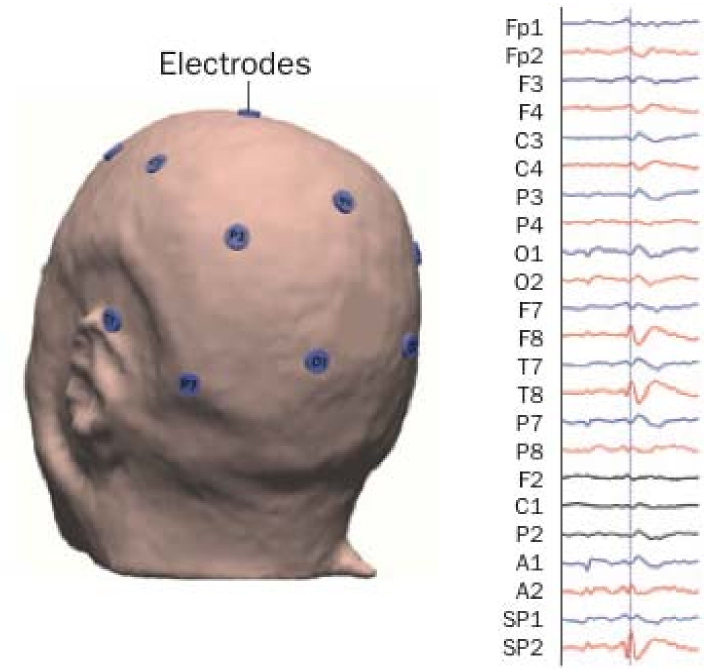
Practical class - neuromodulation and imaging:

# EEG source analysis

Pieter van Mierlo
Willeke Staljanssens
Gregor Strobbe

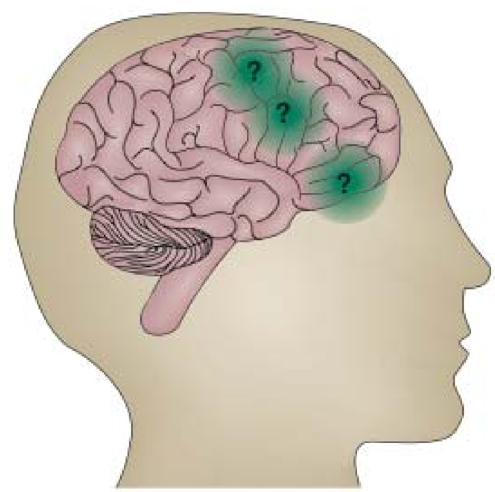
# Introduction

# EEG source analysis

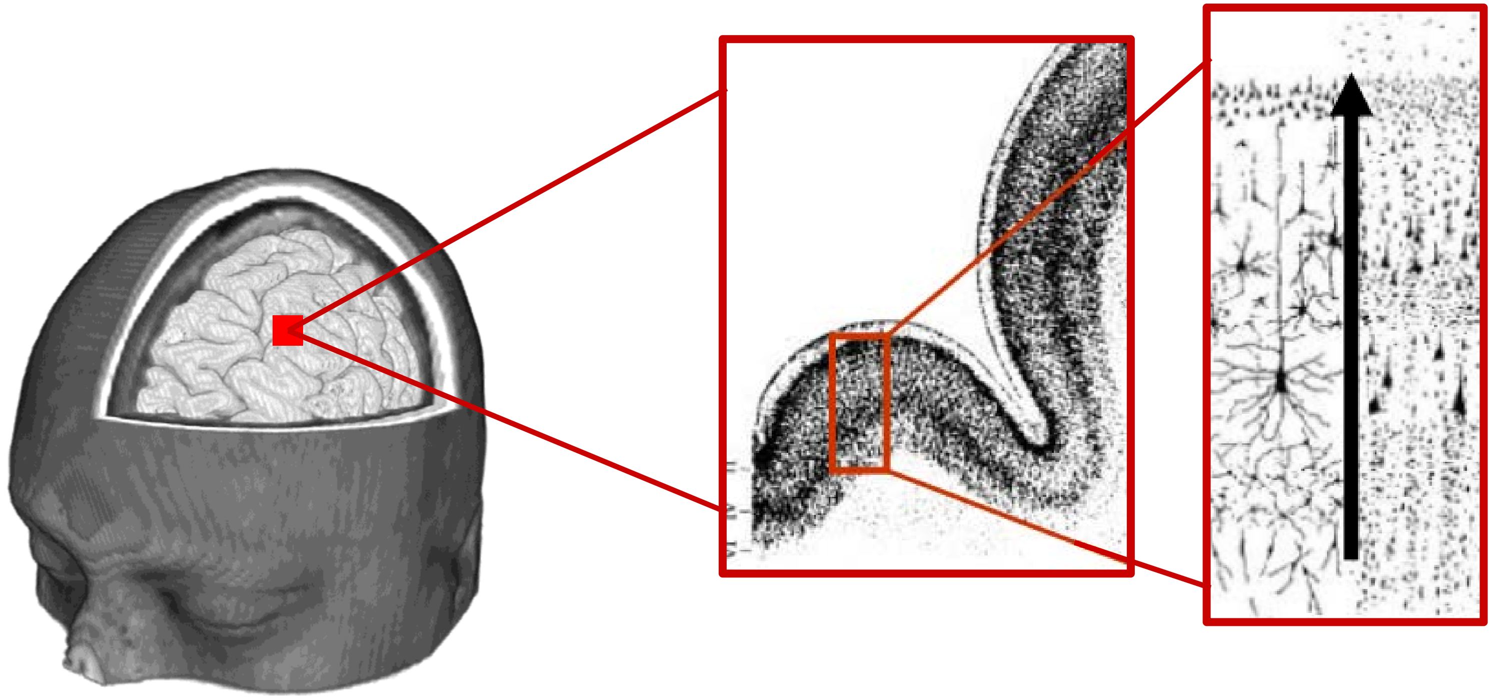



Inverse problem?

→

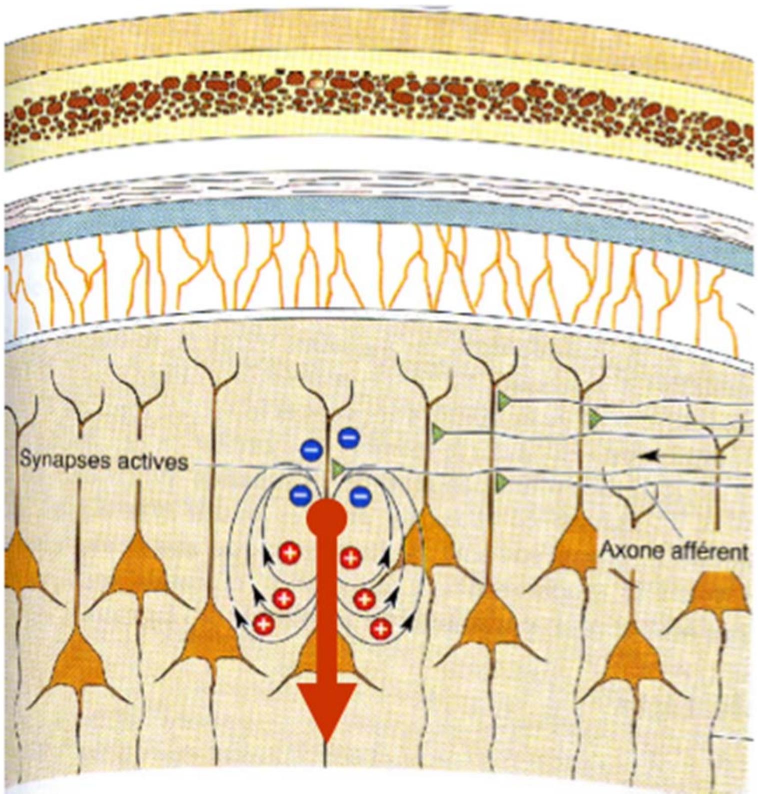


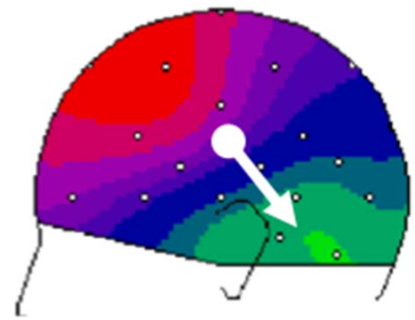
# What are we measuring?



