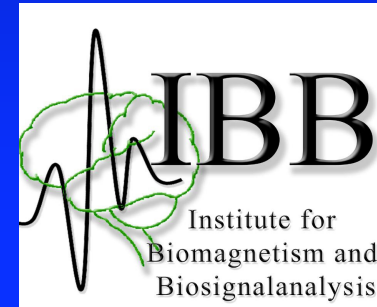


Basics of EEG and MEG source analysis



Carsten H. Wolters

Structure of this lecture

- **Some more basics of EEG and MEG**
- **Validation of EEG and MEG source analysis techniques**
- **Source analysis of somatosensory (SEP/SEF), auditory (AEP/AEF) and visually evoked potentials and fields (VEP/VEF)**
- **Clinical application of SEP/SEF source analysis: Functional mapping**
- **Applications in presurgical epilepsy diagnosis**

Spatial and temporal resolution of brain imaging methods

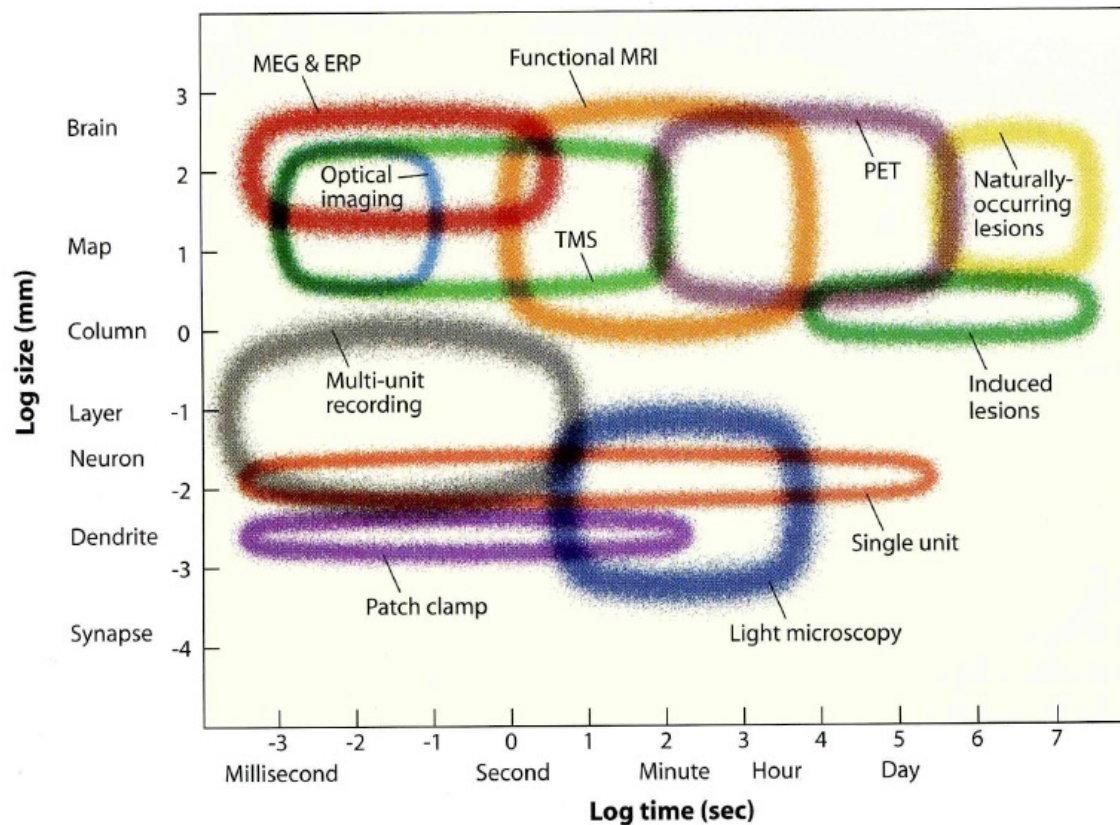
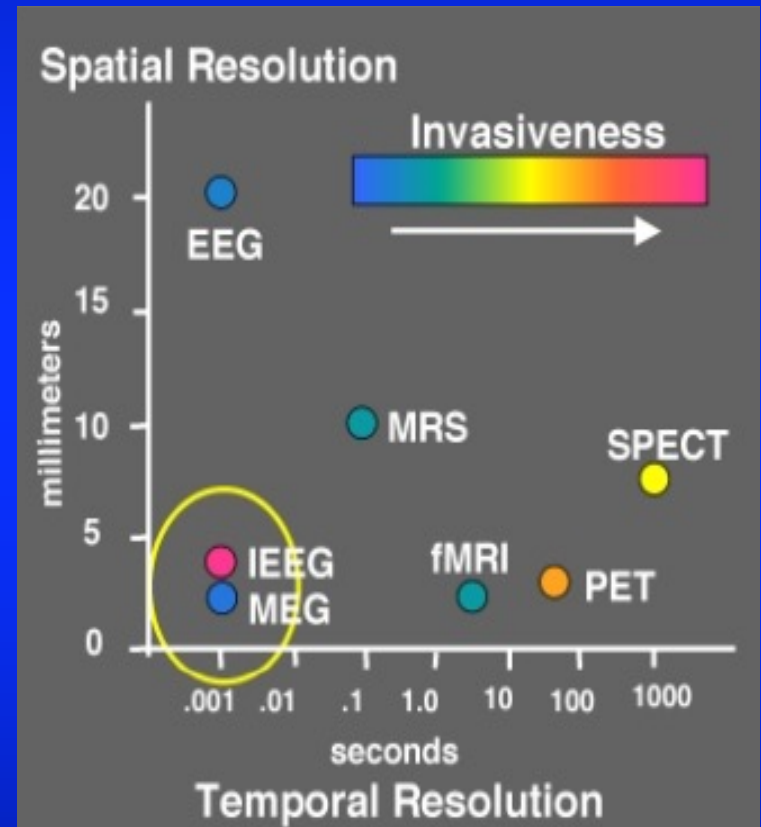


Figure 4.36 Spatial and temporal resolution of the prominent methods used in cognitive neuroscience. Temporal sensitivity, plotted on the x axis, refers to the time scale over which a particular measurement is obtained. It can range from the millisecond activity of single cells to the behavioral changes observed over years in patients who have had strokes. Spatial sensitivity, plotted on the y axis, refers to the localization capability of the methods. For example, real-time changes in the membrane potential of isolated dendritic regions can be detected with the patch clamp method, providing excellent temporal and spatial resolution. In contrast, naturally occurring lesions damage large regions of the cortex and are detectable with MRI.

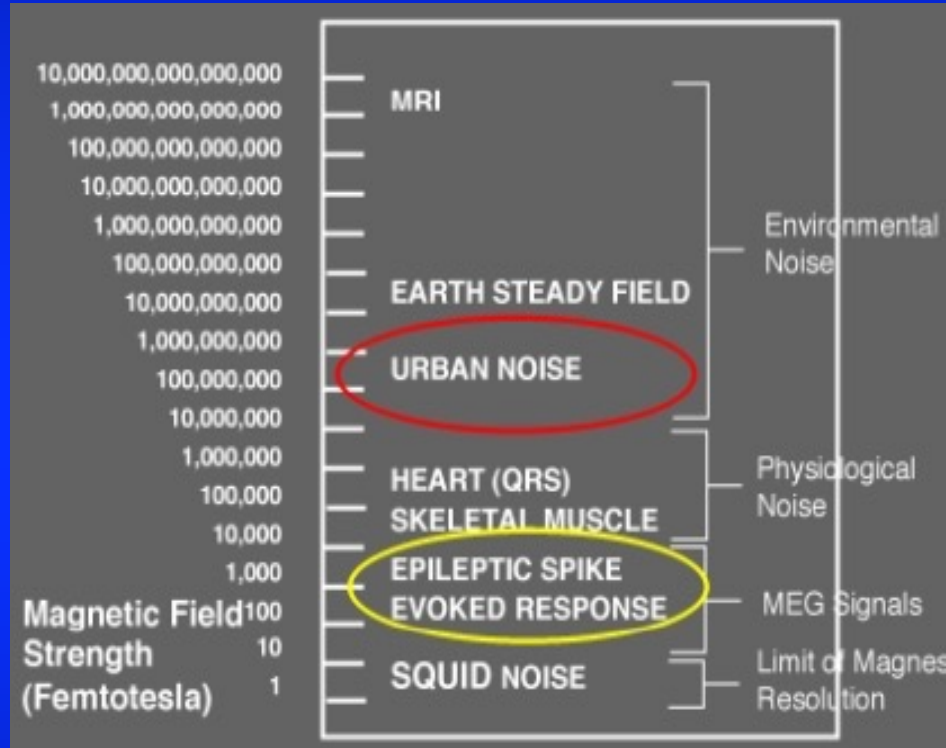
Basics - MEG

- MEG registers non-invasively magnetic fields of neuronal activity
- Similar to EEG: Registration of neuronal activity
- MEG and EEG measure activity of the same generators
- PET or fMRI: Indirect measurement of neuronal activity

