CutFEM forward modeling for combined EEG/MEG source analysis

*[1,2]Tim Erdbrügger; [1,2]Malte Höltershinken; [3,4]Jan-Ole Radecke; [1,5]Yvonne Buschermöhle; [6]Alena Buyx; [7]Fabrice Wallois; [8]Sampsa Pursiainen; [3,4,5,9]Rebekka Lencer; [1,5]Joachim Gross; [2]Christian Engwer; [1,5]Carsten Wolters

[1]Institute for Biomagnetism and Biosignal Analysis, University of Münster, Germany; [2]Institute for Analysis and Numerics, University of Münster , Germany; [3] Dept. of Psychiatry and Psychotherapy, University of Lübeck, Germany; [4] Center of Brain, Behavior and Metabolism, University of Lübeck, Germany; [5] Otto Creutzfeldt Center for Cognitive and Behavioral Neuroscience, University of Münster, Germany; [6] Institute of History and Ethics in Medicine, Technical University of Munich, Germany; [7] Institut National de la Santé et de la Recherce Médicale, University of Picardie Jules Verne, Amiens, France; [8] Computing Sciences Unit, Faculty of Information Technology and Communication Sciences, Tampere University, Finland; [9] Institute for Translational Psychiatry, University of Münster, Germany

tim.erdbruegger@uni-muenster.de

IBB Institute for Biomagnetism and Biosignalanalysis

WWU MÜNSTER

Introduction

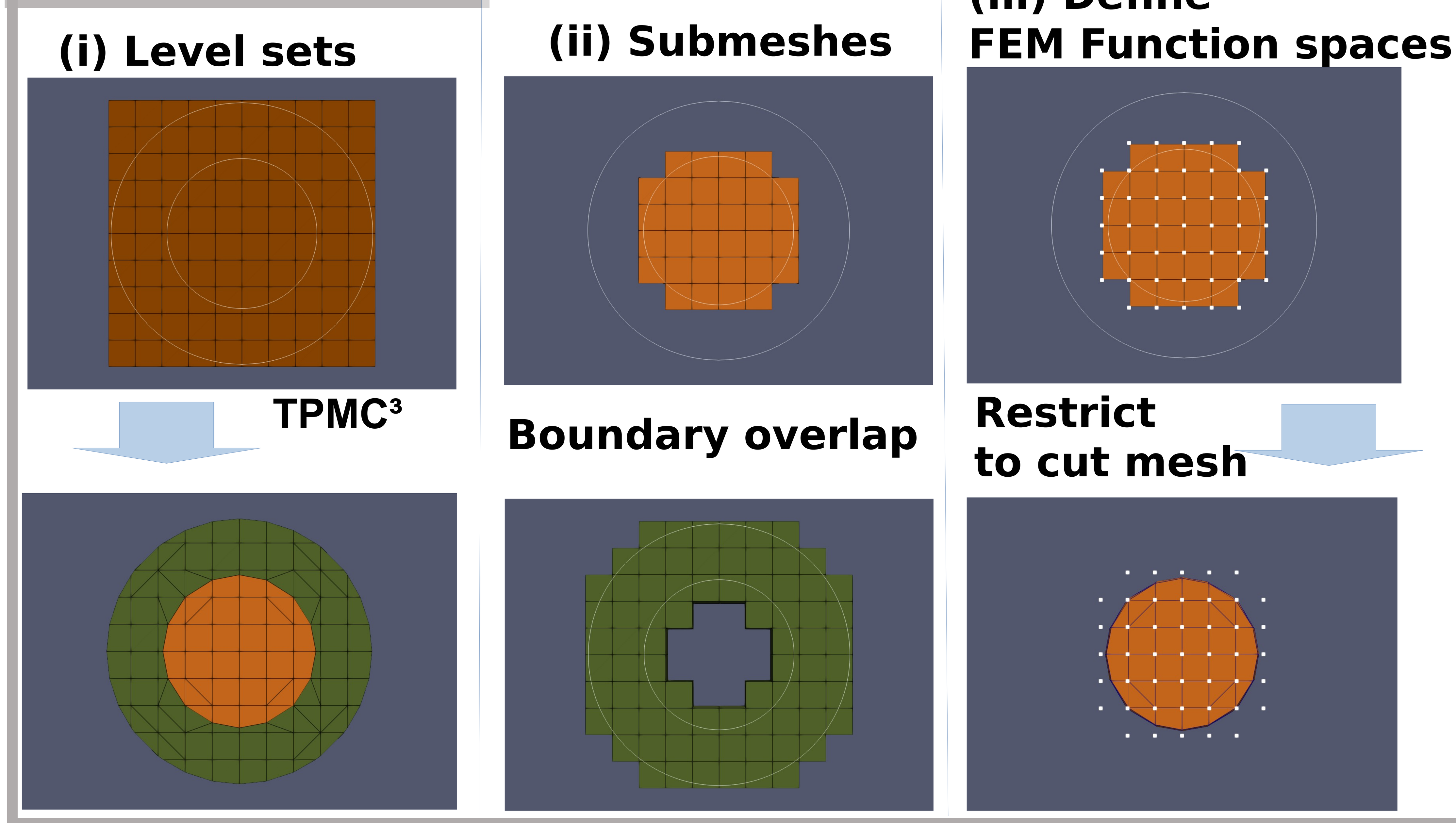
Localization of neural sources using Electro- and Magnetoencephalography (EEG/MEG) requires the solution of their respective forward problems, computed e.g. via the finite element method (FEM).