- ~100,000 simultaneously active neurons are needed to generate a measurable EEG signal
- Pyramidal cells are the main direct neuronal sources of EEG signals
- Synaptic currents but not action potentials generate EEG signals

# How do we model these generating sources?

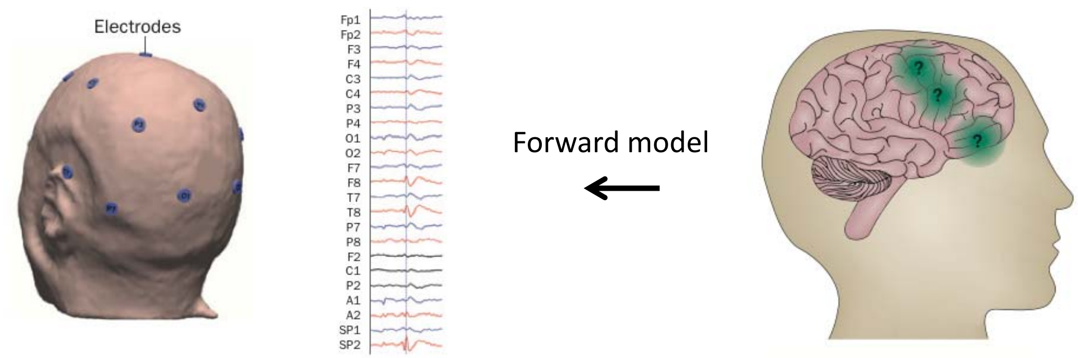


Current dipole:

- orientation
- intensity
- location

# Forward model characterization



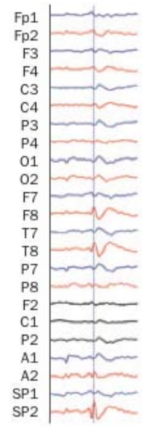

Head model

- Geometrical properties of the head
- Electromagnetic properties of the head
- Position of the electrodes

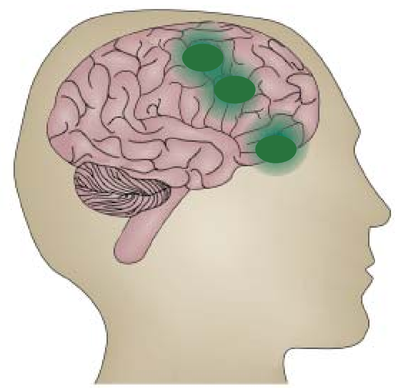
Source space

- The number of dipoles
- Location of the dipoles
- (clustering of dipoles)

# Forward model




Forward model ←



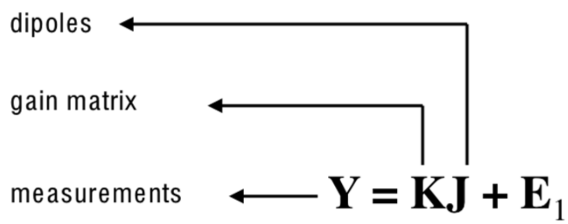
*Maxwell*

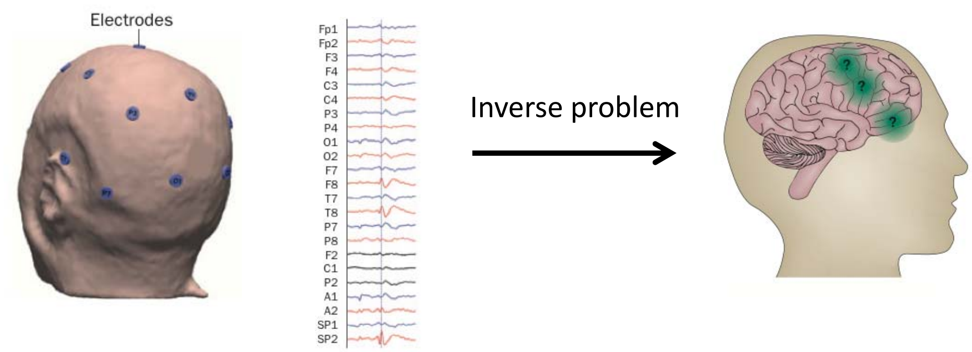
dipoles ← J

gain matrix ← K

measurements ← $\mathbf{Y} = \mathbf{K}\mathbf{J} + \mathbf{E}_1$

# Solution?




Example: minimize $||\mathbf{Y} - \mathbf{KJ}||^2$ in function of the parameters of the forward model

# Inverse methods

Using focal source models:

- Single dipole fitting
- Multiple dipole fitting

→ Good performance when source is expected to be focal, e.g. epilepsy spikes

Using distributed source models:

- Dipole distributions: LORETA, MUSIC, MSP, …

→ Good performance when source is expected to be distributed or patchy

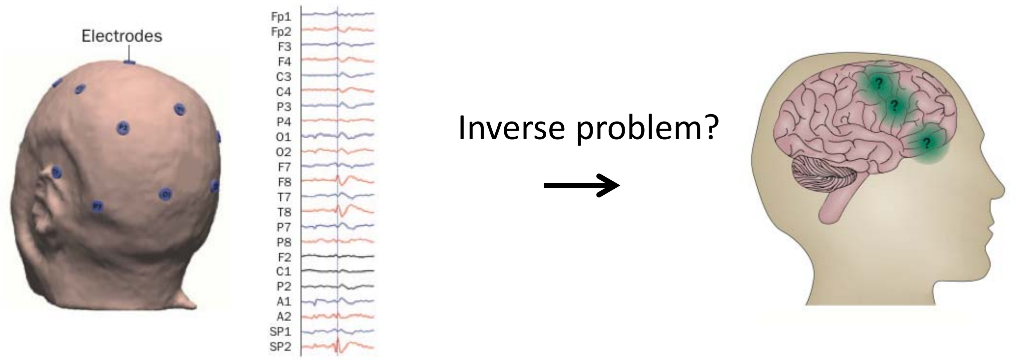
# Hands-on

# Goal?

Get familiar with EEG signals – EEG source analysis

Introduction to the processing of these signals:

- Get relevant information from signals
- Interpretation of the results



# **Part 1**: Influence of the head model

3-layered versus 4-layered head models:
Investigate the effect of modeling extra layers in the brain

Do localization of an epileptic spike

(optional) Investigate the effect of high versus low skull conductivity

# **Part 2**: Influence of the source space and inverse technique

Single dipole sources
Multiple dipole sources
Distributed dipole sources

Reconstruction of realistic ERP data

# Practicum

Class notes (summarized theory - exercises)

Apply pre-written matlab programs:

– Located on **C:\temp\Code_data**

Interpretation of the figures:

– what did you plot?