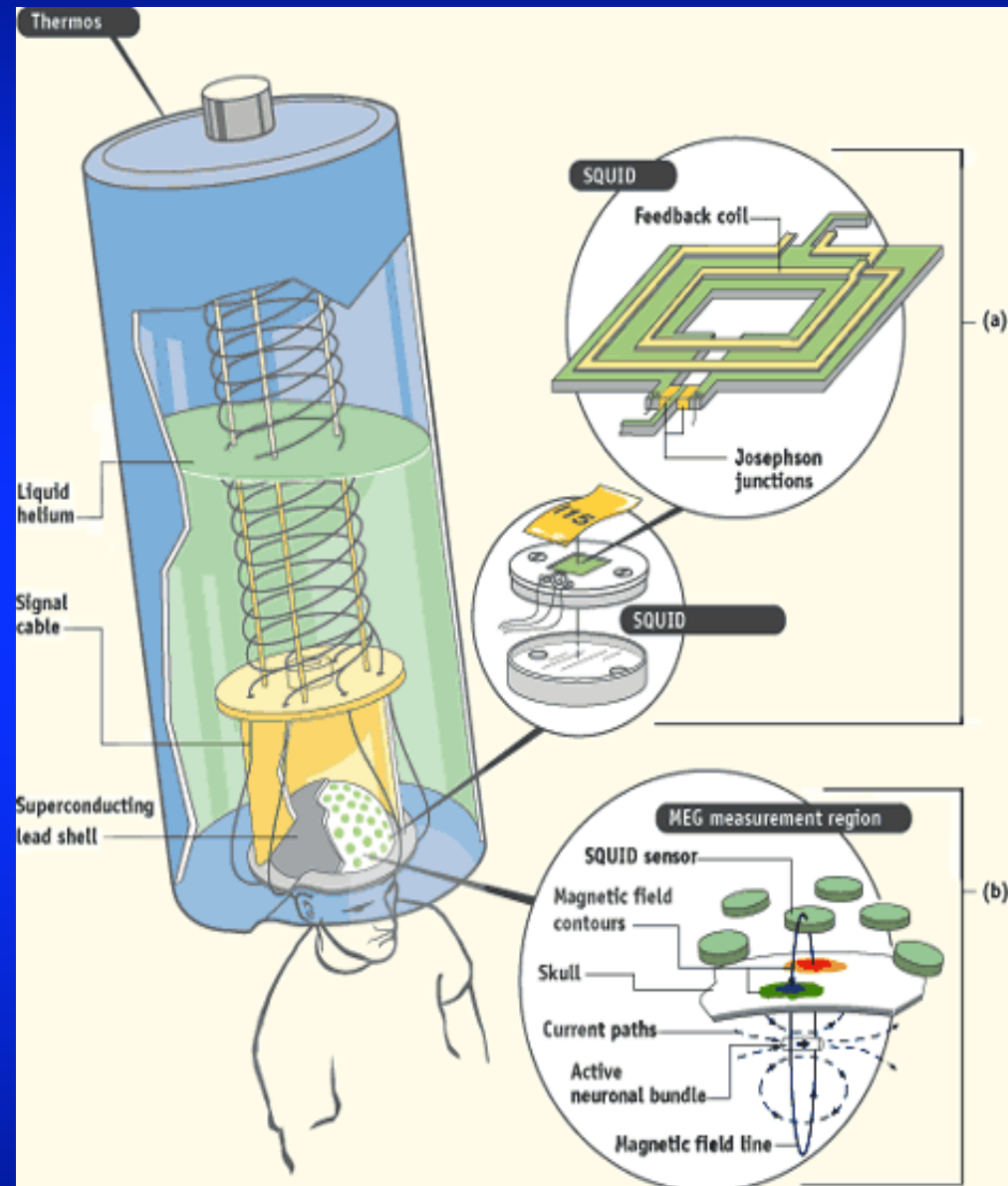


4D Neuroimaging, San Diego, CA, USA

Magnetically shielded room



MEG Interna



Registration of the magnetic flux

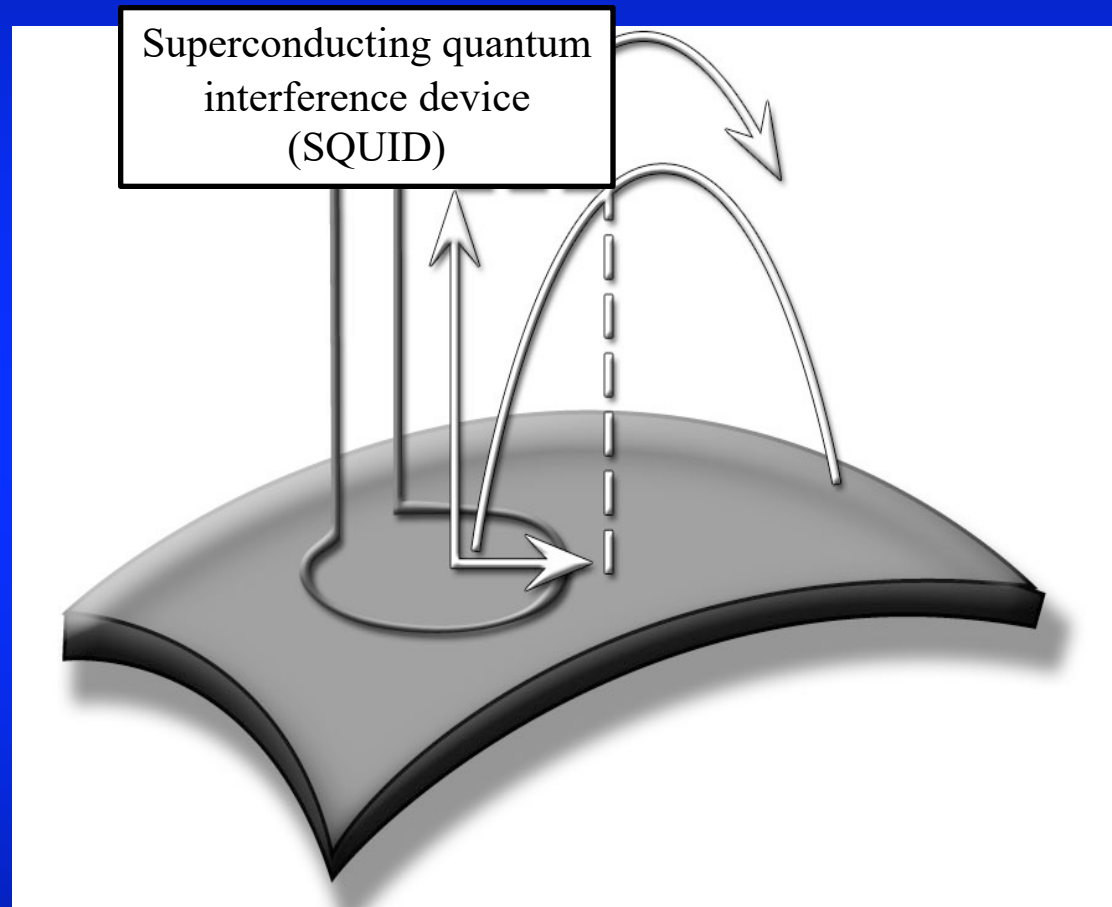
Magnetometer



Axiales Gradiometer

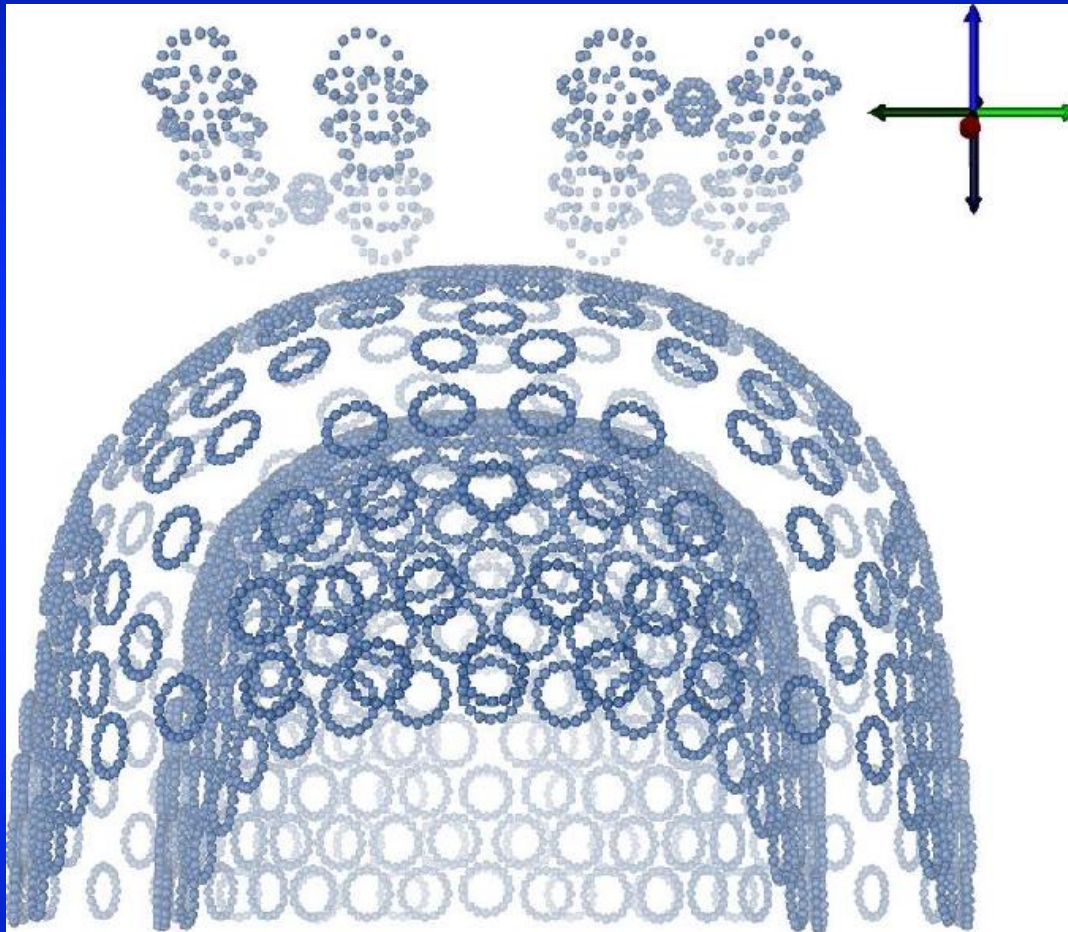


Planares Gradiometer



Papanicolaou (Ed.): Clinical
Magnetoencephalography and Magnetic Source
Imaging

MEG-system at IBB, Uni Münster

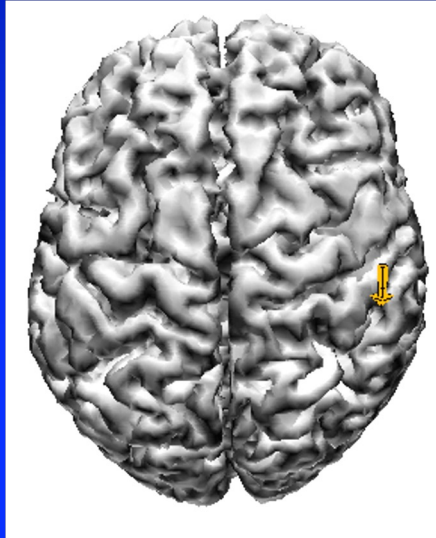


Finite Element nodes for MEG sensor description

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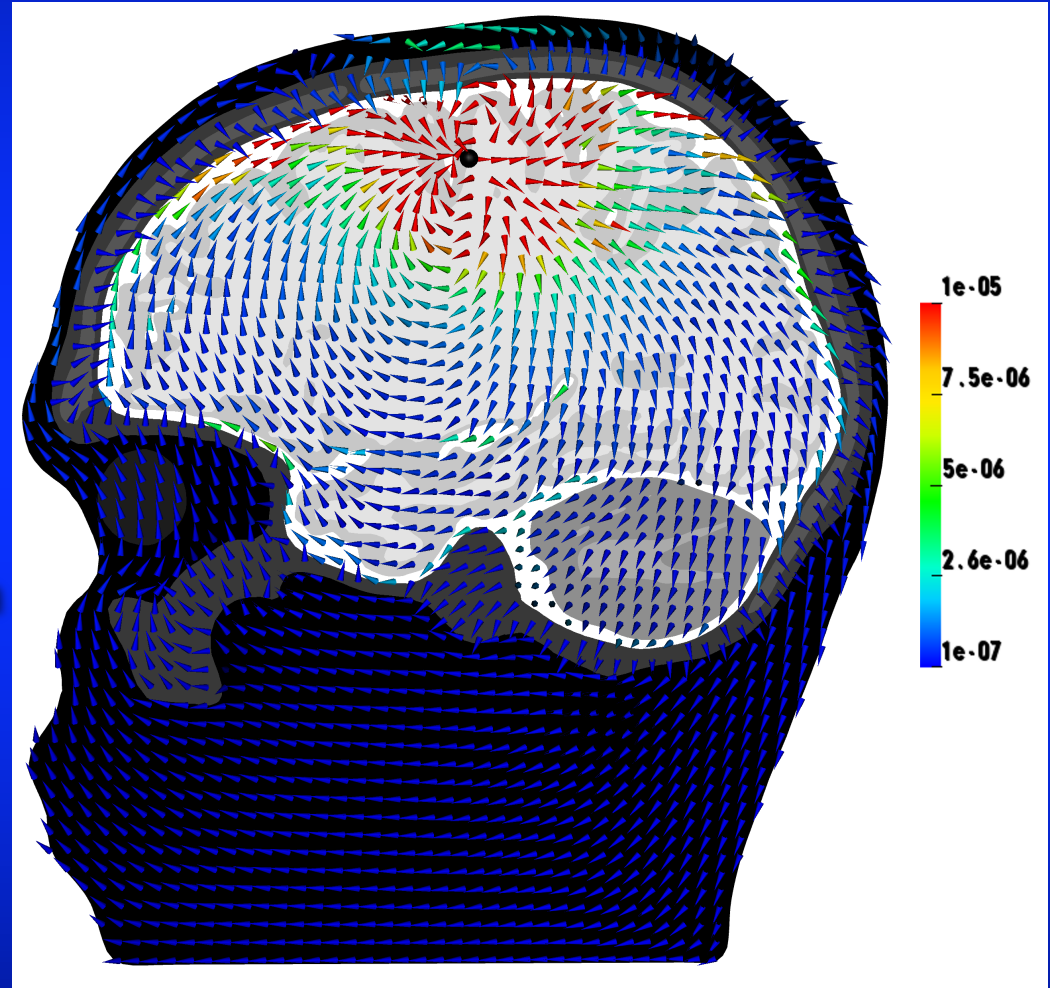
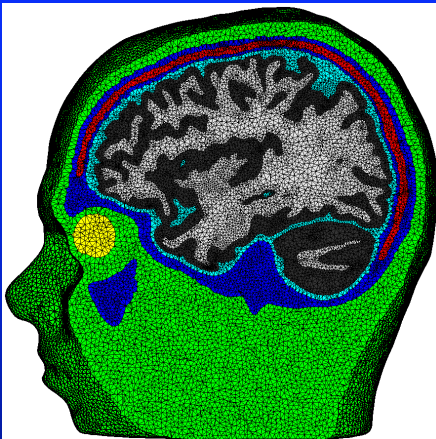
Reminder to the forward problem in EEG/MEG



Simulate

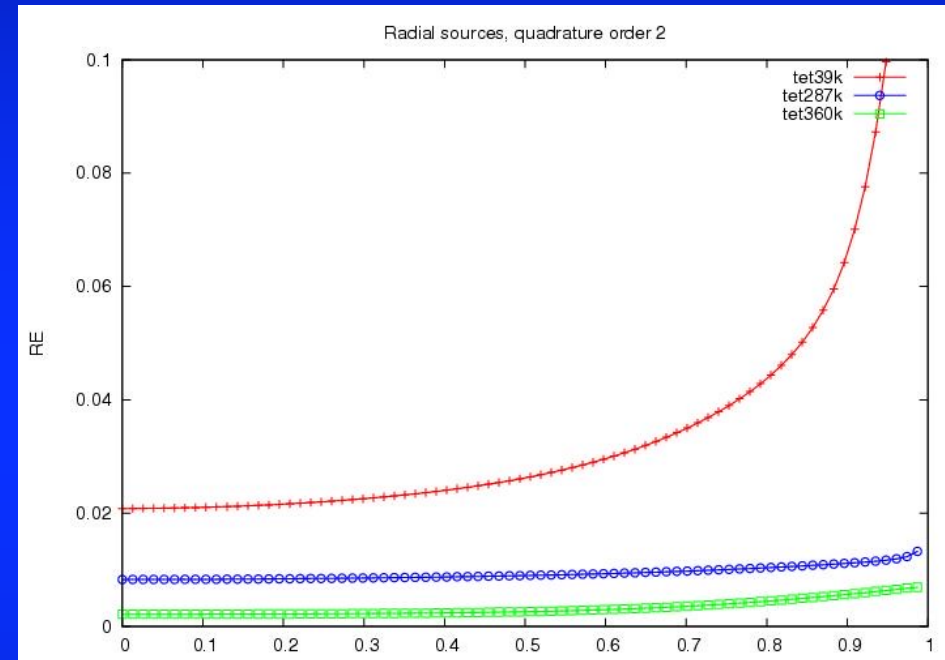
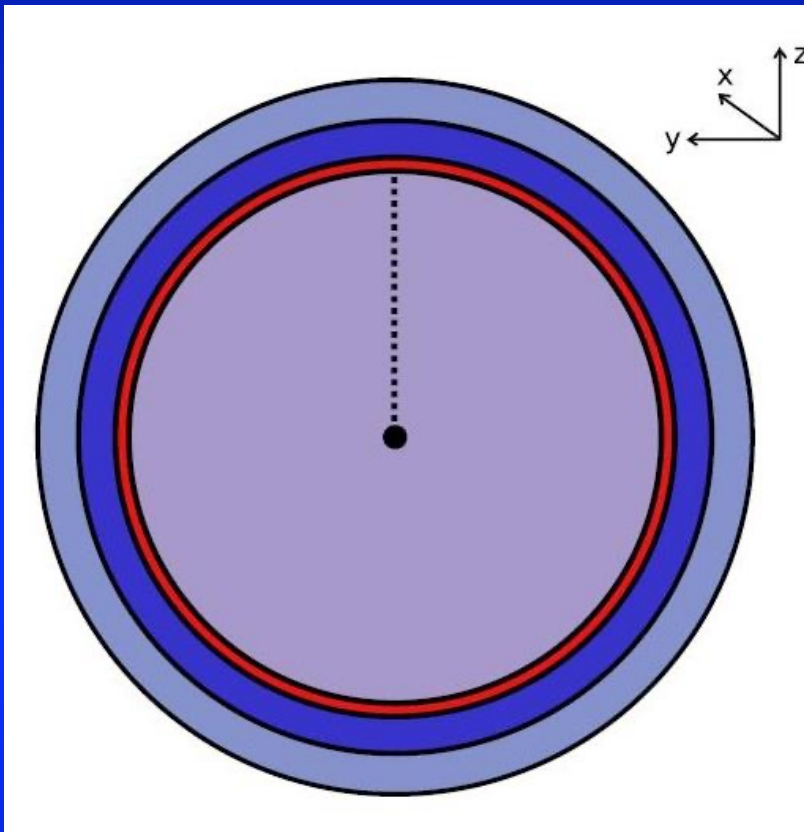


potential
distribution
or current



**Step 1 in validation of forward modeling:
Computer simulations in multi-layer sphere
models**

Analytical solutions in multilayer sphere model



4-layer sphere model with 3-layer skull:

Radii: 92, 86:84:82:80, 78mm;