FEM requires high quality meshes which are difficult to create. Hexahedral meshes cannot approximate curvatures while tetrahedral meshes require surface triangulations.

CutFEM makes use of level set functions to represent compartments by cutting a background mesh into pieces. This approach allows for arbitrarily touching surfaces and a simplified meshing process.

Here, we compare it to established forward modeling approaches in an n=19 somatosensory group study.

I. The cut mesh



II. FEM formulation[1]

$$\nabla \cdot \sigma \nabla u = f, \quad \text{in } \bigcup_i \Omega_i$$
$$\langle \sigma \nabla u, n \rangle = 0, \quad \text{on } \partial\bar{\Omega}$$

Standard EEG forward problem (MEG uses transfer matrix approach)

$$[\![u]\!] = 0, \quad \text{on } \Gamma$$

Potential continuity

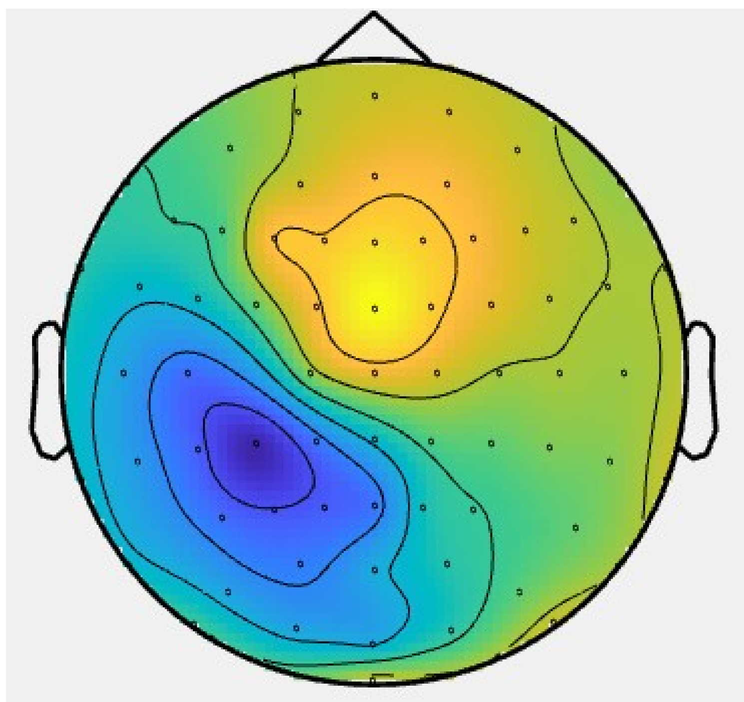
$$[\![\sigma \nabla u]\!] = 0, \quad \text{on } \Gamma.$$