Minimal programming

Sometimes demands to be creative

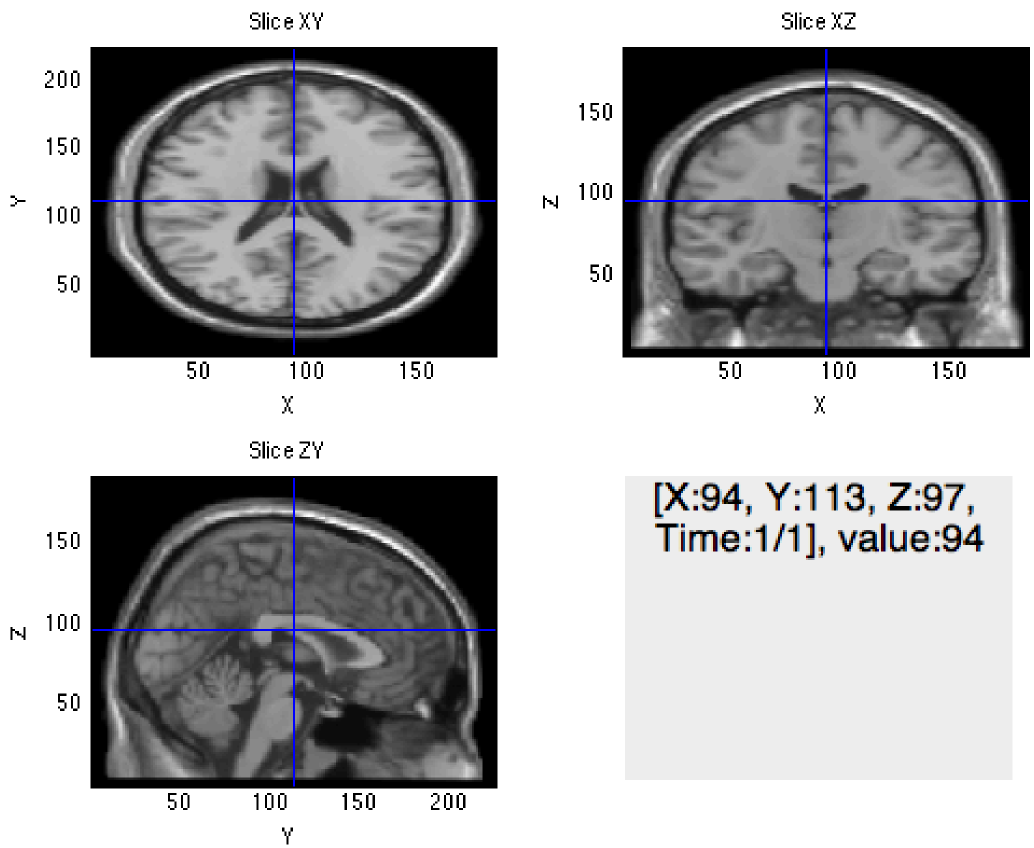
# What do we expect from you?

Report:

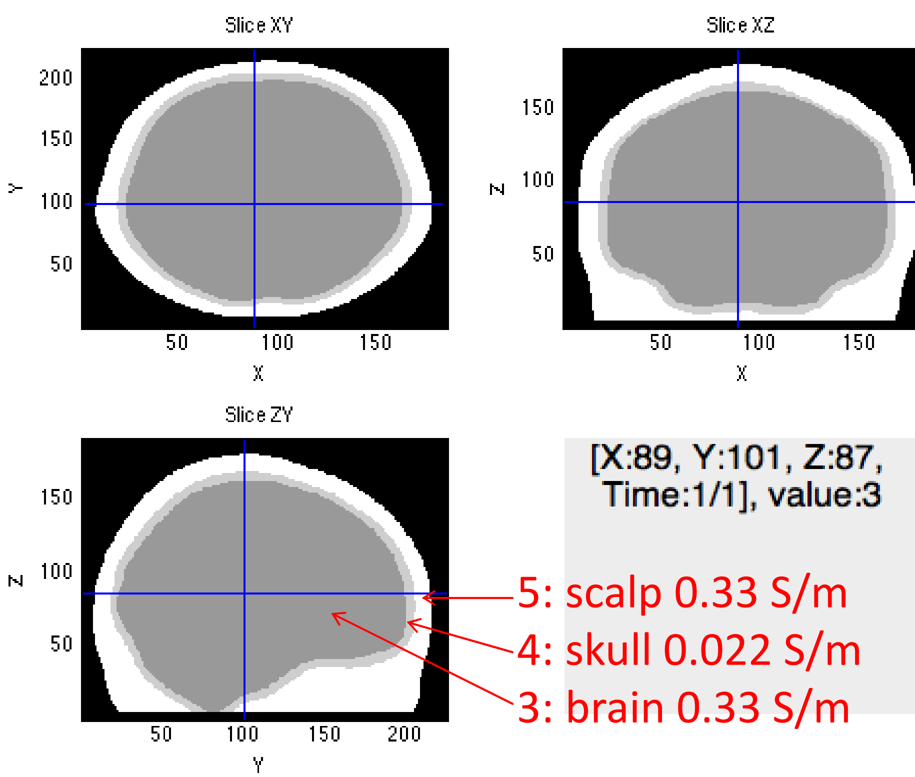
- Answer to the questions
- Illustrate with figures
  - Don’t forget labels!
- Be short and concise (**NO matlab code**!)
- One report for each 2 persons **in pdf**
- Use dropbox (on minerva) to upload the report
- Deadline: April 13th **at 23:59!**