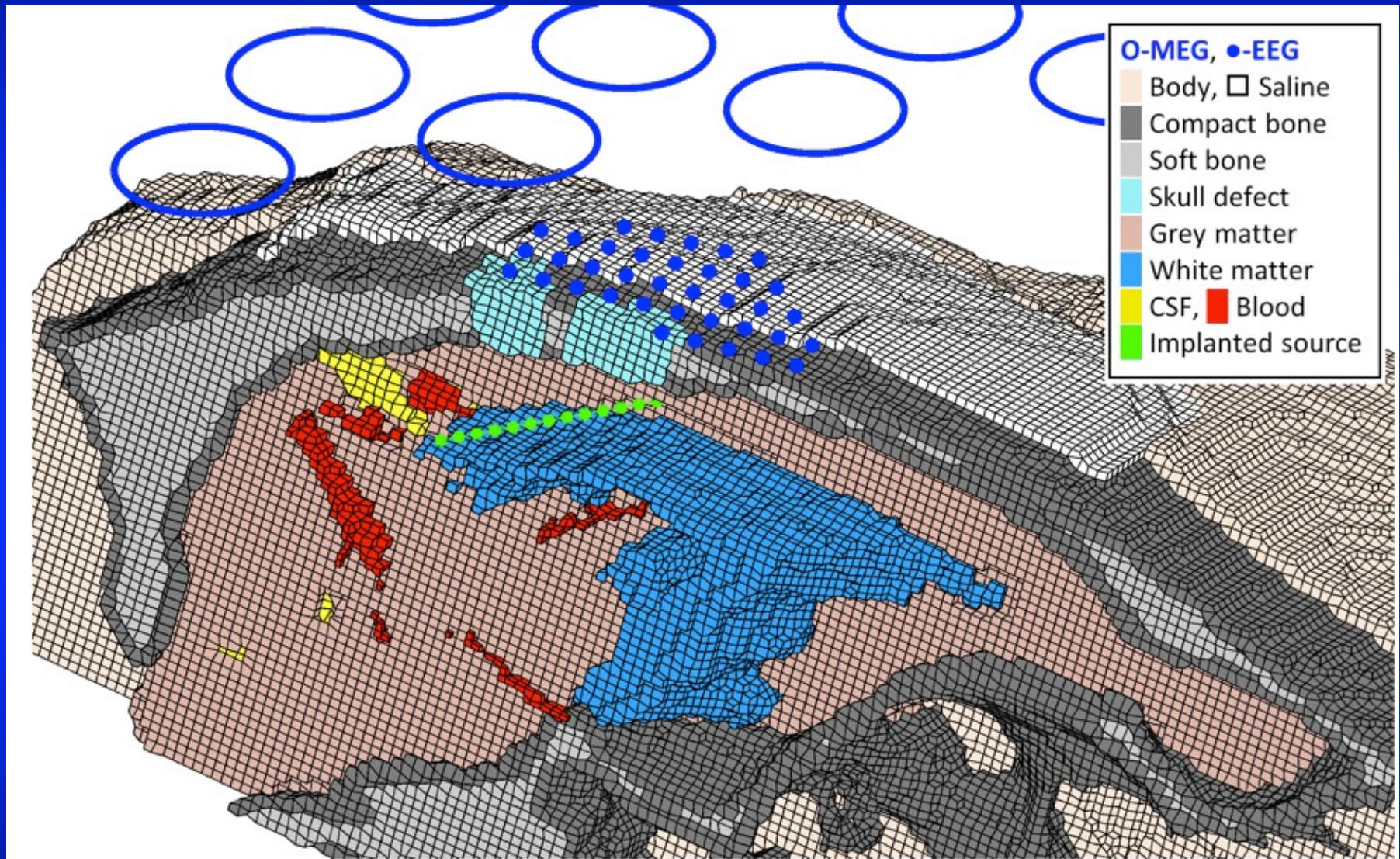
Cond.: 0.33, 0.0062:0.021:0.0049, 1.79, 0.33 S/m

Sources:

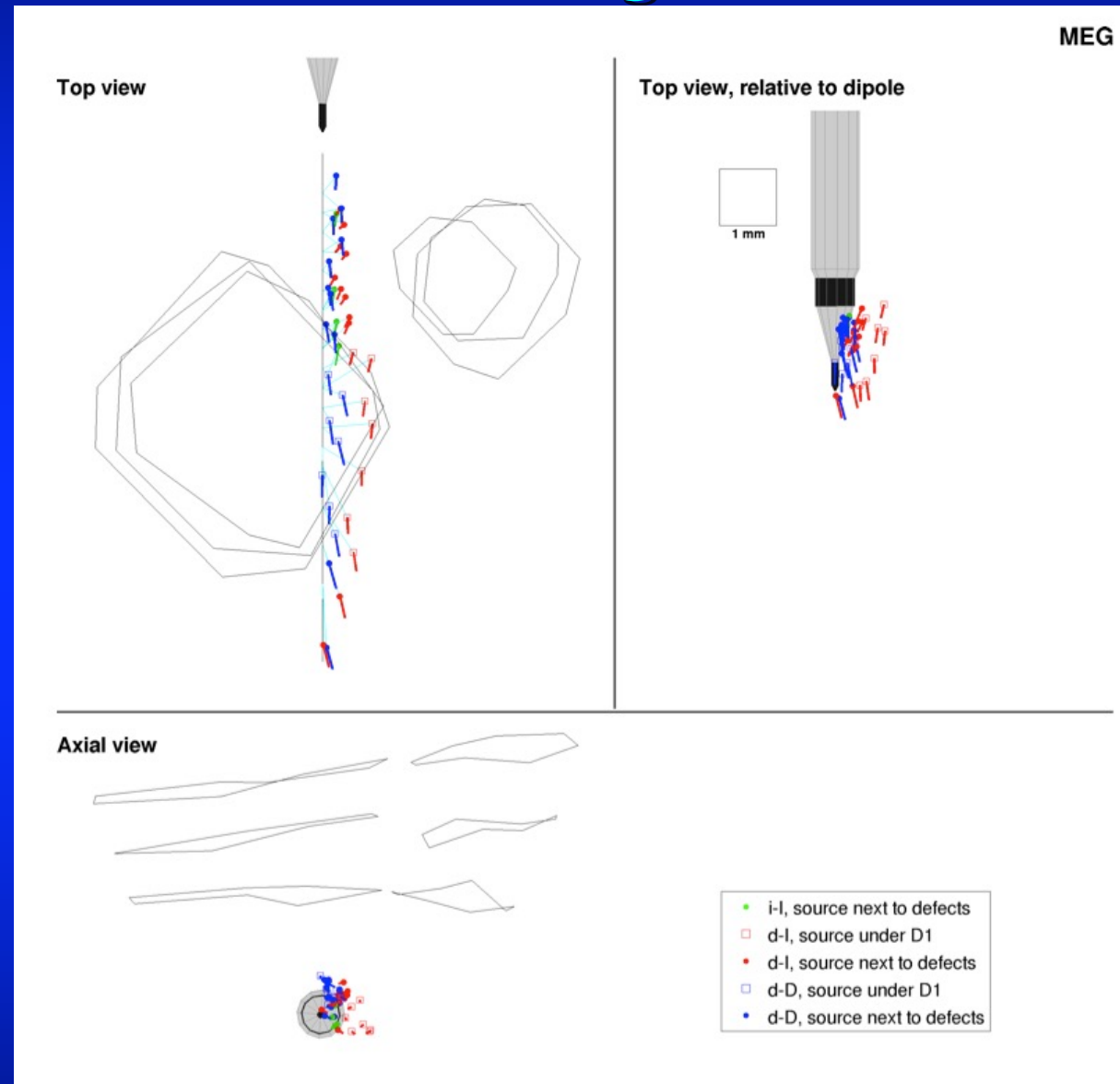
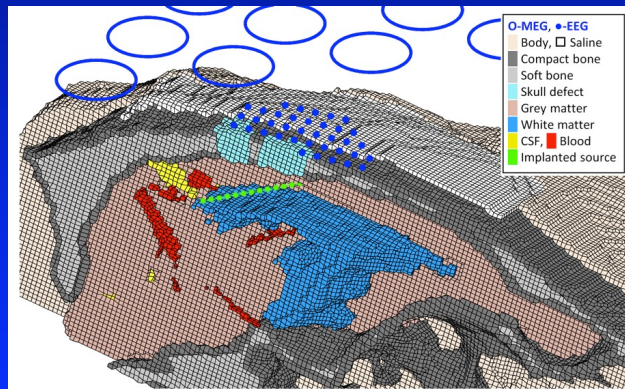
Depth from midpoint to CSF boundary

Next step in validation of source analysis techniques: Animal model

Validation in rabbit investigations



Validation in rabbit investigations

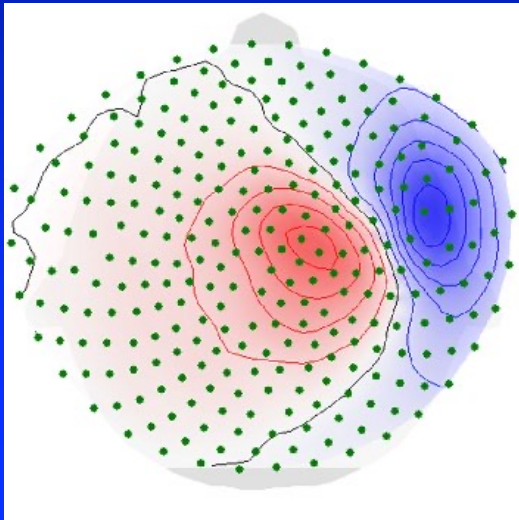


Structure of this lecture

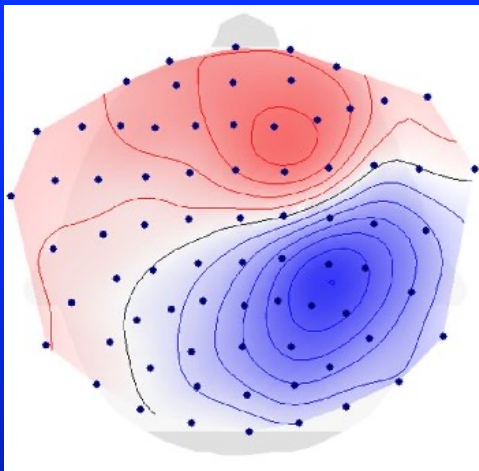
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Source analysis: The inverse Problem

SEF-P20



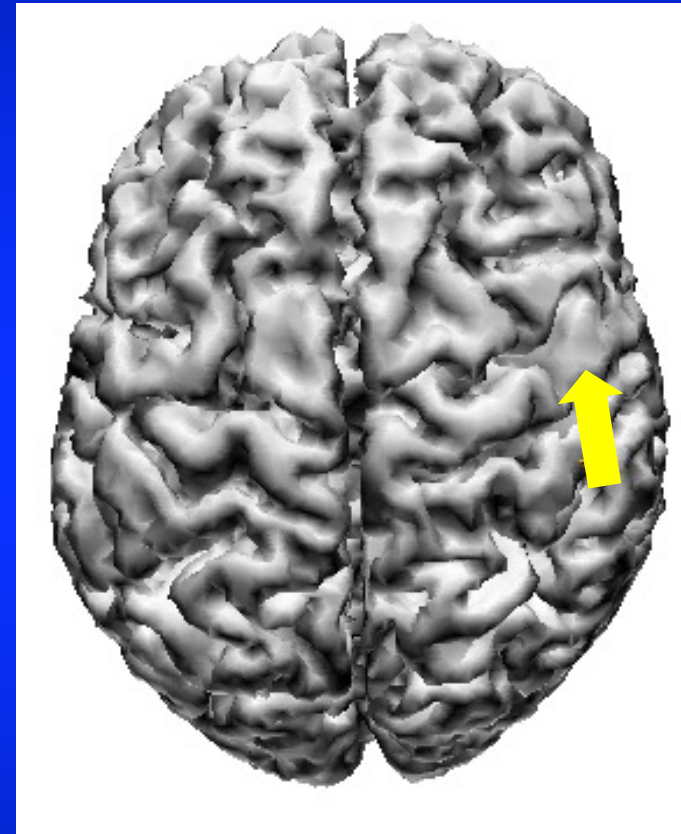
SEP-P20



Reconstruct

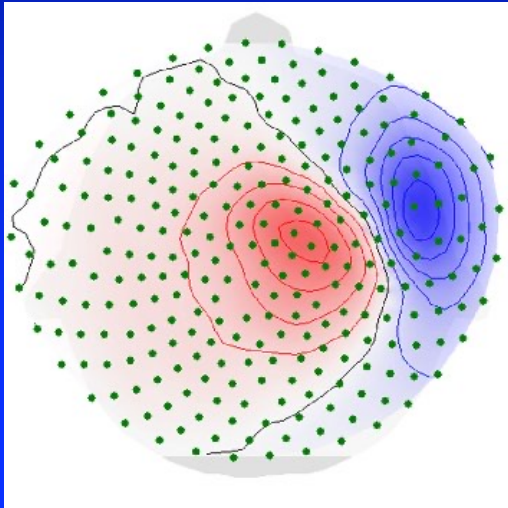


source



Source analysis: The inverse Problem

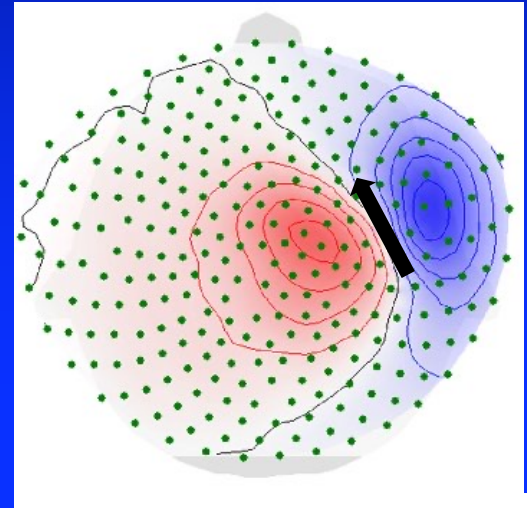
SEF-P20



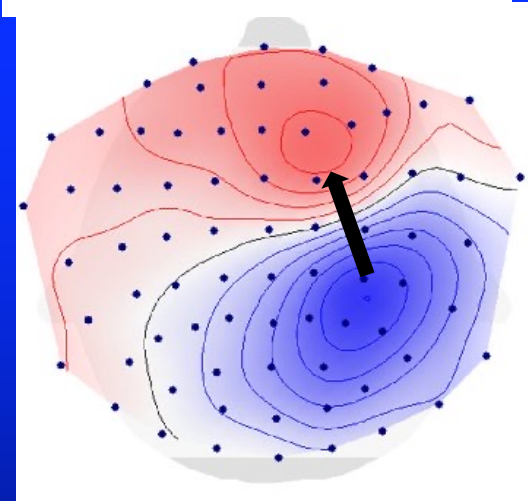
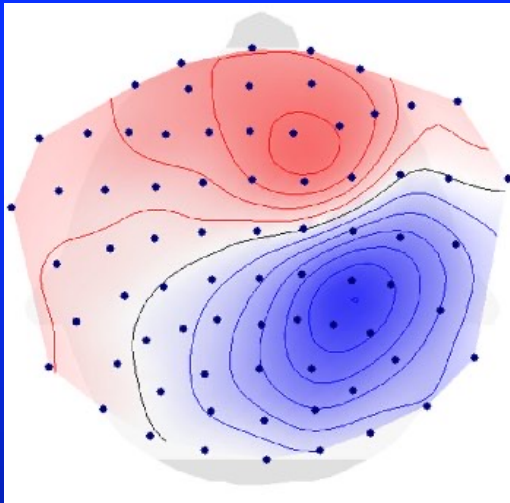
Reconstruct