Charge conservation

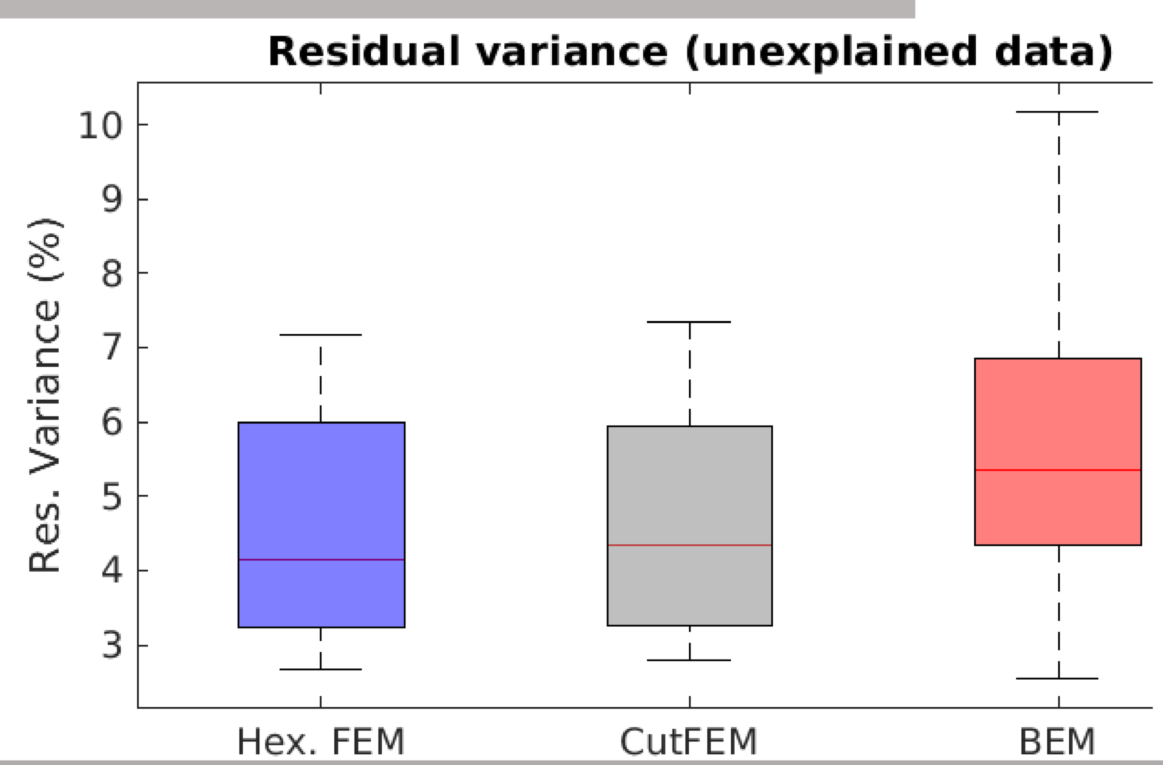
- Jump conditions are enforced weakly through Nitsche coupling
- Ghost penalty is used to stabilize deformed cut cells

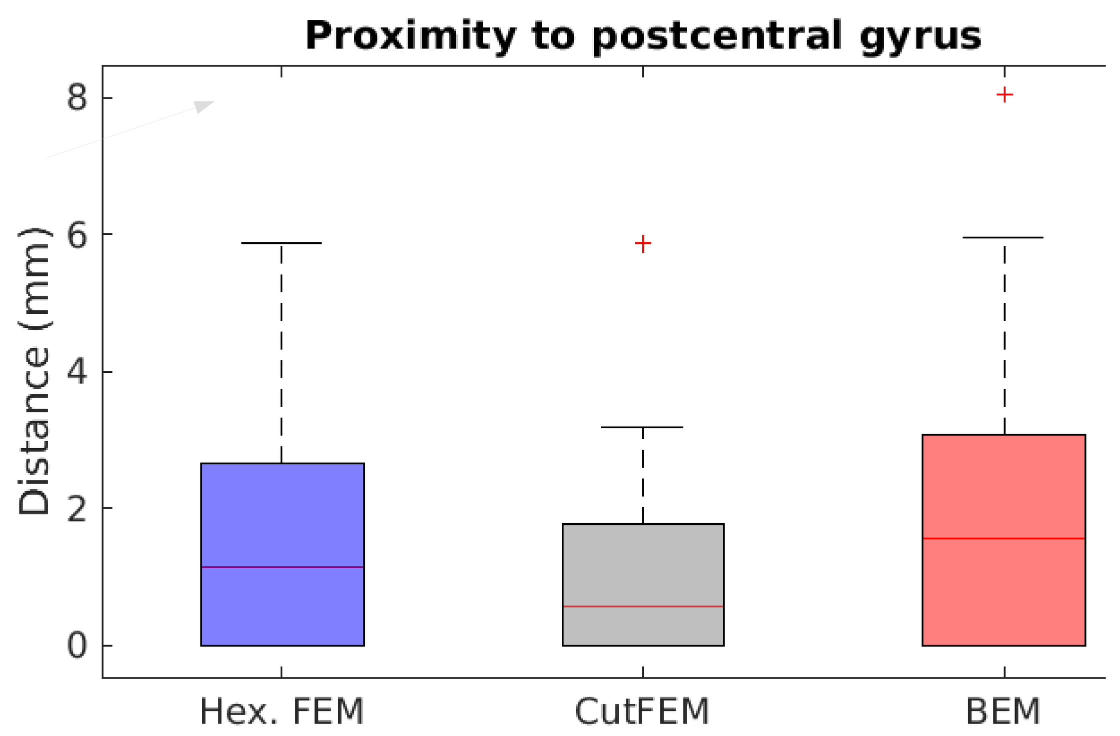
III. Reconstruction of somatosensory evoked potential