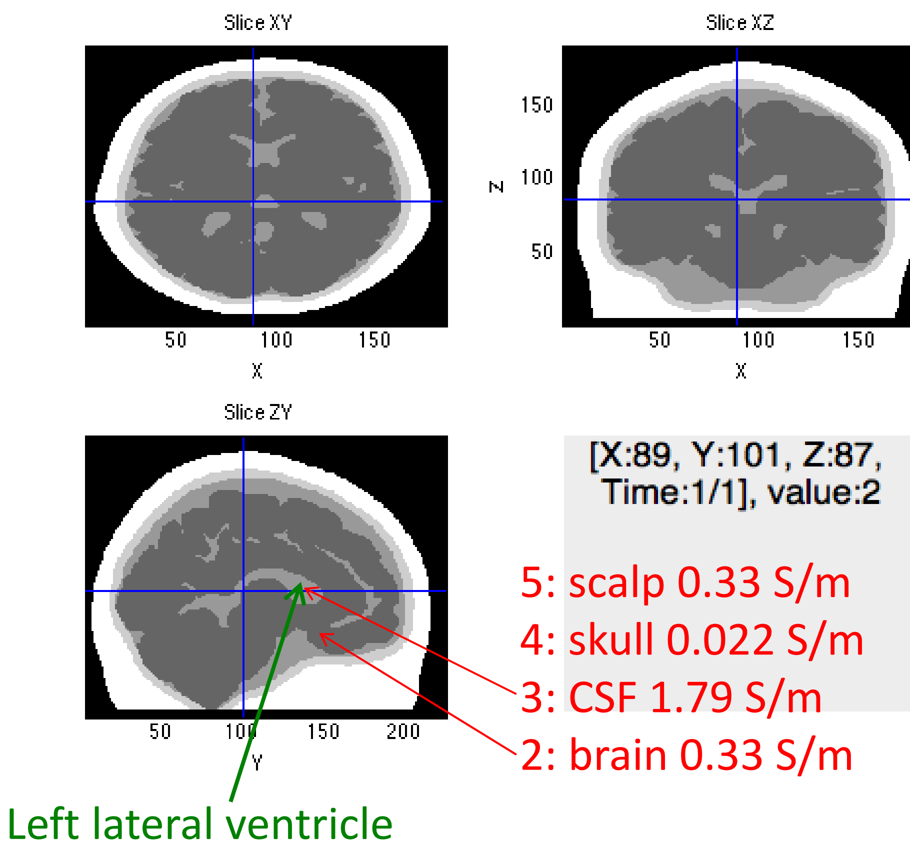
# Influence of the head model

# 3-layered versus 4-layered head models



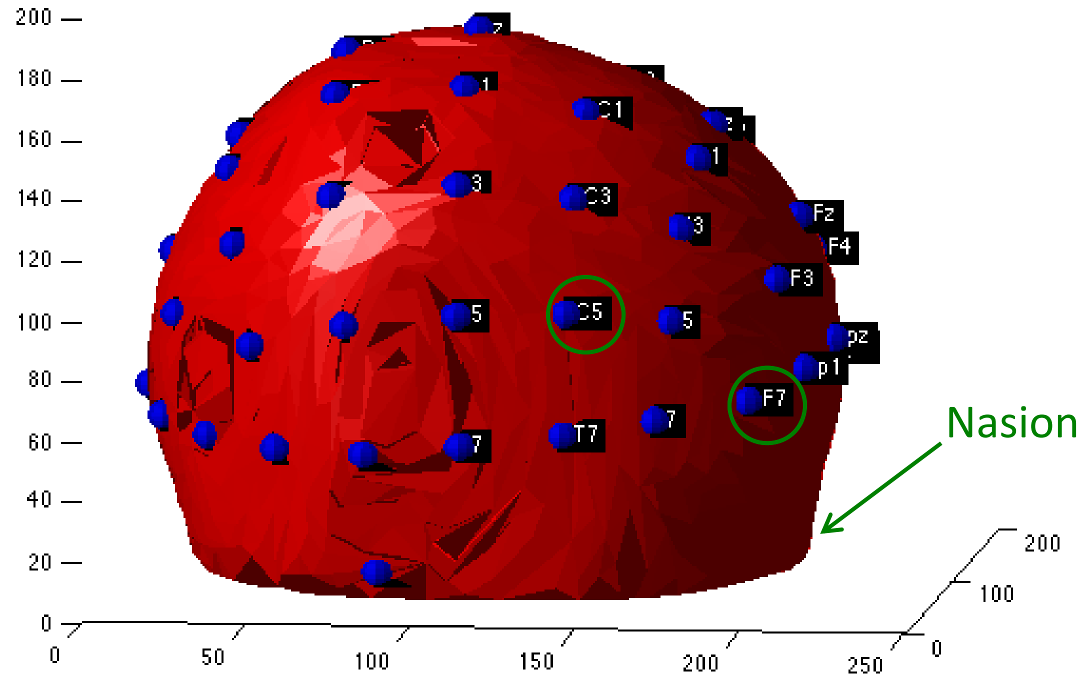
# 3-layered versus 4-layered head models



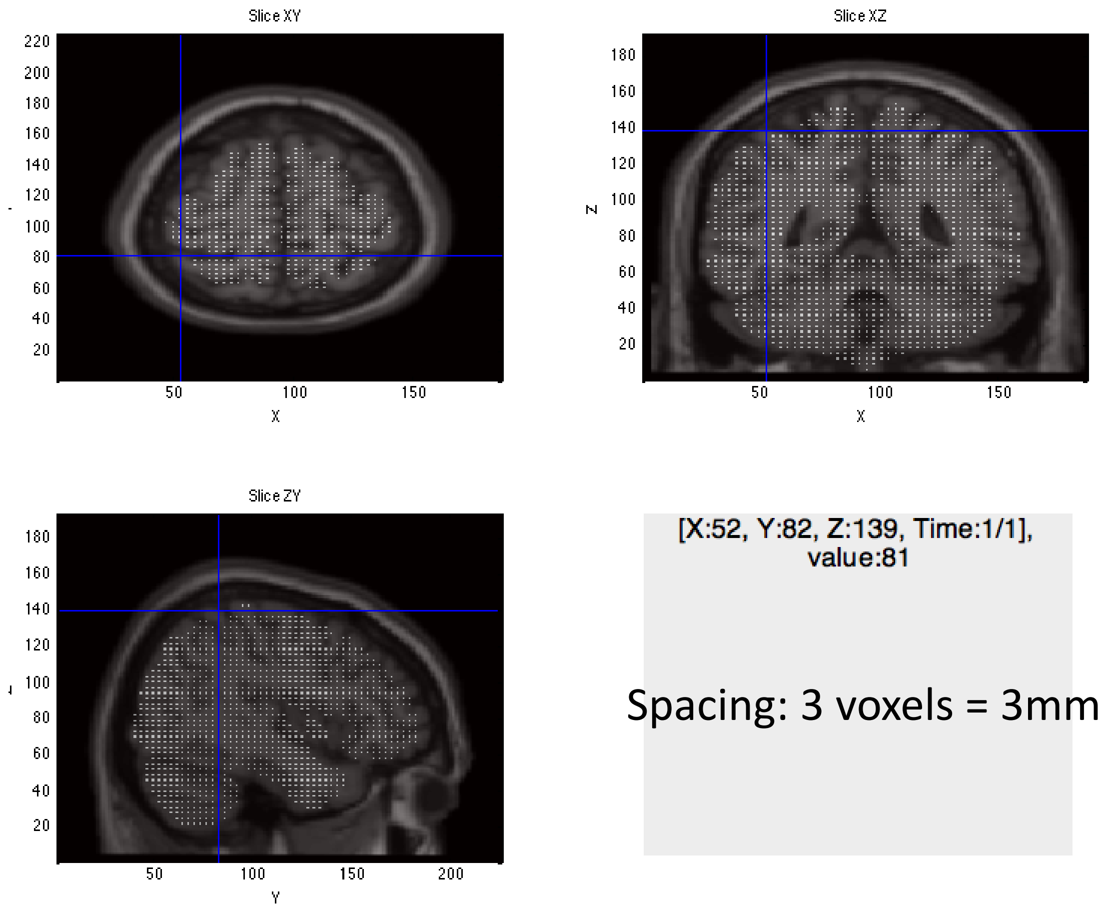
# 3-layered versus 4-layered head models