source

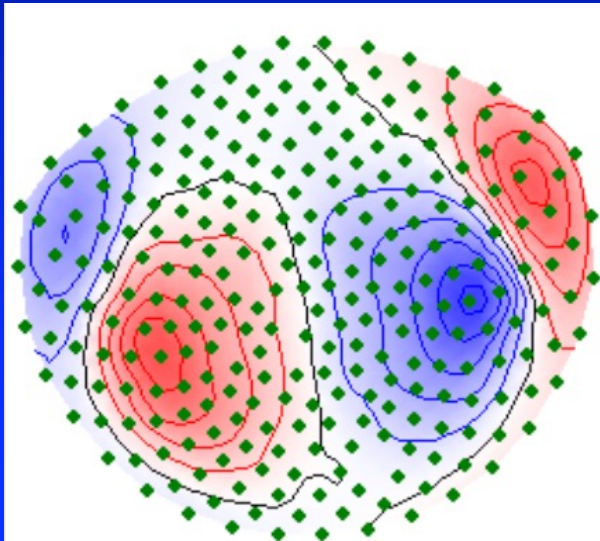


SEP-P20

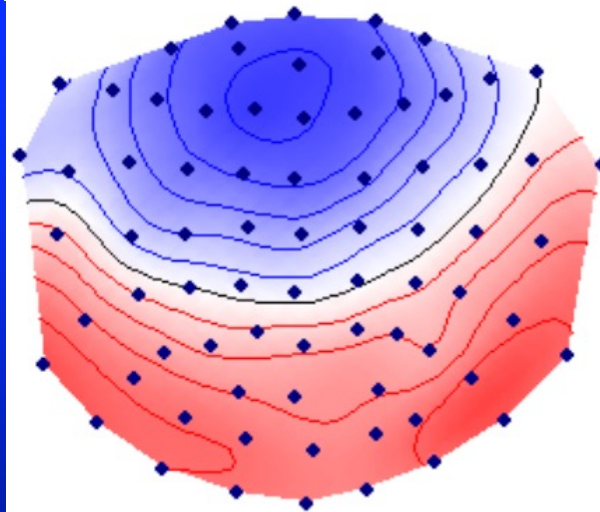


Source analysis: The inverse Problem

AEF-N100



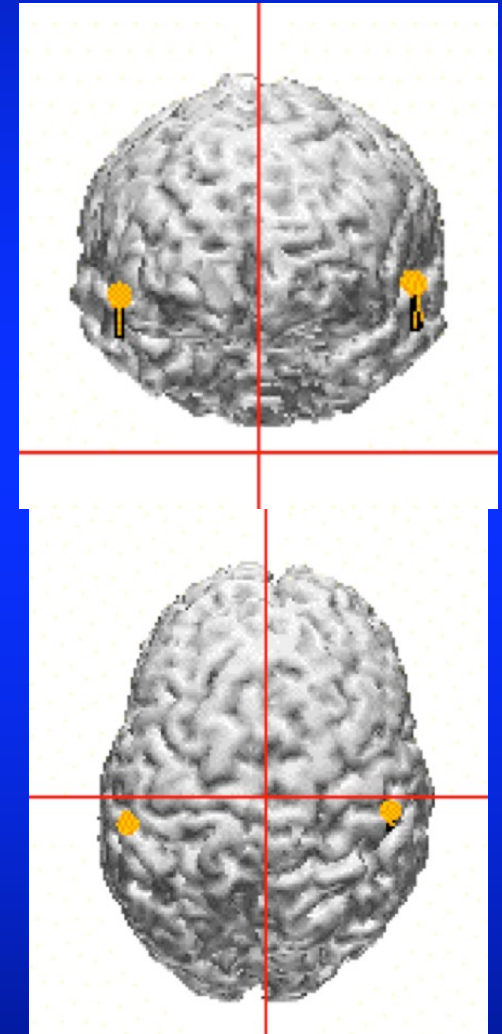
AEP-N100



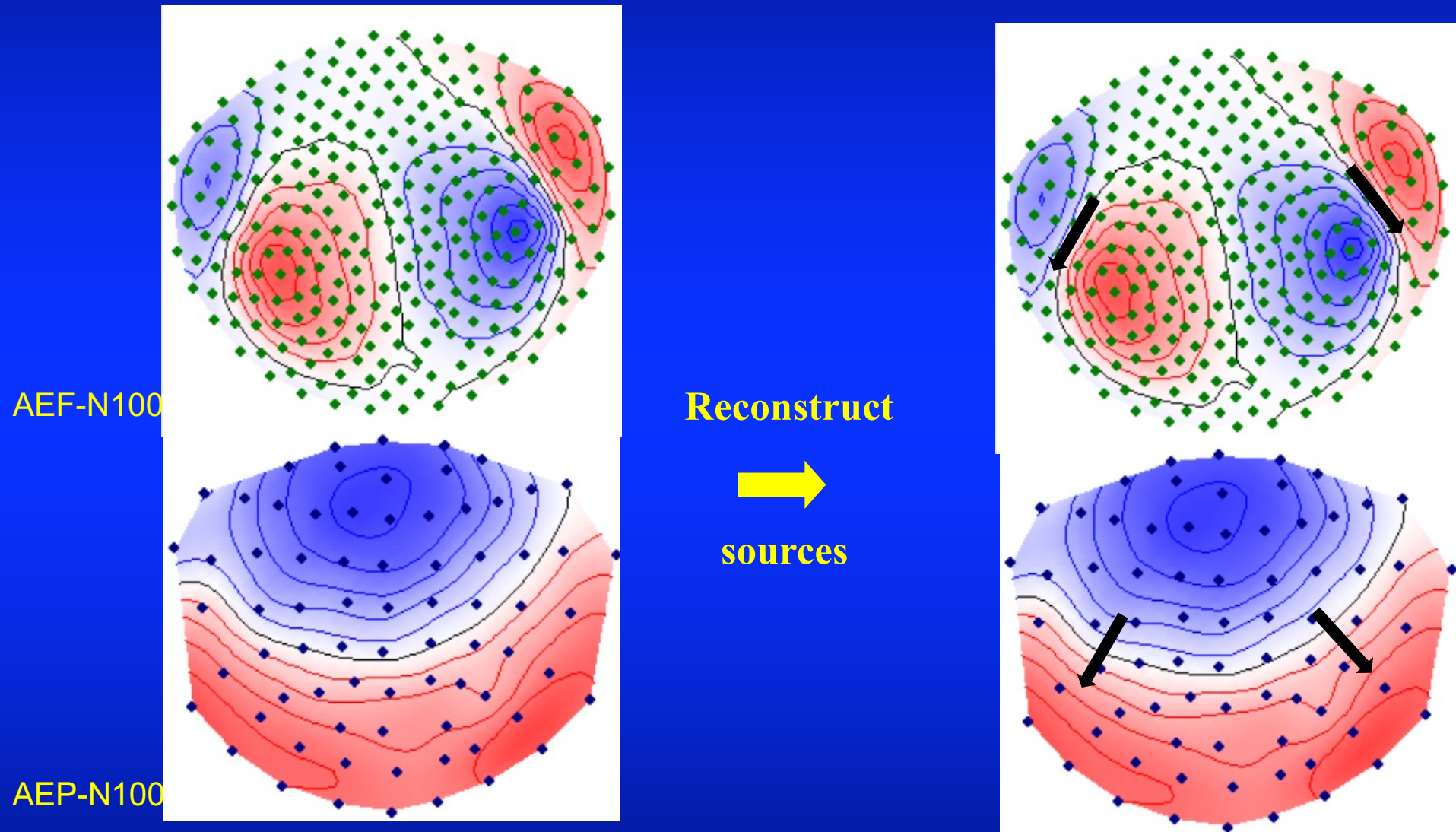
Reconstruct



sources



Source analysis: The inverse Problem



Visually evoked potentials (VEP) and Fields (VEF)

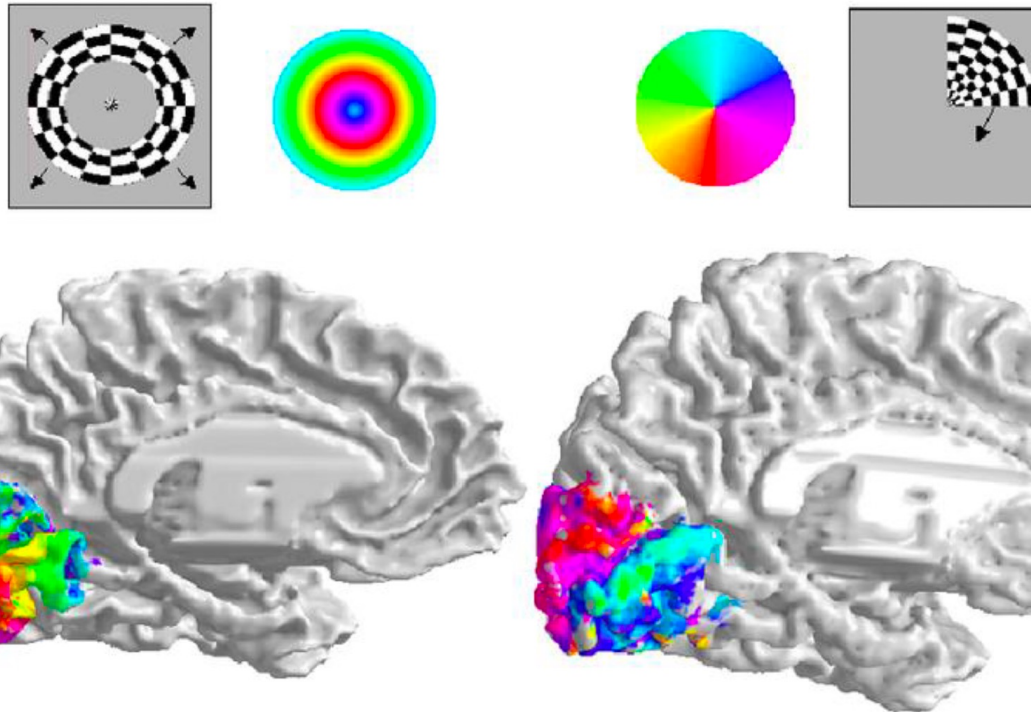


Abbildung 2.3: Anhand zwei Stimuli wurde mittels funktioneller Magnetresonanztomografie die retinotop Karte im visuellen Kortex gemessen. Links: Mit zunehmender Exzentrizität des Rings verlagert sich die Aktivierung des Kortex vom okzipitalen Pol tiefer entlang des Sulcus calcarinus. Rechts: Die obere Hälfte des Gesichtsfeldes wird im inferioren Teil des Sulcus calcarinus repräsentiert (Grün- und Blautöne), die untere Hälfte des Gesichtsfeldes wird superior des Sulcus Calcarinus projiziert (Lila- und Rottöne). (Quelle: Dougherty et al., 2003)

Visually evoked potentials (VEP) and Fields (VEF)

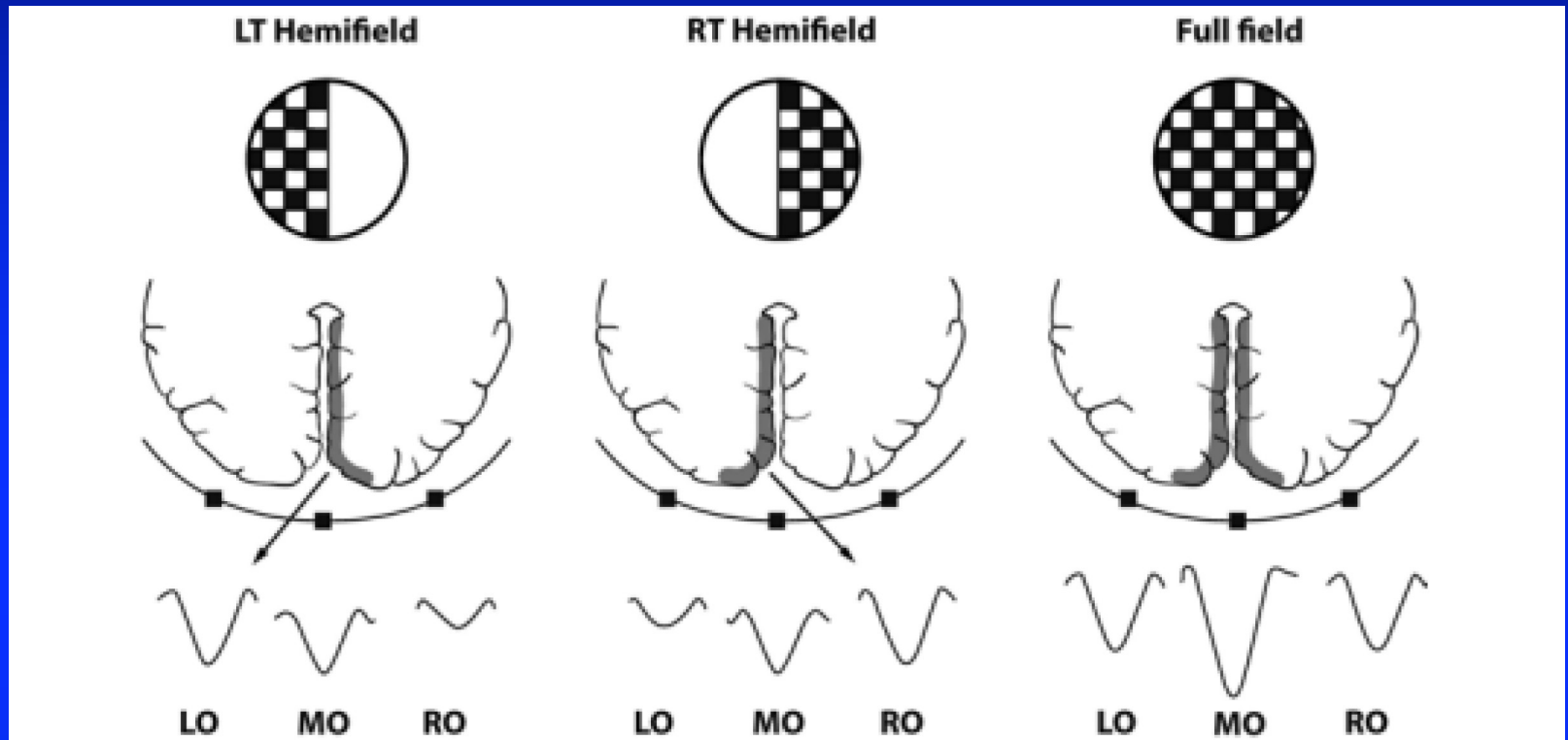


Abbildung 2.4: Paradoxe Lateralisation bei der Ableitung von visuell evozierten Antworten nach Halbfeldstimulation.

