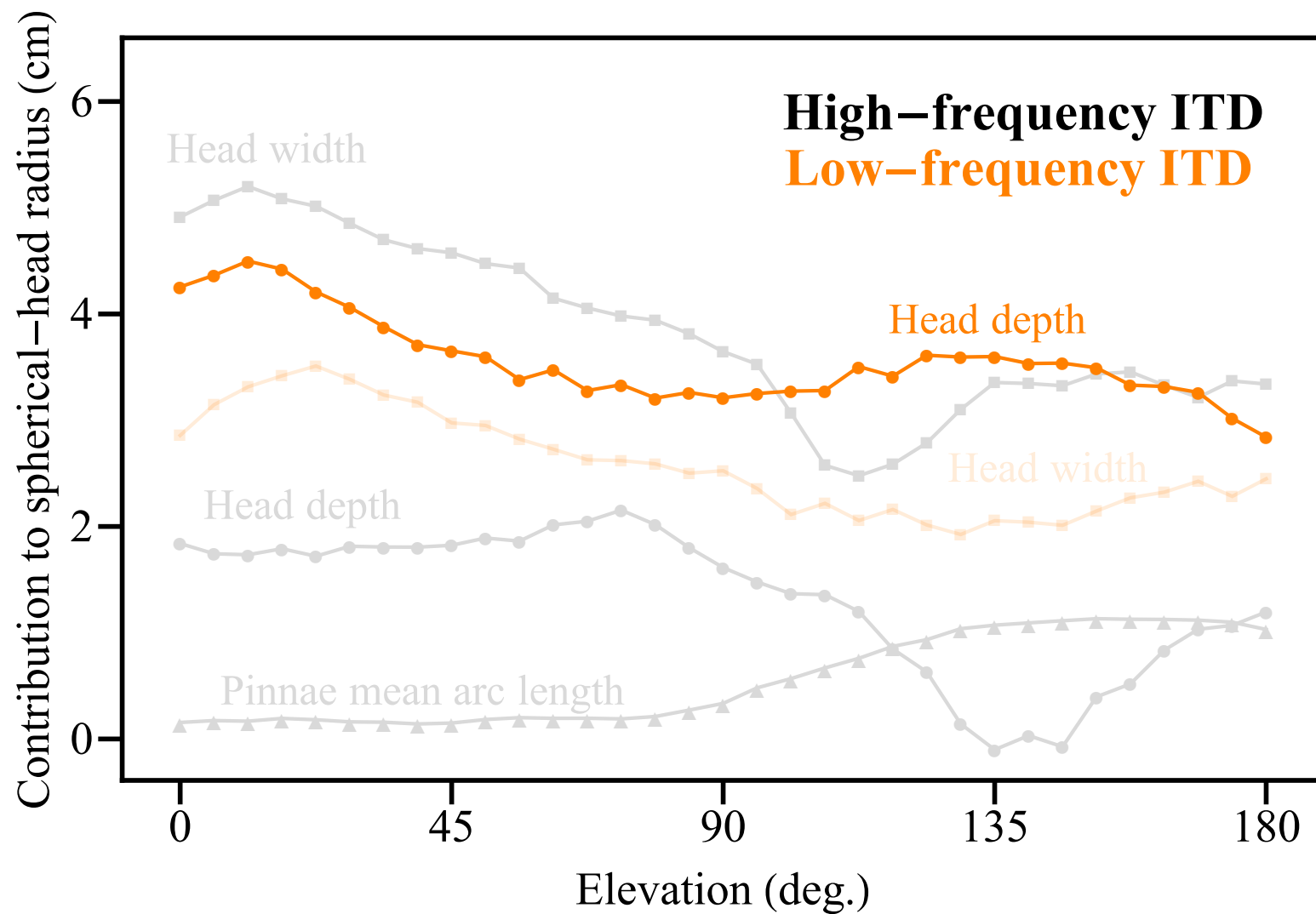
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Contribution of anthropometric features to head radius



Proposed extension to spherical-head model

Contribution of anthropometric features to head radius



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Conclusions

- Spherical-head model doesn't capture elevation dependence of ITDs
 - Results in inaccurate estimates of ITD at large azimuths
- Proposed extension to spherical-head model captures elevation dependence of ITDs
 - Results in up to 9% (47%) reduction in avg. error when estimating high- (low-) frequency ITDs.

Conclusions

- Influence of anthropometric features on ITD estimate varies based on sound source location
 - Pinnae mean arc length influences high-frequency ITD for sources behind the listener
 - Head depth influences high-frequency ITD for sources in front of the listener