Electrode positions



# 3-layered versus 4-layered head models

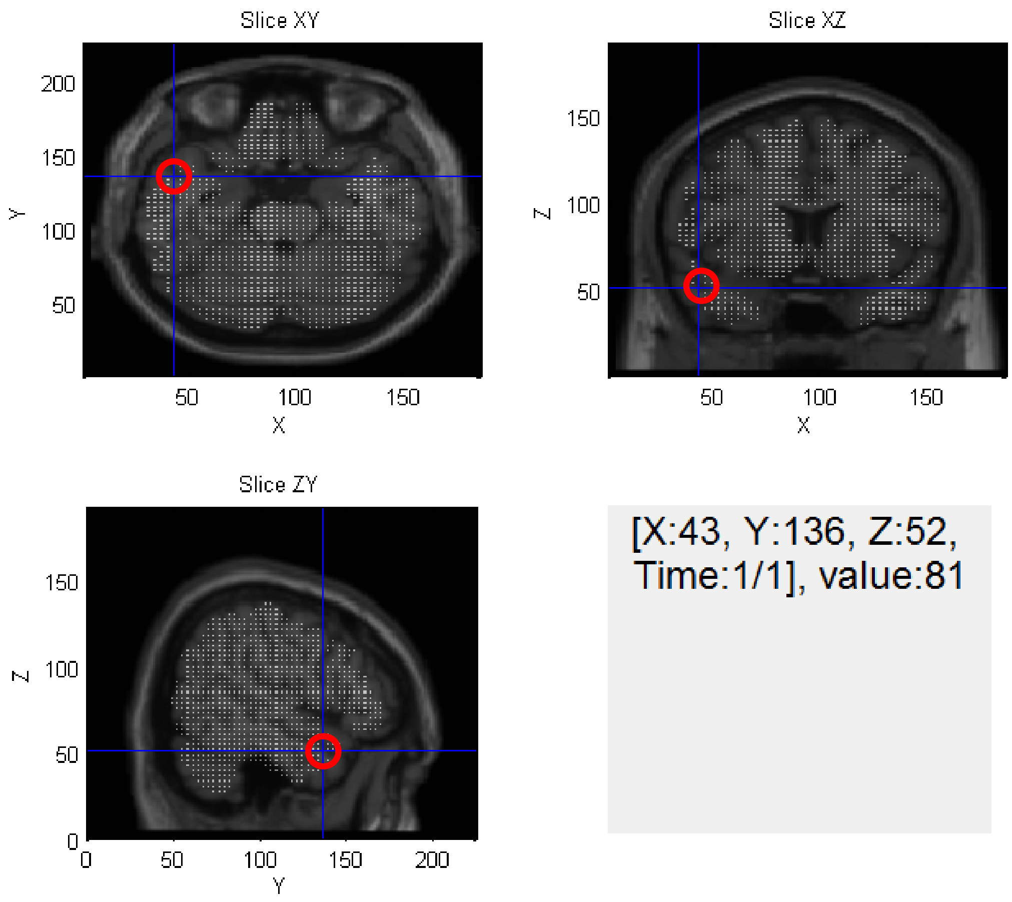
Dipole locations




Spacing: 3 voxels = 3mm

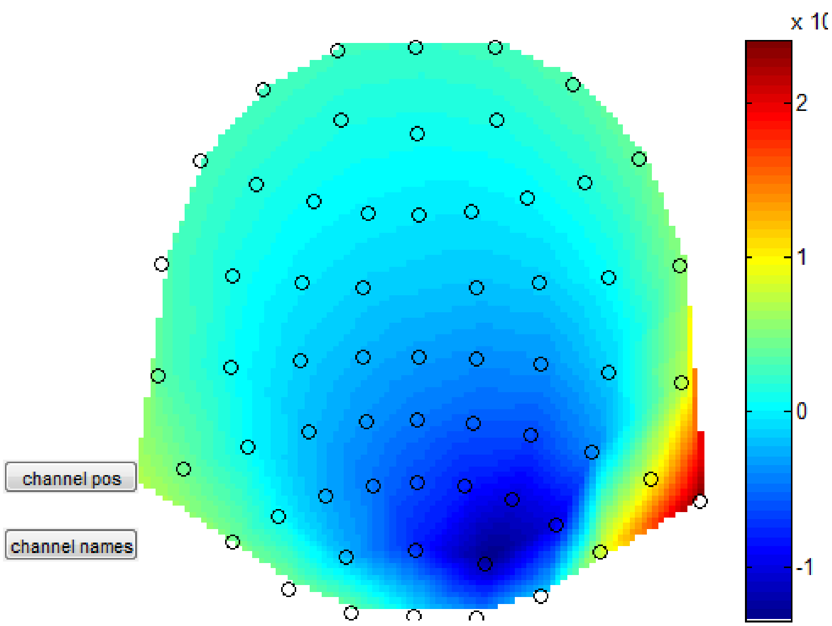
# 3-layered versus 4-layered head models

Unit dipole z-direction at location 3000: V=L(:,9000)

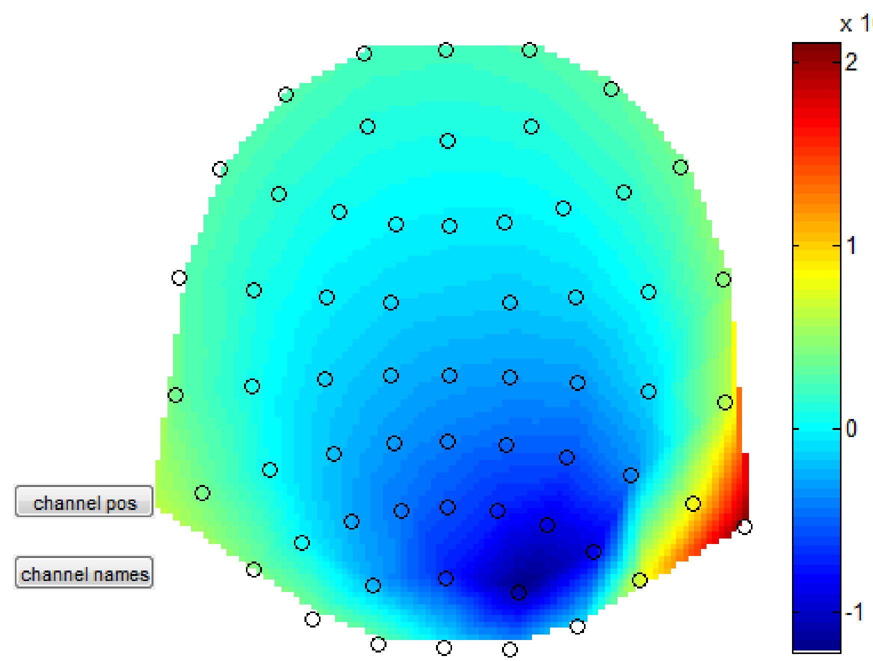


# 3-layered versus 4-layered head models

Unit dipole z-direction at location 3000: V=L(:,9000)



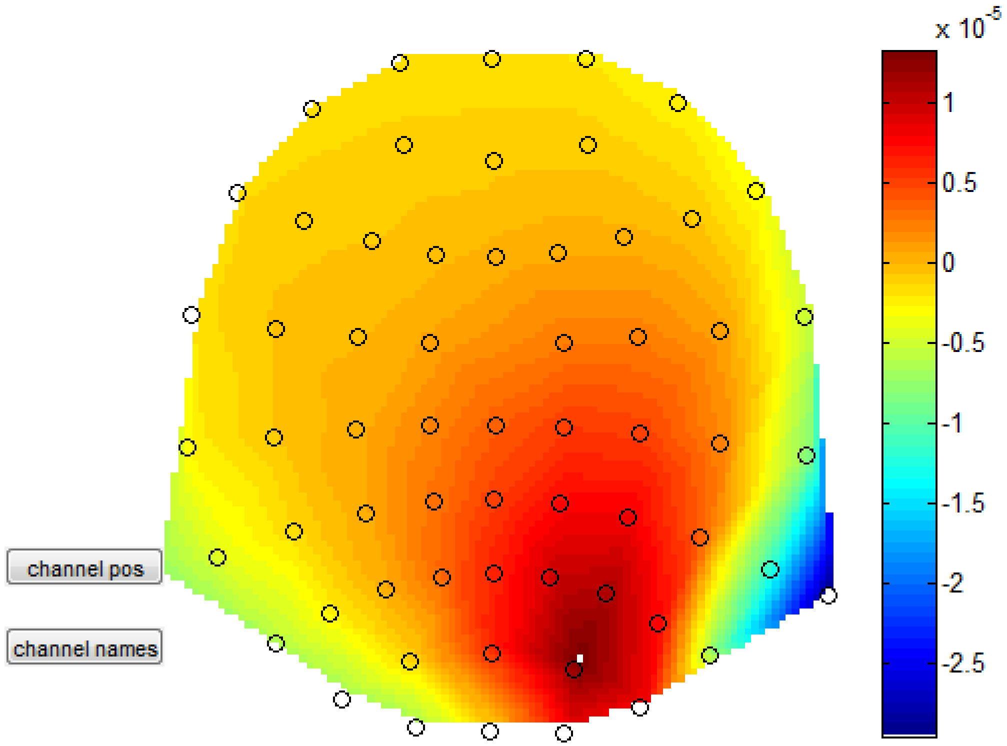

3-layered




4-layered

# 3-layered versus 4-layered head models

Unit dipole z-direction at location 3000: V=L(:,9000)