Links: Die Stimulation der linken Gesichtsfeldhälfte aktiviert die rechte Hemisphäre, die größte evozierte Antwort wird dabei über der LO Elektrode abgeleitet. Mitte: Die Stimulation der rechten Gesichtsfeldhälfte aktiviert die linke

Hemisphäre, die größte evozierte Antwort wird dabei über der RO Elektrode abgeleitet. Rechts: Die Ganzfeldstimulation aktiviert den visuellen Kortex in beiden Hemisphären, die größte evozierte Antwort wird dabei

über der MO Elektrode abgeleitet. (Quelle: Markland, 2020)

Visually evoked potentials (VEP) and Fields (VEF)

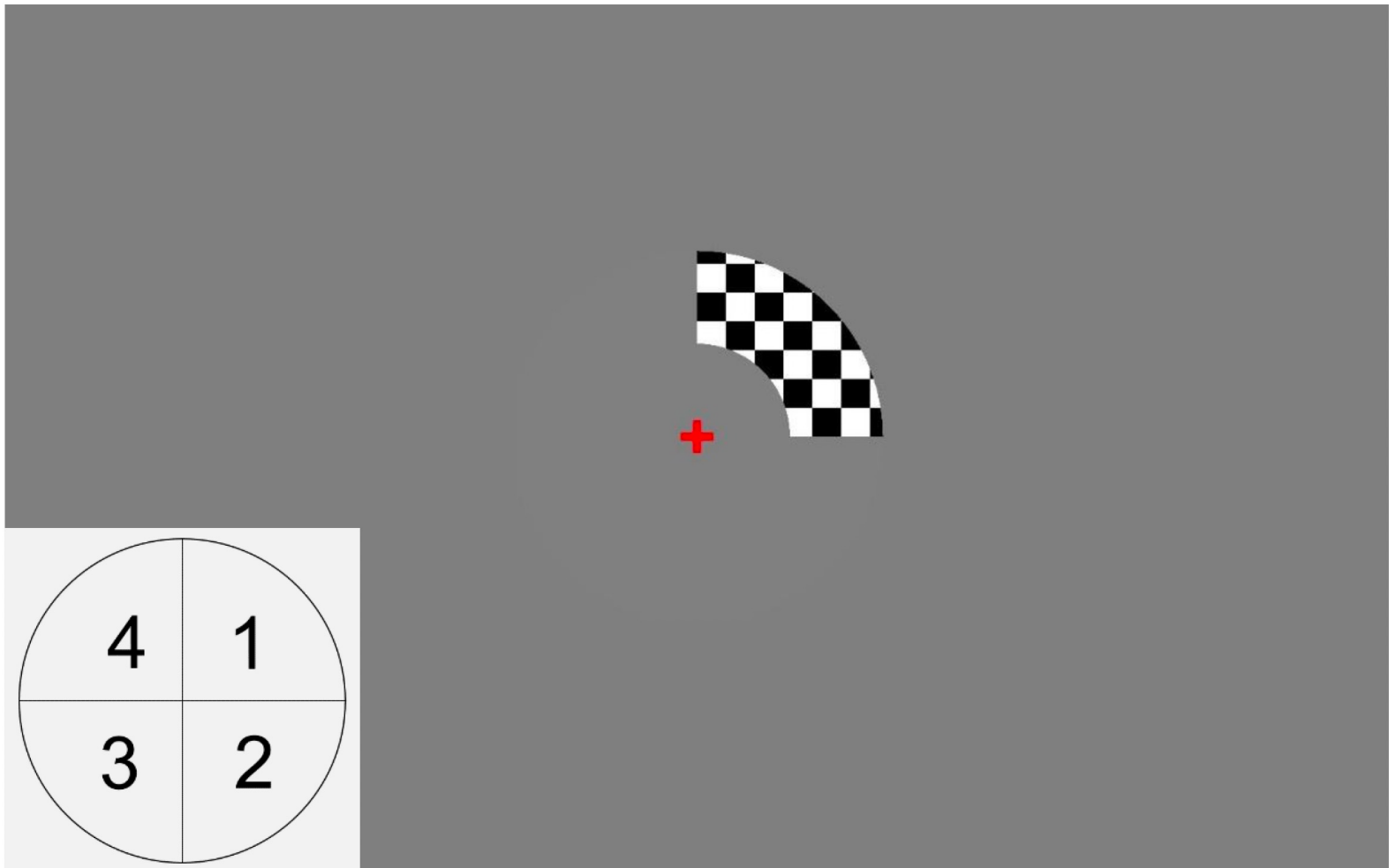


Abbildung 3.1: Darstellung des Monitors bei der Stimulation. In der Mitte des Monitors befindet sich ein rotes Fixationskreuz, um das herum jeweils ein Quadrant des Schachbrettringes gezeigt wird (hier: Quadrant 1). Unten

links: Einblendung der Quadrantenbezeichnung.

Visually evoked potentials (VEP) and Fields (VEF)

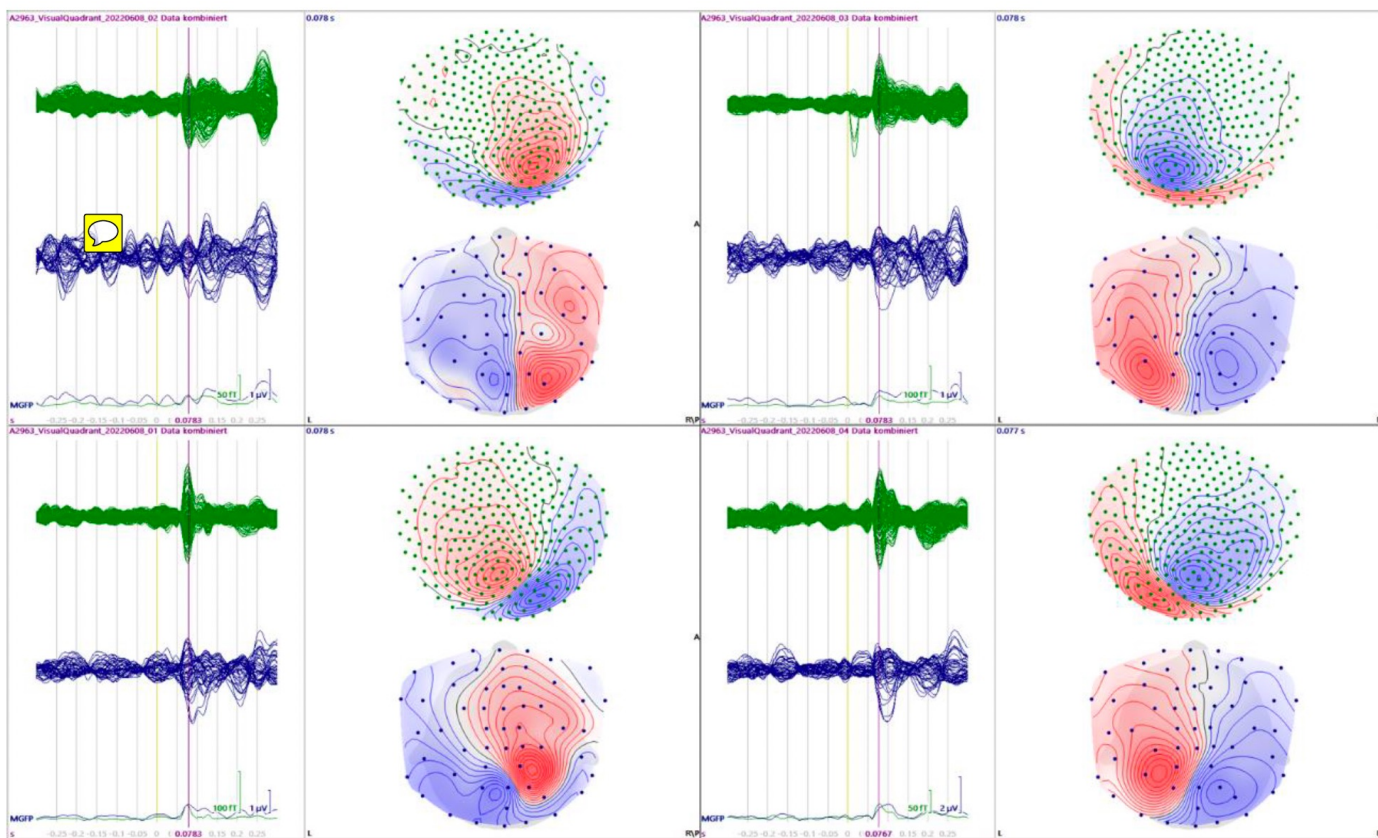


Abbildung 4.1: Darstellung der MEG- und EEG-Butterflyplots und Topographien der evozierten Antworten nach Reizung der vier Quadranten von Proband S6. Die Antworten sind jeweils in dem Quadranten dargestellt, der im visuellen Feld stimuliert wurde. Die Topographien (jeweils rechts) zeigen die Feldverteilungen zu dem Zeitpunkt der in den Butterflyplots (jeweils links) markiert ist. Die oberen in grün dargestellten Daten sind die MEG-Daten, die unteren in blau dargestellten Daten sind die EEG-Daten. Bei EEG-Topographien in grau hinterlegt: schematische

Draufsicht eines Kopfes mit Nase und Ohren.

Carsten Wolters, IBB, WWU Münster

Visually evoked potentials (VEP) and Fields (VEF)

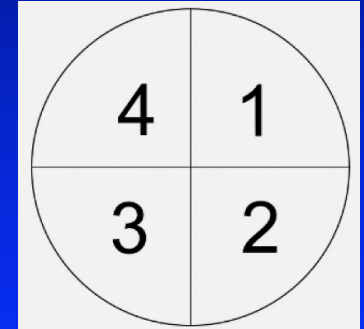
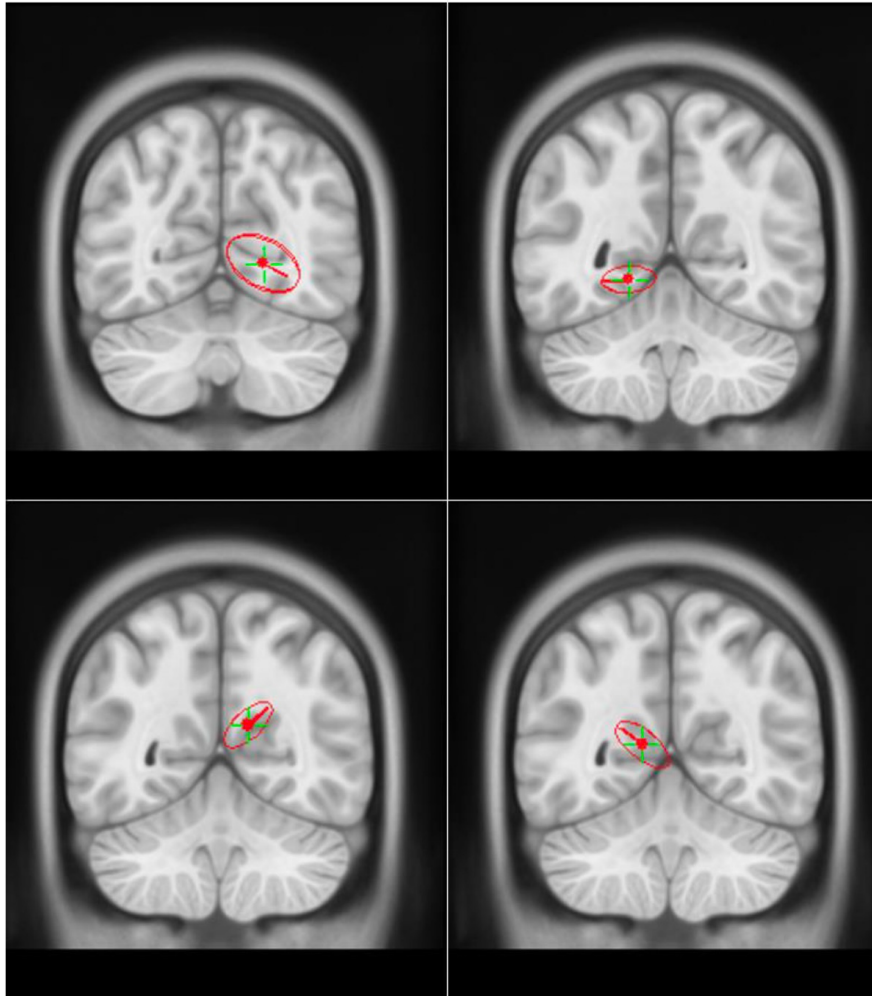


Abbildung 4.2: Darstellung der Ergebnisse der Quellenlokalisierung von Proband S6 in der Frontalansicht. Die Dipole sind von Konfidenzellipsen umgeben. Die Anordnung in den Quadranten der Abbildung entspricht der Stimulation des jeweiligen Quadranten.

Visually evoked potentials (VEP) and Fields (VEF)

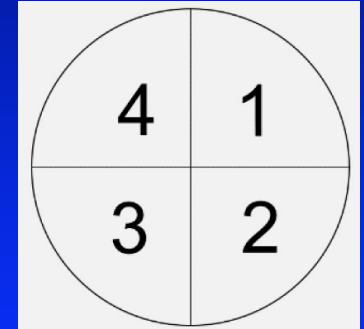
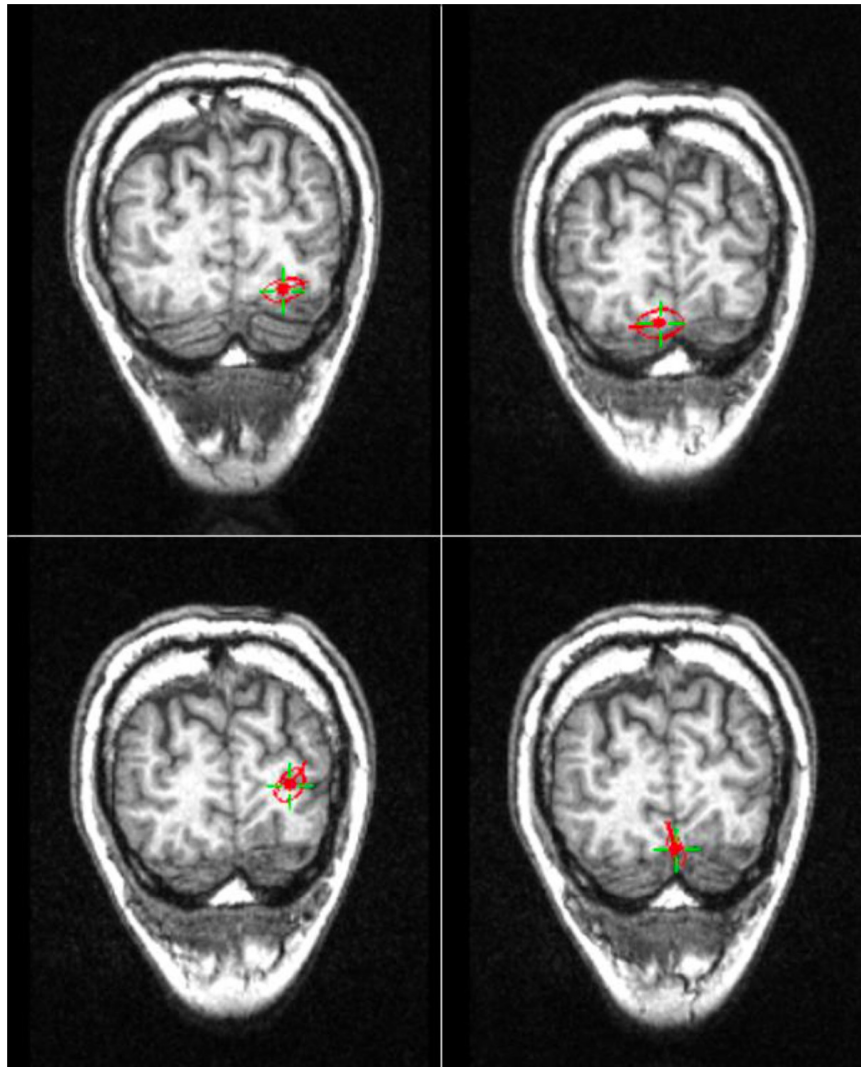


Abbildung 4.3: Darstellung der Ergebnisse der Quellenlokalisierung von Proband S1 in der Frontalansicht. Die Dipole sind von Konfidenzellipsen umgeben. Die Anordnung in den Quadranten der Abbildung entspricht der Stimulation des jeweiligen Quadranten.