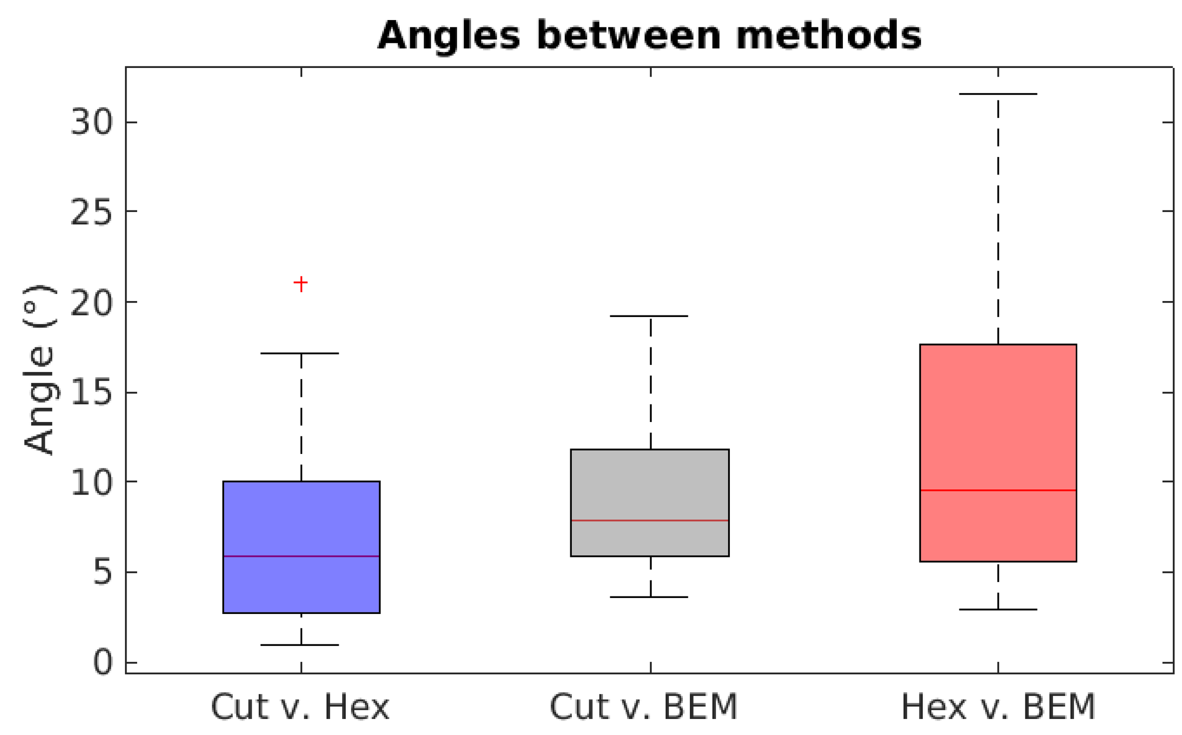
- electric wrist stimulation
- elicits highly focal source in somatosensory cortex
- calculate EEG/MEG lead fields using :
  - 6 Compartment CutFEM
  - 6C Hexahedral FEM (standard FEM)
  - 3C BEM (standard BEM)
- optimal for dipole scan
- compare residual variance, distance to somatosensory cortex (postcentral gyrus), angles
- n = 19 subjects



IV. Results







Conclusion

In this study we investigated the performance of 3 different forward modeling approaches when reconstructing somatosensory evoked potentials.

We found that using 6 compartments significantly reduces the amount of unexplained data compared to 3 compartments.

The new CutFEM approach yielded localizations that were closer to the somatosensory cortex than the other methods, albeit the differences are small.

The angles of the reconstructed dipoles are strongly dependent on the forward modeling approach, an important result for applications such as transcranial direct current stimulation.

Acknowledgements

This study was supported by ERA PerMed as project ERAPERMED2020-227 PerEpi (Bundesministerium für Gesundheit, project ZMI1-2521FSB006; Academy of Finland, project 344712; Bundesministerium für Bildung und Forschung, project FKZ 01KU2101; French National Research Agency, project RPV21010EEA) and by the Deutsche Forschungsgemeinschaft (DFG), projects WO1425/10-1, GR2024/8-1, LE1122/7-1. CE was supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy EXC 2044-390685587, Mathematics Münster: Dynamics-Geometry-Structure. TE, MH, CW, and SP were additionally supported by the DAAD/AoF researcher mobility project (DAAD project 57663920, AoF decision 354976) and SP by the AoF Centre of Excellence (CoE) in Inverse Modelling and Imaging 2018–2025 (AoF decision 353089).

[1]Erdbrügger, Tim, et al. "CutFEM forward modeling for EEG source analysis." Frontiers in Human Neuroscience 17 (2023).