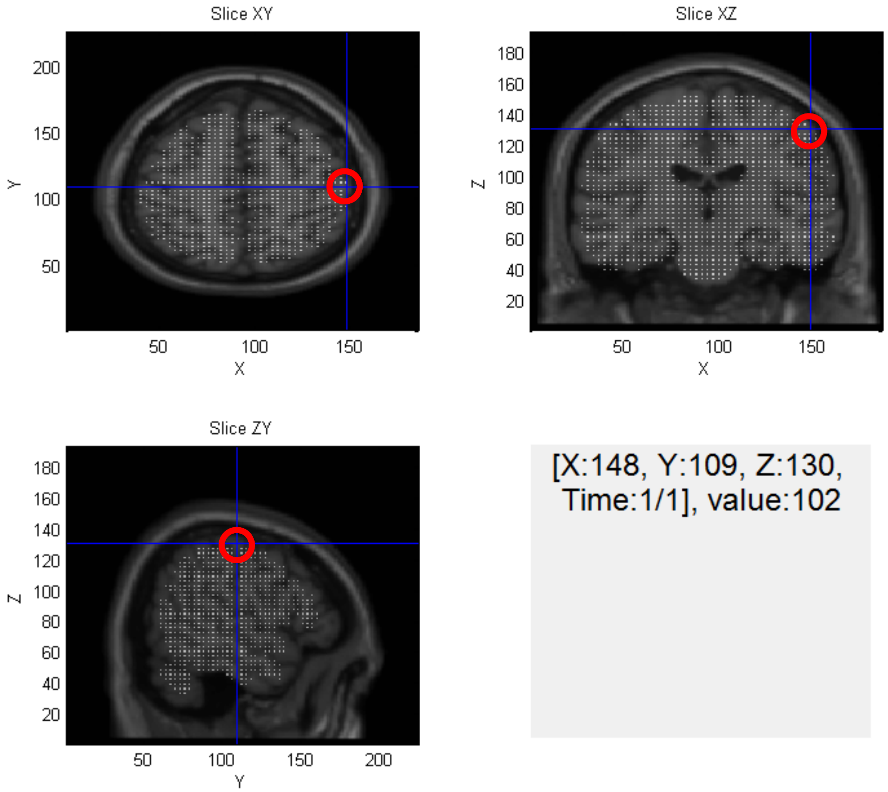



4-layered – 3-layered

# 3-layered versus 4-layered head models

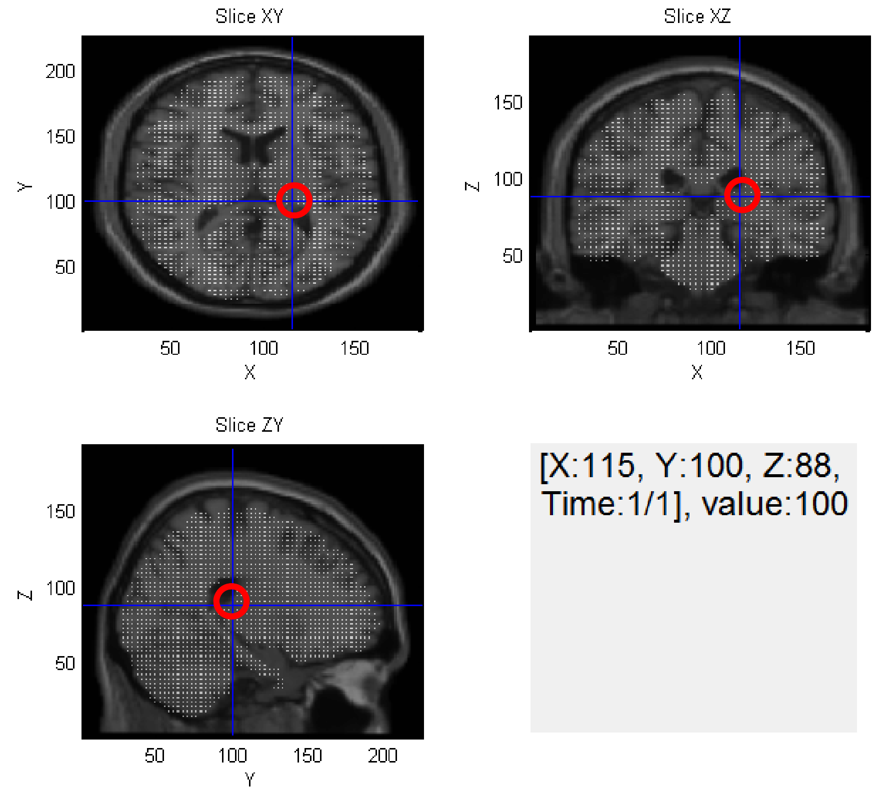
Unit dipole [1 1 -0.5] at 49233

close to skull




Unit dipole [1 1 -0.5] at 28533

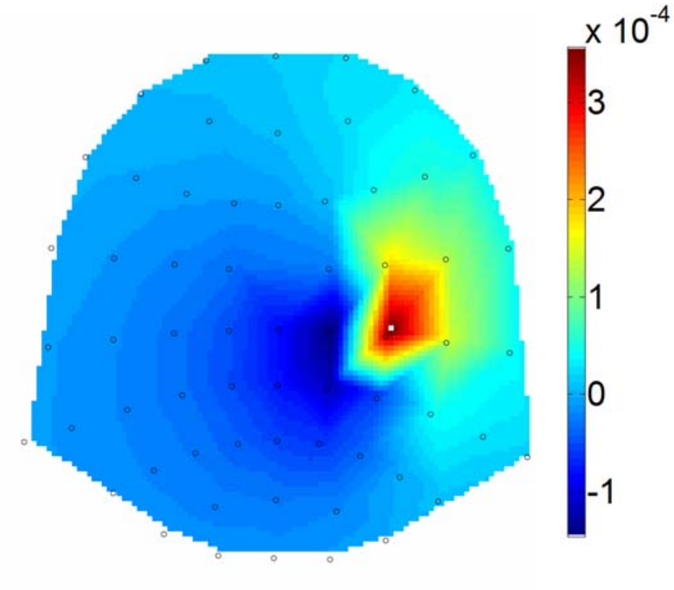
close to CSF



# 3-layered versus 4-layered head models

Unit dipole [1 1 -0.5] at 49233

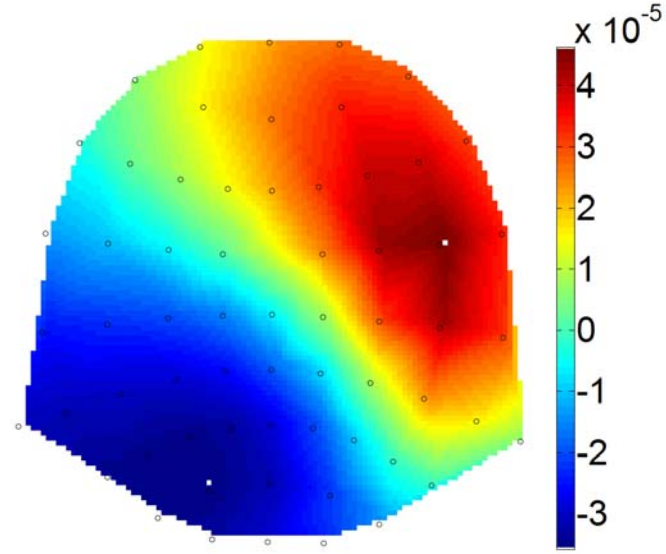
close to skull




4-layered – 3-layered

Unit dipole [1 1 -0.5] at 28533

close to right ventricle




4-layered – 3-layered

modeling CSF for dipole close to center is more spread out

# 3-layered versus 4-layered head models

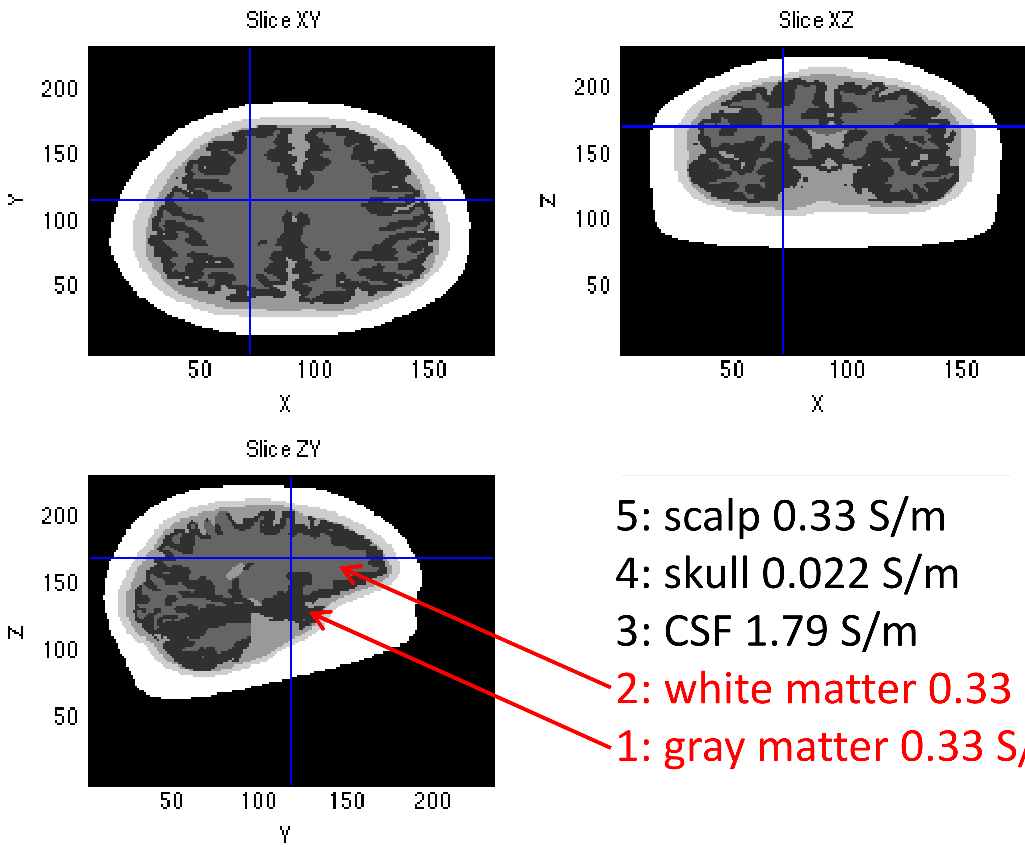
| dipole close to O2 | Residual energy | Localization error |
|---|---|---|
| 3-layered | 0.0468 | 3.7237 mm |