Visually evoked potentials (VEP) and Fields (VEF)

Proband	Quadrant	Dipolstärke/ μAmm	erklärtes Signal/%
S1	1	12,2	74,1
	2	19,8	82,2
	3	20,8	74
	4	14	57,7
S6	1	23,4	77,8
	2	22,1	85,1
	3	20,1	80,5
	4	10,4	72,9

Tabelle 4.1: Übersicht über die Dipolstärken und die Höhe des Signalanteils, der durch den Dipol erklärt wird für alle kombinierten MEG- und EEG-Daten. Bei den ersten drei Probanden wurde ein realistisches Kopfmodell der

Visually evoked potentials (VEP) and Fields (VEF)

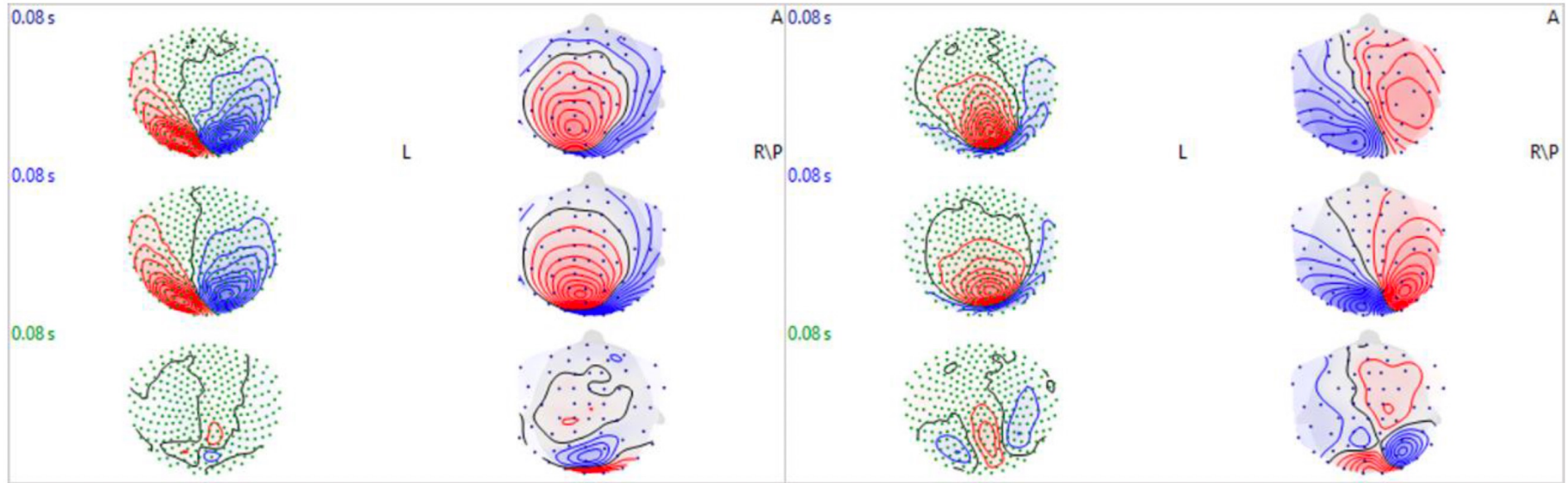
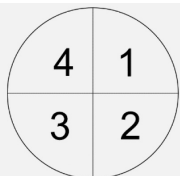
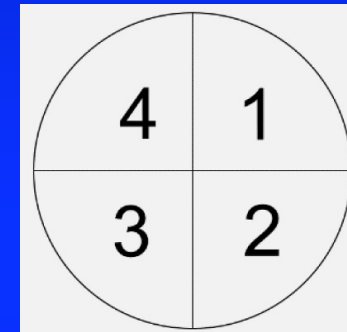
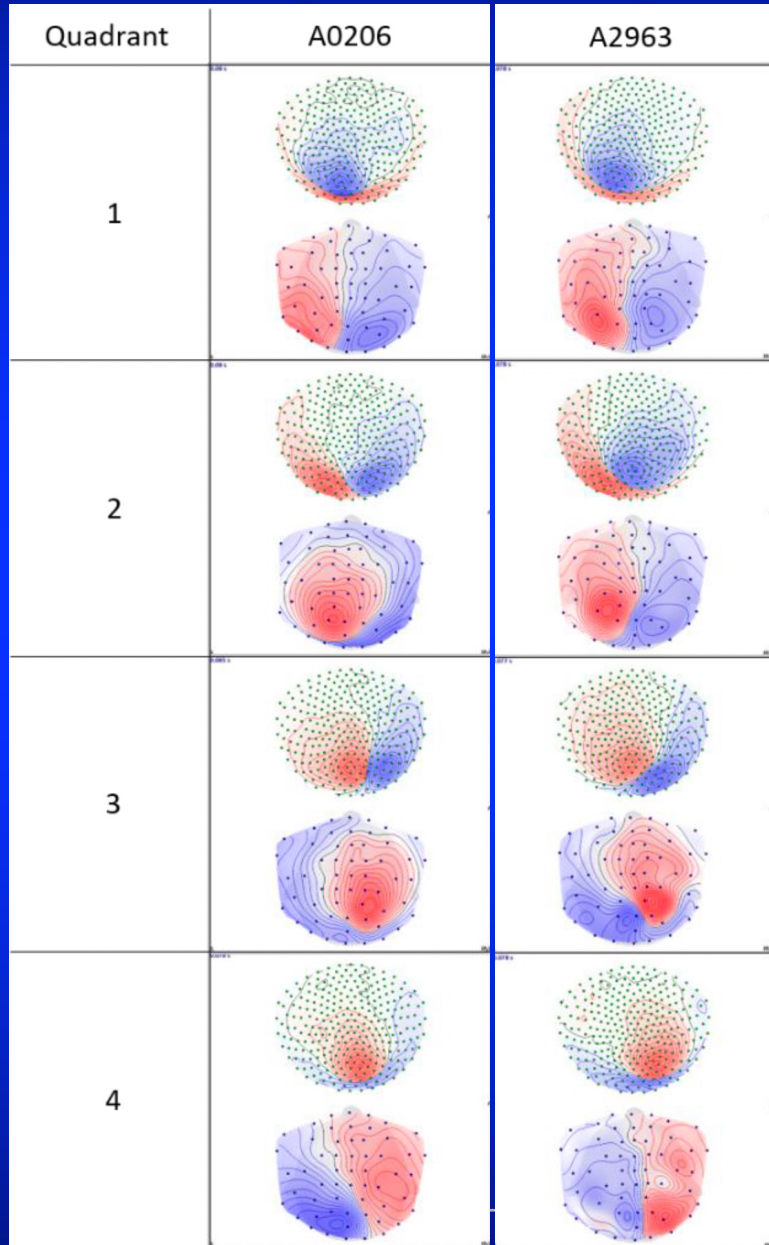


Abbildung 4.7: Darstellung der Topographien von Proband S1. Links: Topographien ca. 80 ms nach Stimulation des zweiten Quadranten, rechts: Topographien ca. 80 ms nach Stimulation des vierten Quadranten. Die jeweils linken Topographien zeigen die MEG-Topographien, die rechten sind die EEG-Topographien. Die oberen Topographien basieren auf den gemessenen Signalen, die mittleren zeigen die Topographien, die der berechnete Dipol erzeugt und die jeweils untere Topographie zeigt die Differenz zwischen den oberen beiden Topographien.

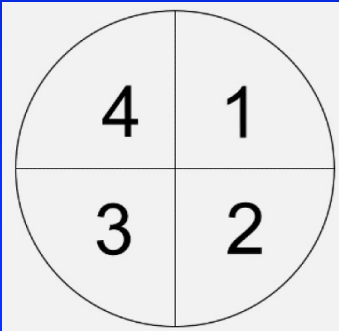


Visually evoked potentials (VEP) and Fields (VEF)



Anhang 3: Übersicht aller Topographien, der VEF- (oben) und VEP- (unten) Komponente, die mit der kombinierten MEG- und EEG-Messung aufgezeichnet wurden. Die Topographien wurden den Probanden und Quadranten entsprechend angeordnet.

Visually evoked potentials (VEP) and Fields (VEF)

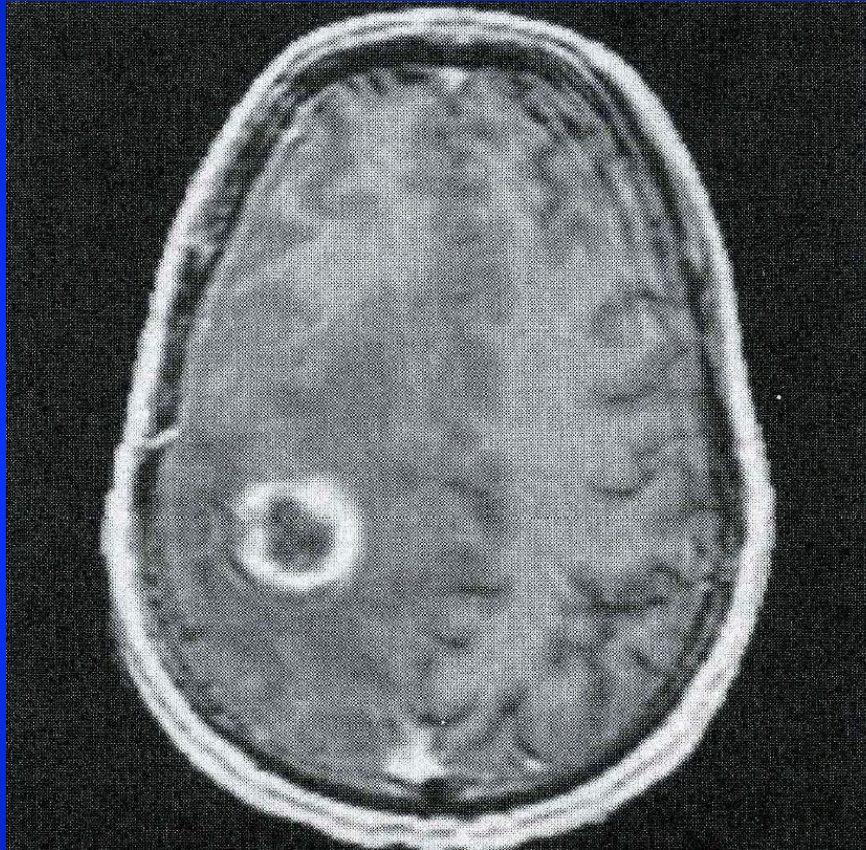


Datum	Proband	Messsystem	Quadrantenreihenfolge	Kommentar
05.05.2022	Denis	MEG	4, 3, 2, 1	Kein Triggerdelay
10.05.2022	Denis	EEG (EGI)	1, 2, 3, 4	Latenz -10 ms
25.05.2022	Lotta	EEG (EGI)	1, 2, 3, 4	Latenz +30 ms
02.06.2022	Carsten	MEG+EEG	4, 3, 2, 1	Kein Triggerdelay
07.06.2022	Lena	EEG(EGI)	1, 3, 2, 4	Latenz -10 ms
08.06.2022	Lotta	MEG+EEG	4, 3, 2, 1	Kein Triggerdelay
08.06.2022	Denis	MEG+EEG	3, 4, 1, 2	Kein Triggerdelay
08.06.2022	Andreas	EEG (EGI)	1, 2, 3, 4	Latenz -10 ms
10.06.2022	Carsten	EEG (EGI)	3, 4, 1, 2	Latenz -10 ms

Structure of this lecture

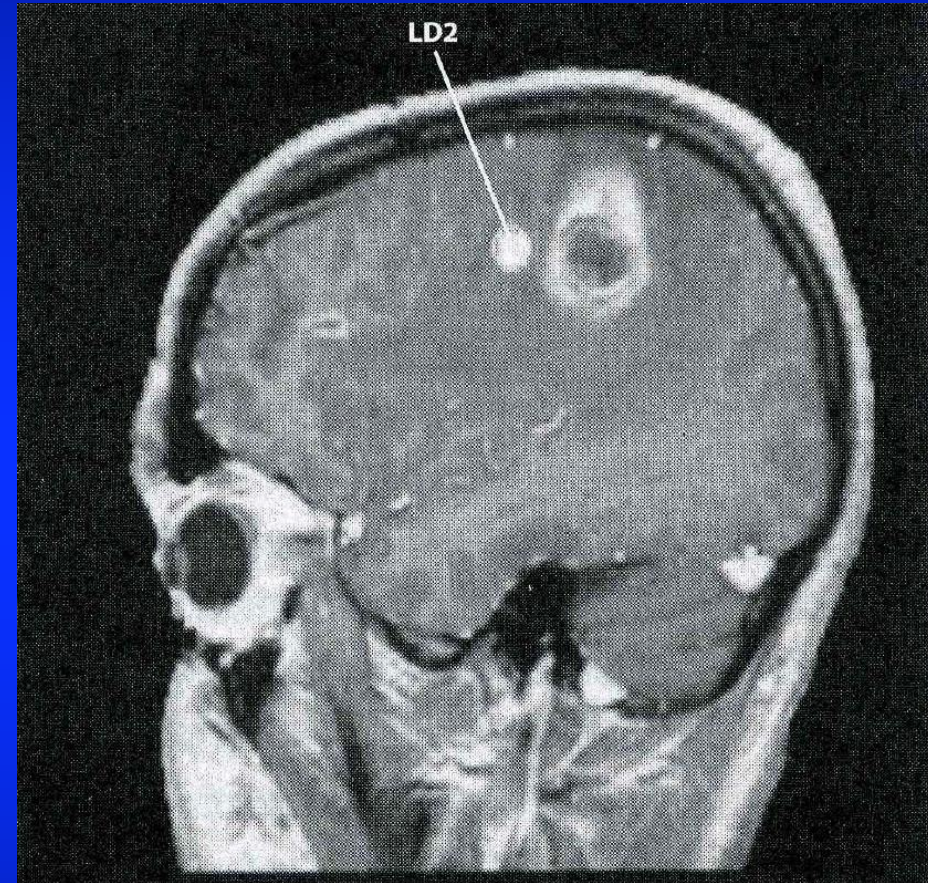
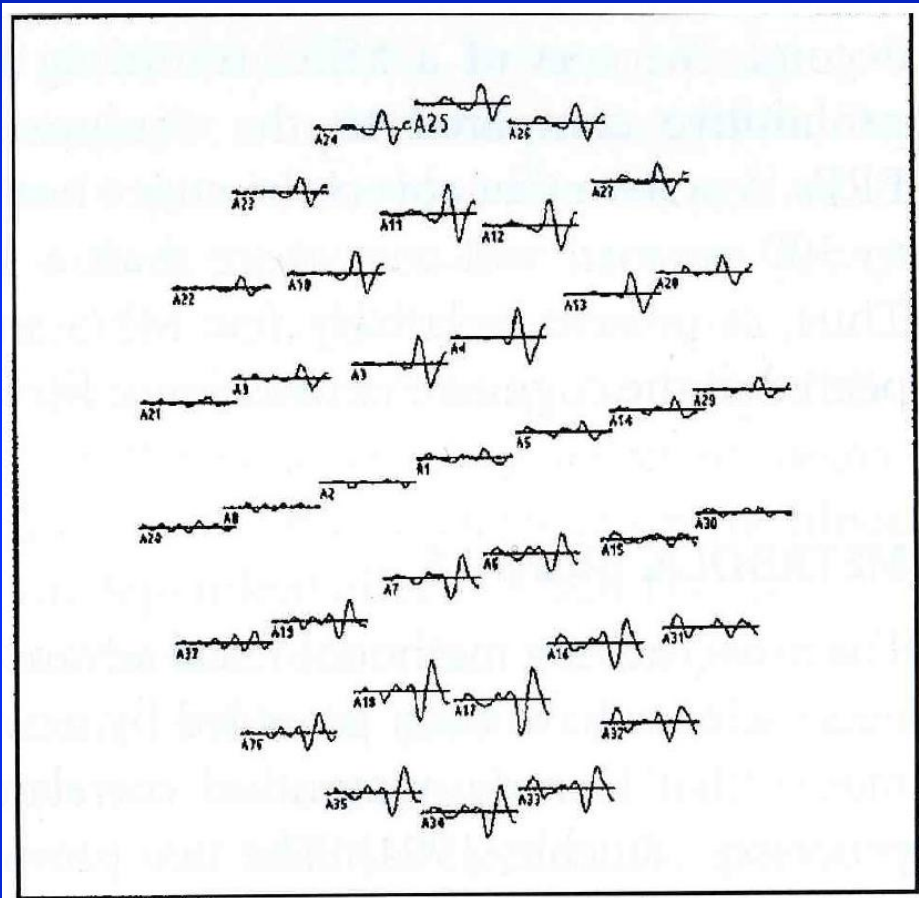
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Clinical applicability of SEP/SEF source analysis



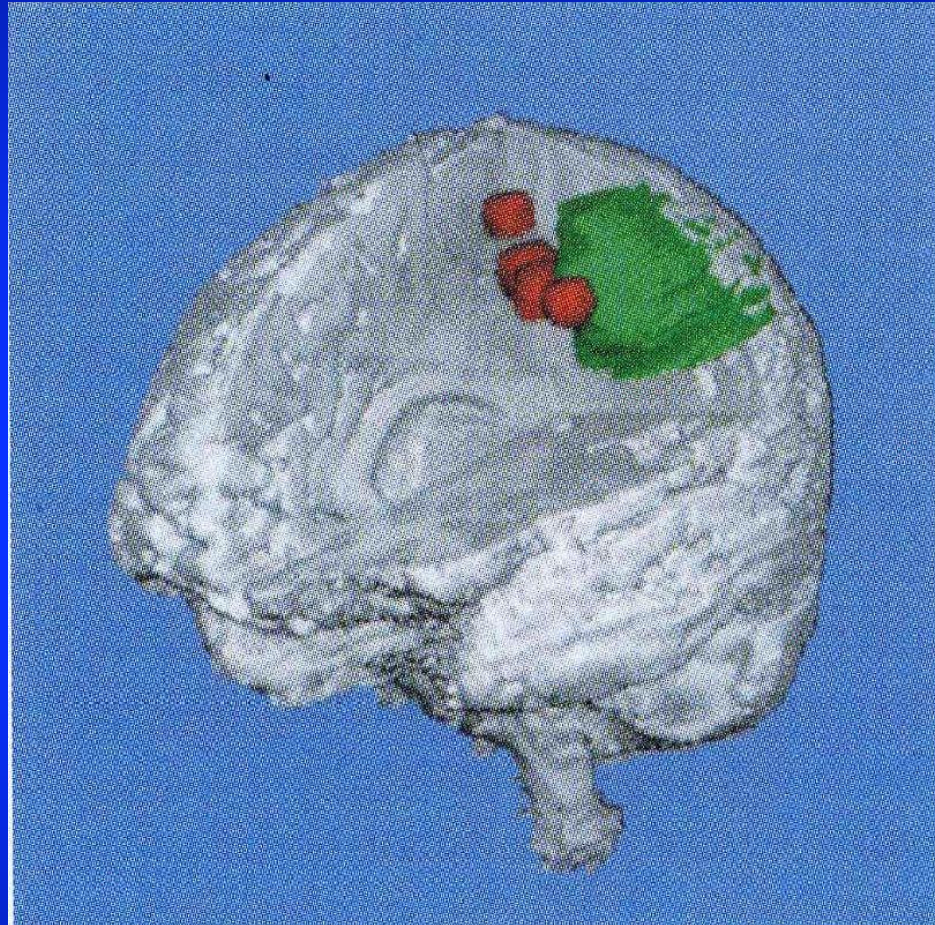
Tumor near the central sulcus

Clinical applicability of SEP/SEF source analysis



Tactile stimulation of the right index finger: SEF (left) and fitted dipole (right)

Clinical applicability of SEP/SEF source analysis



Tumor (green) and MEG dipole fits (red) for continuous stimulation of fingers and toes

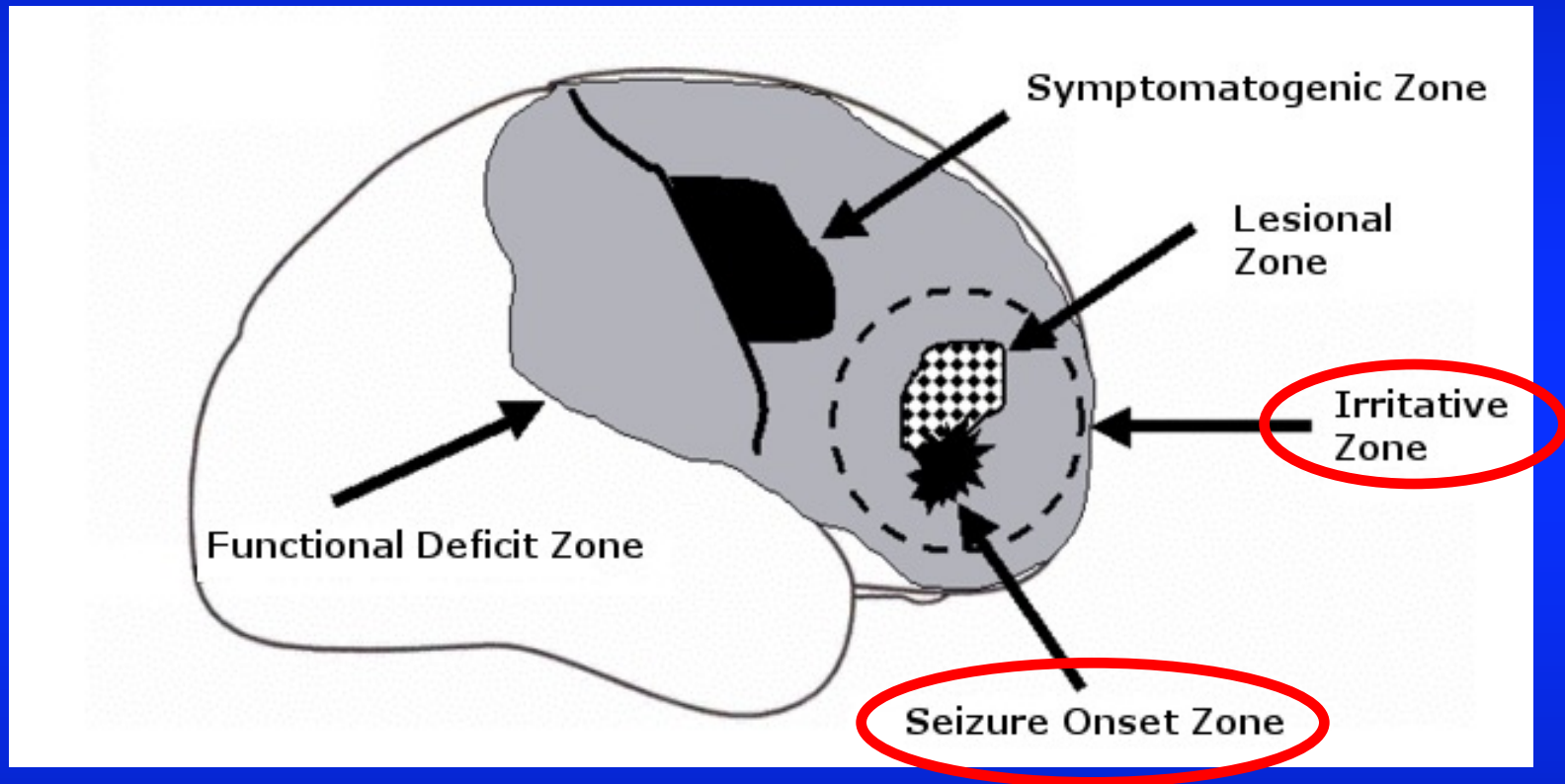
Structure of this lecture

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Source analysis in presurgical epilepsy diagnosis

- 0.5%-1% of world population suffers from epilepsy, most of them from focal epilepsy
- 70-80% of patients successfully treated with drugs
- For those who are still pharma-resistant after 2-3 drugs
 - Probability of success of a further different drug: 6% (Wiebe et al 2001)
 - Probability of success of a surgical treatment: 50% (Wiebe et al 2001)
- Indispensable prerequisite for surgery: Focal epilepsy->Localization
 - Gold standard: Video-monitoring and visual inspection of the EEG (Wilson 1996)
 - MRI: Identification of an underlying lesion
 - PET and Neuropsychology: Localization of a functional deficit
 - Source analysis of
 - EEG seizure (ictal) activity (Plummer et al., 2008)
 - EEG/MEG interictal activity: “irritative zone” (Stefan et. al., 2003)

Zone-concept in epilepsy diagnosis



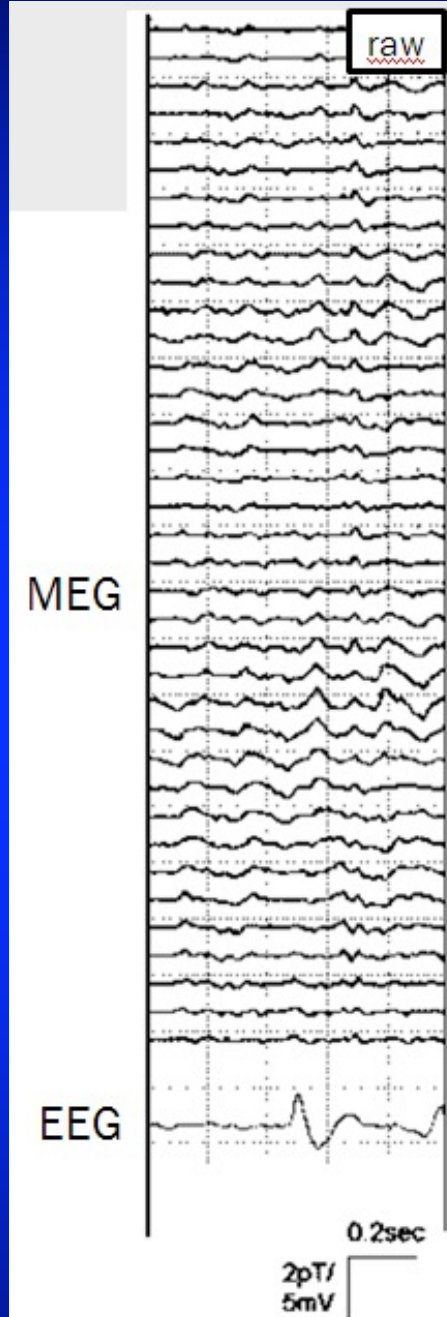
EEG(/MEG) registration during a seizure (ictal)

Interictal spikes in EEG/MEG

Epileptic spikes in EEG and MEG

Clear spike in EEG

Nearly no/no signal in MEG



Epileptic spikes in EEG and MEG

Clear spike in EEG

Nearly no/no signal in MEG

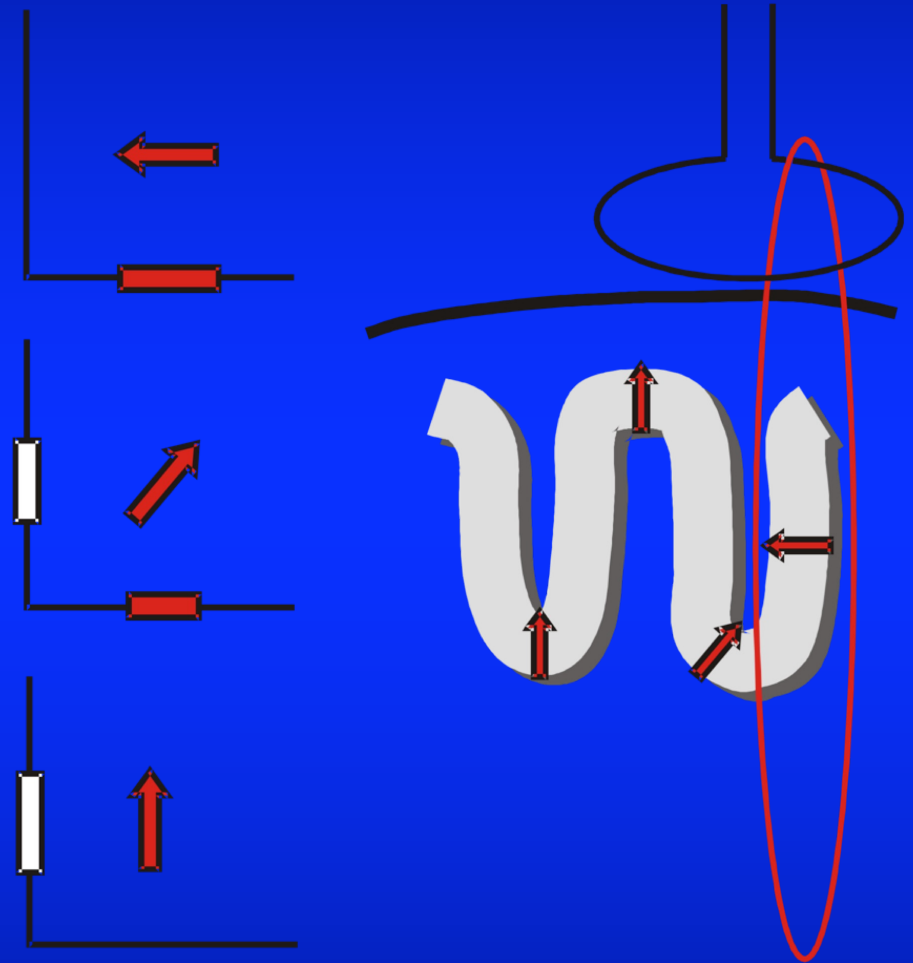
⇒ Deep source

⇒ Strongly radially oriented source



Sensitivity for radial and tangential sources

- MEG registers mainly tangential source components: Sulci-walls: tangential pyramidal cells -> High amplitudes
- „Diagonal“ orientation -> Medium amplitude
- Radial sources hardly produce an MEG: Depth and crown of sulci: radial pyramidal cells -> Low contribution