| dipole close to center | Residual energy | Localization error |
|---|---|---|
| 3-layered | 0.0268 | 3.1172 mm |

For the dipole close to O2 the effect of modeling CSF is directly measured by the electrodes, the localization error is larger compared to the dipole in the center for which the effect of modeling CSF is more spread out

# 3-layered versus 4-layered head models

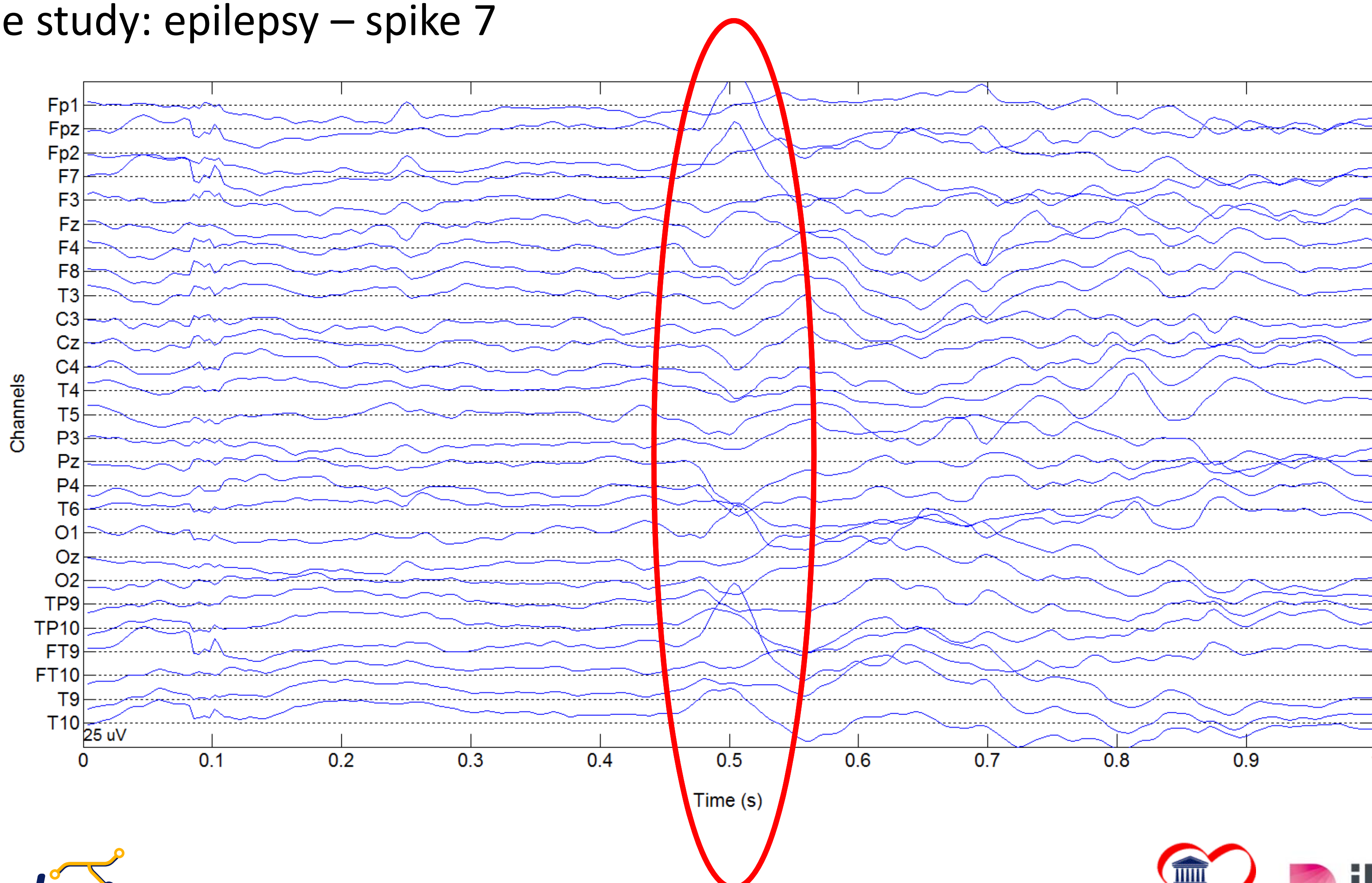
Case study: epilepsy – head model




5: scalp 0.33 S/m
4: skull 0.022 S/m
3: CSF 1.79 S/m
2: white matter 0.33 S/m
1: gray matter 0.33 S/m

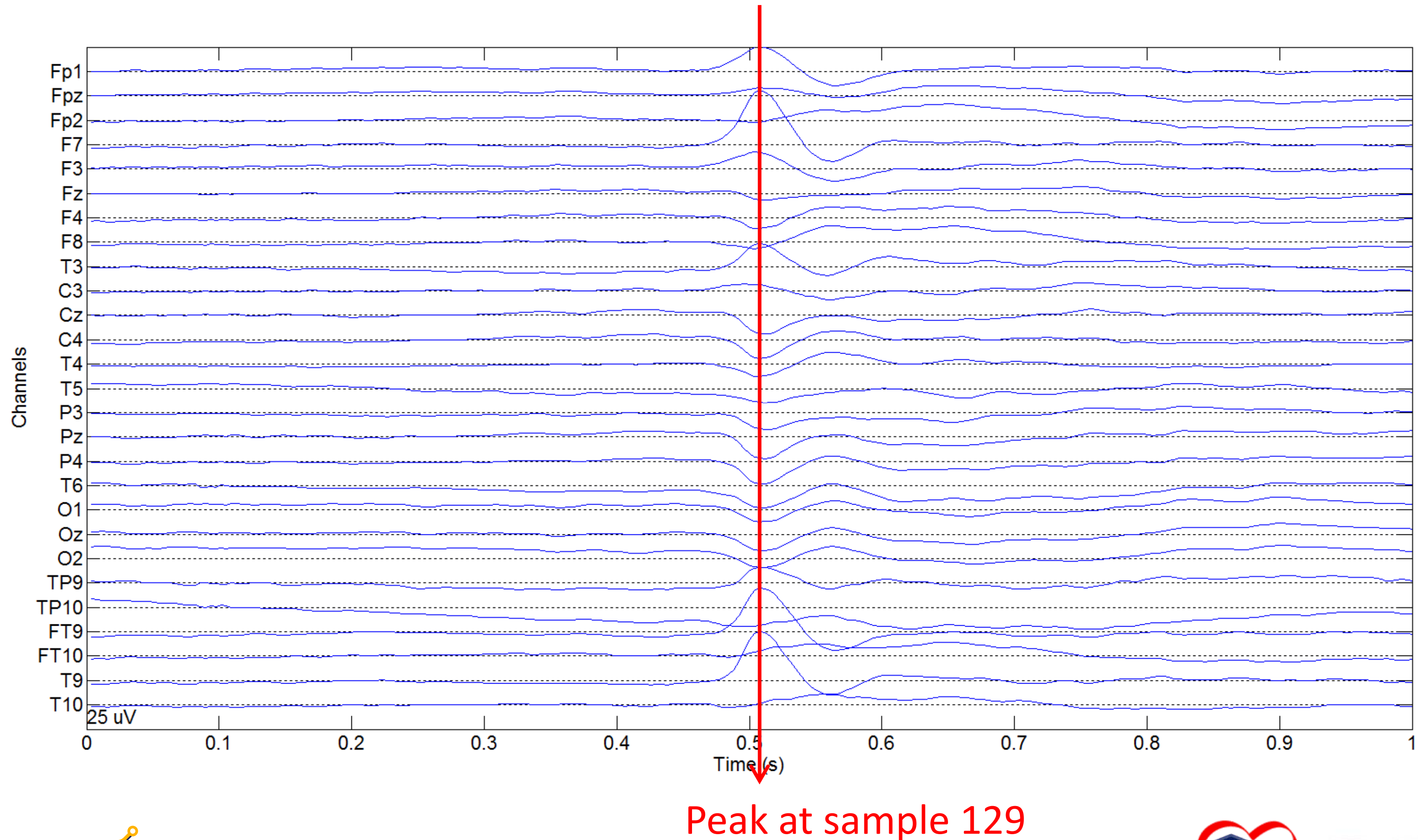
# 3-layered versus 4-layered head models