Epileptic spikes in EEG and MEG

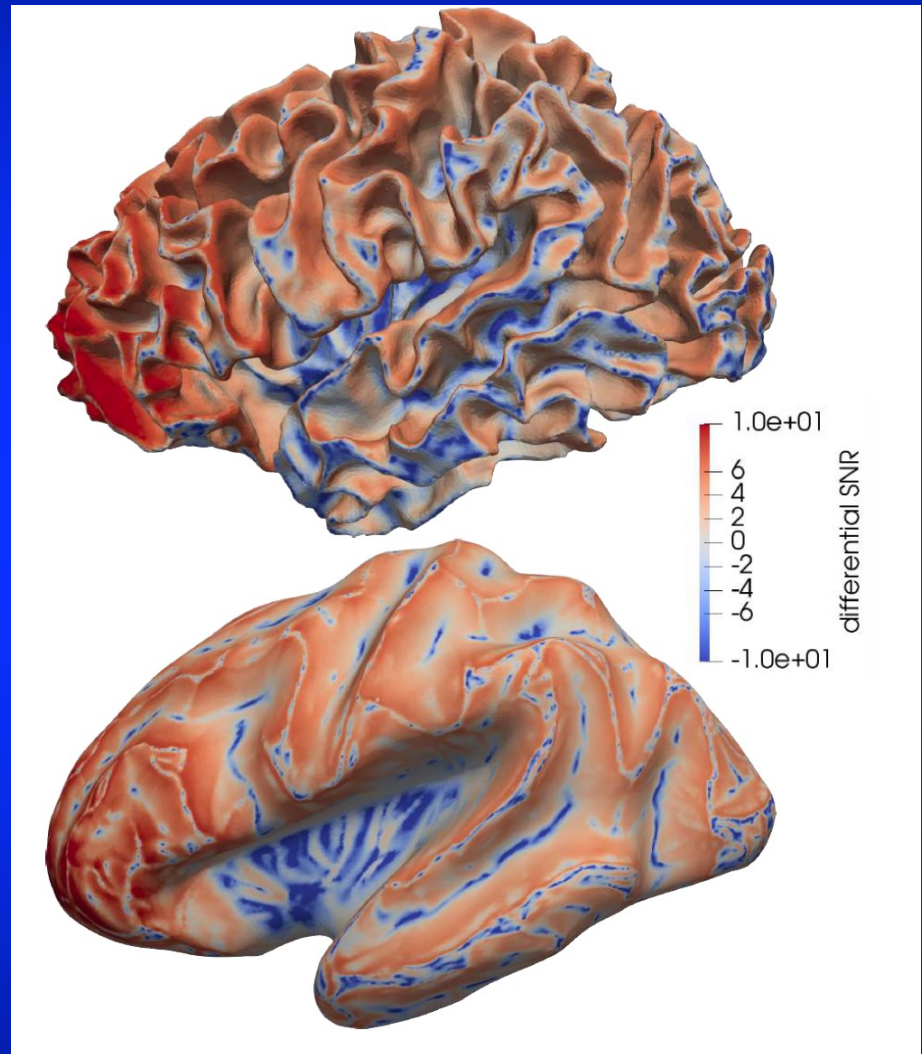
Clear signal in MEG,
poor signal in EEG

Explanation?



Sensitivity

- Blue: Sensitivity EEG > MEG for radial and deep sources
- Red: Sensitivity MEG > EEG in sulcal wall areas



Goldenholz et al., 2009

Complementarity of EEG and MEG

- Iwasaki et al 2005:
 - EEG/MEG: 72% (31/43 pat)
 - Only EEG: 2% (1/43 pat)
 - Only MEG: 19% (8/43 pat)
 - None: 7% (3/43 pat)
- Knake et al 2006:
 - EEG/MEG: 75% (50/67 pat)
 - Only EEG: 3% (2/67 pat)
 - Only MEG: 13% (9/67 pat)
 - None: 25% (17/67 pat)

What should we use?
MEG instead of EEG?
Only EEG?

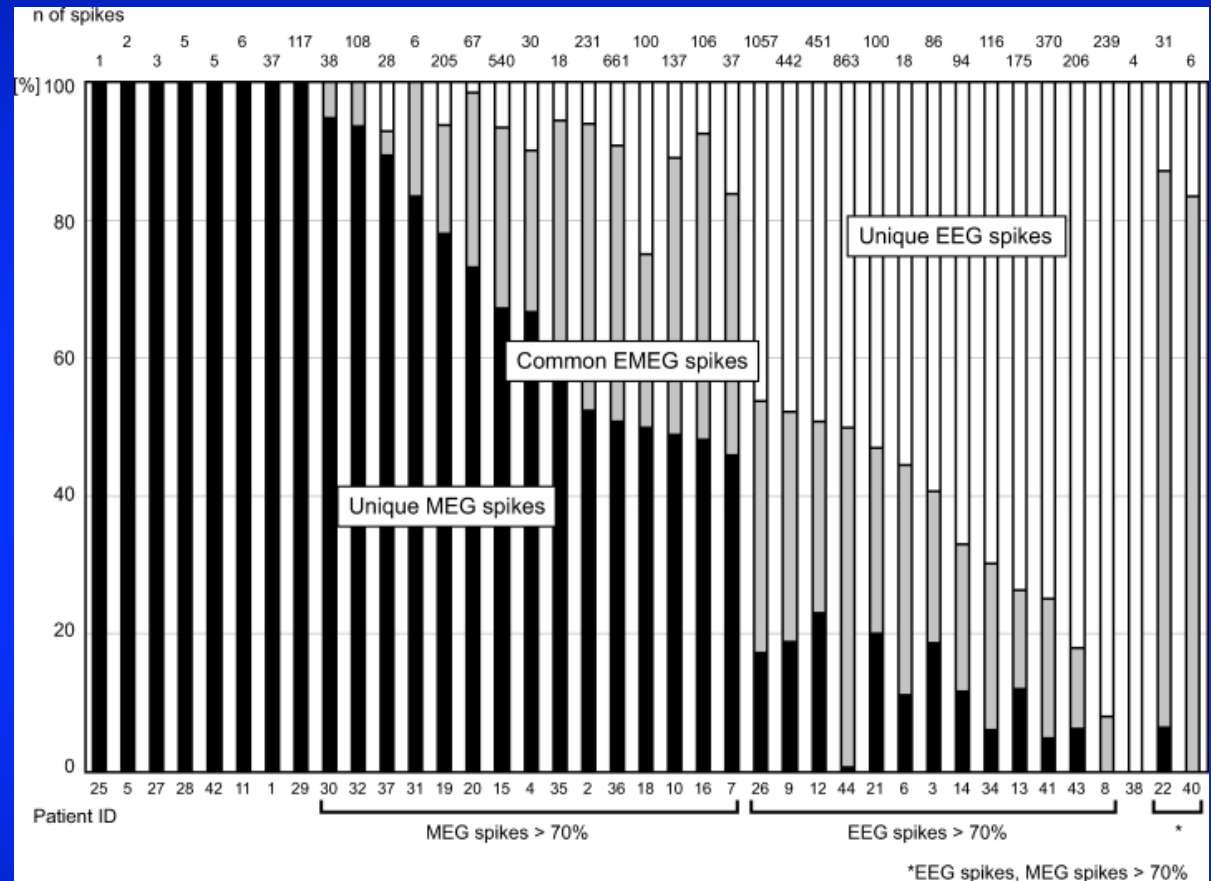


Fig. 3. Populations of spikes that were detected only in magnetoencephalography (MEG) (unique MEG spikes in black), only in EEG (unique EEG spikes in white), and commonly in both EEG and MEG [same spike detected in both modalities (EMEG) spikes in gray] are shown on a percentage scale for 39 patients who had at least one spike. Common EMEG spikes account for a relatively small proportion of the total spikes (median, 25.7%). The patients are roughly divided into those with a large number of EEG spikes ($n = 13$), those with a large number of MEG spikes ($n = 15$), and those with no dominance ($n = 2$).

Combined EEG and MEG



275 channel axial gradiometer whole-cortex MEG
128 channel EEG

Patient study 1: Source analysis of interictal spikes in presurgical epilepsy diagnosis

Averaged interictal EEG spikes

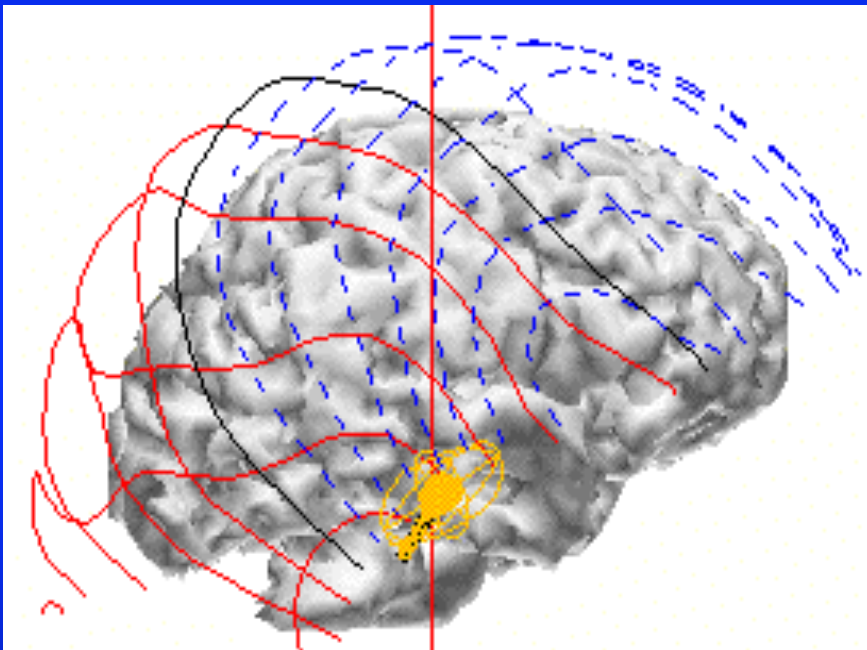
ChannelSet: VIRTUAL-SENS Trial 9 of 12: Unclassified.



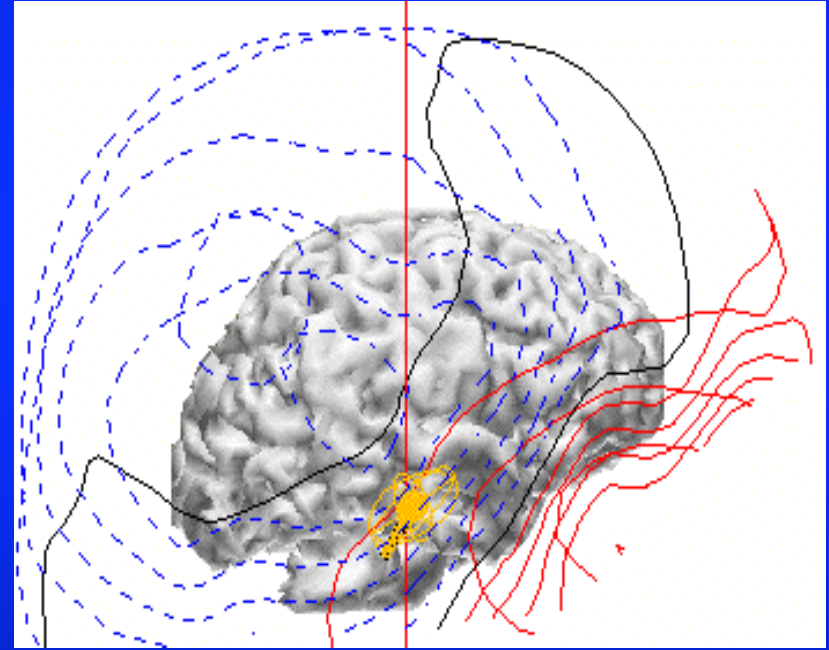
Measure EEG and/or MEG

Results of combined EEG/MEG dipole fit

EEG data and (transparent) cortex



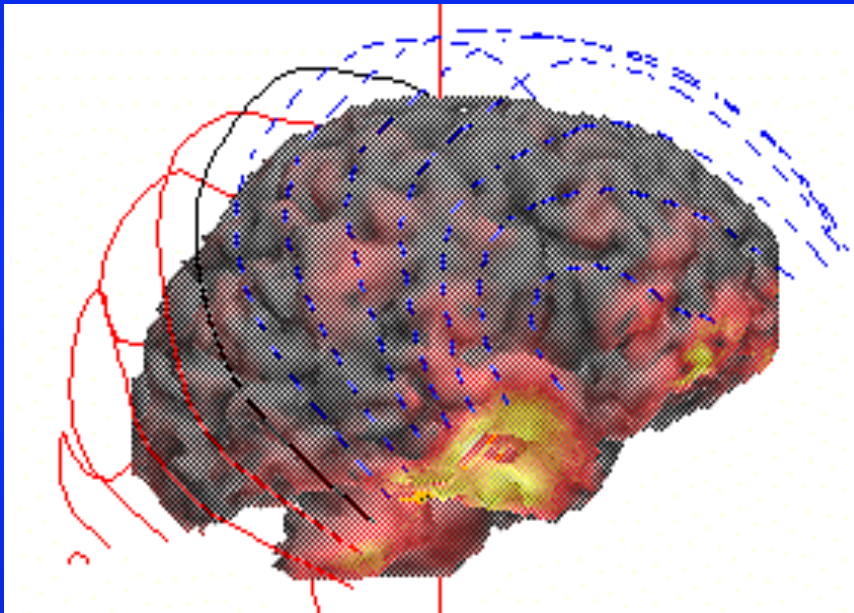
MEG data and (transparent) cortex



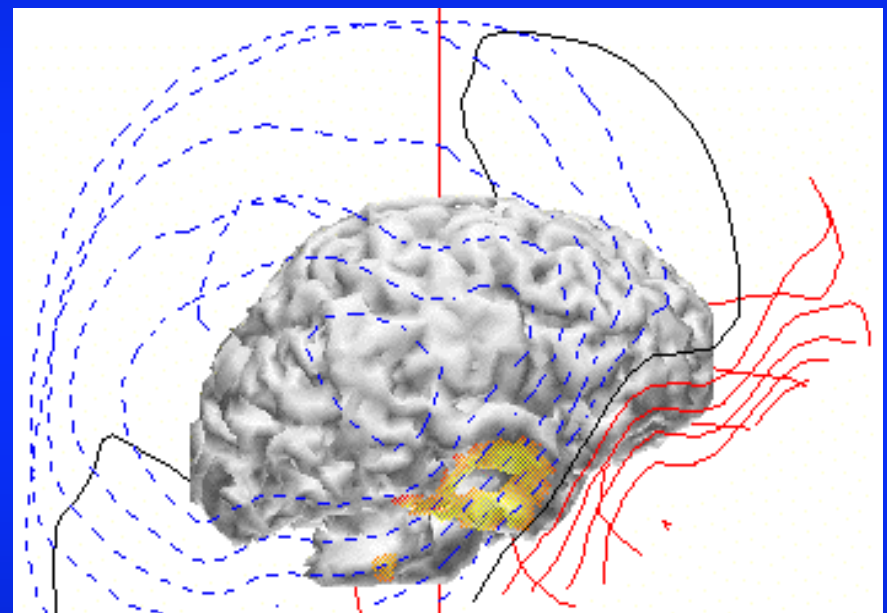
Inverse method: **Single current dipole**

Results of combined EEG/MEG L1 norm current density reconstruction

EEG data and (nontransparent) cortex



MEG data and (nontransparent) cortex



Inverse method: **L1 norm current density**

Thank you for your attention!



SIM-NEURO
work-group



DFG



DAAD