Case study: epilepsy – spike 7



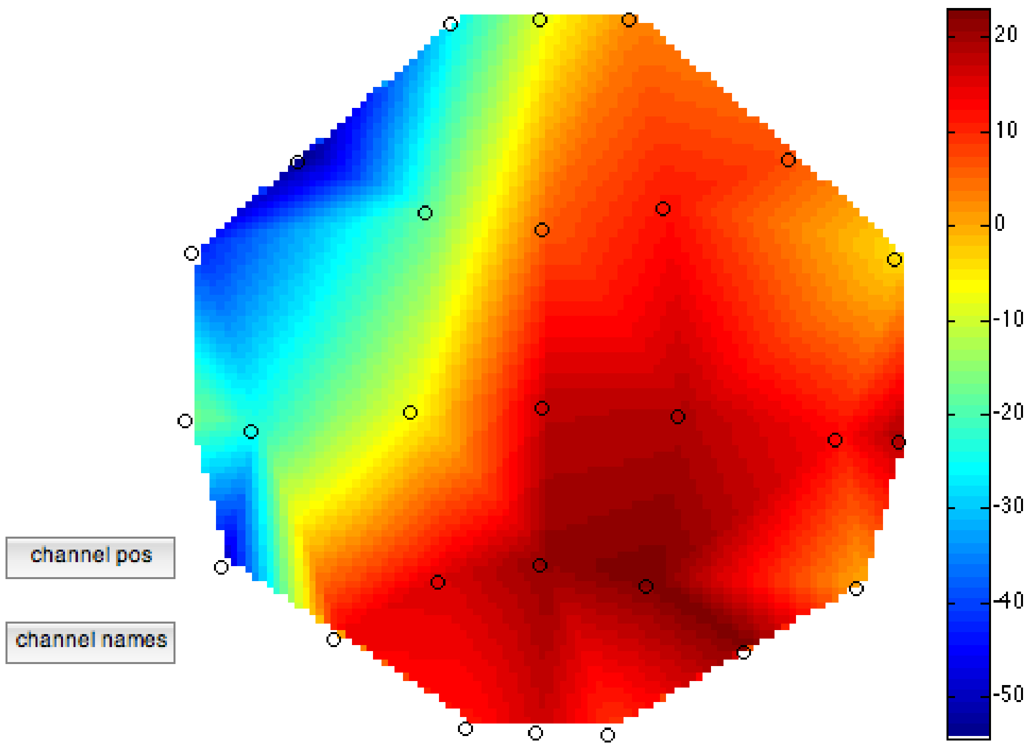
# 3-layered versus 4-layered head models

Case study: epilepsy – average spike



# 3-layered versus 4-layered head models

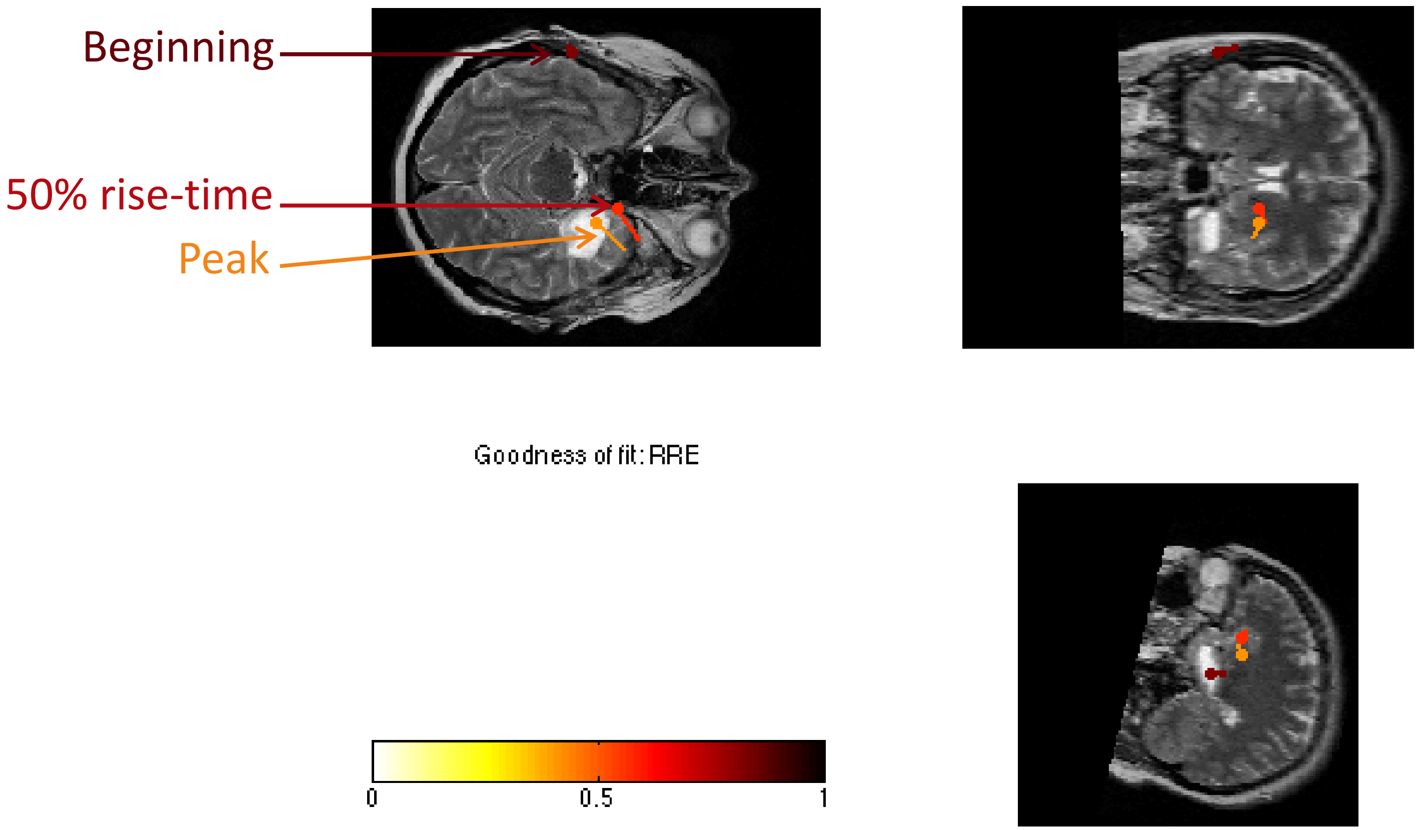
Case study: epilepsy – average spike scalp map at peak




From the scalp map it is hard to see where the spike originated

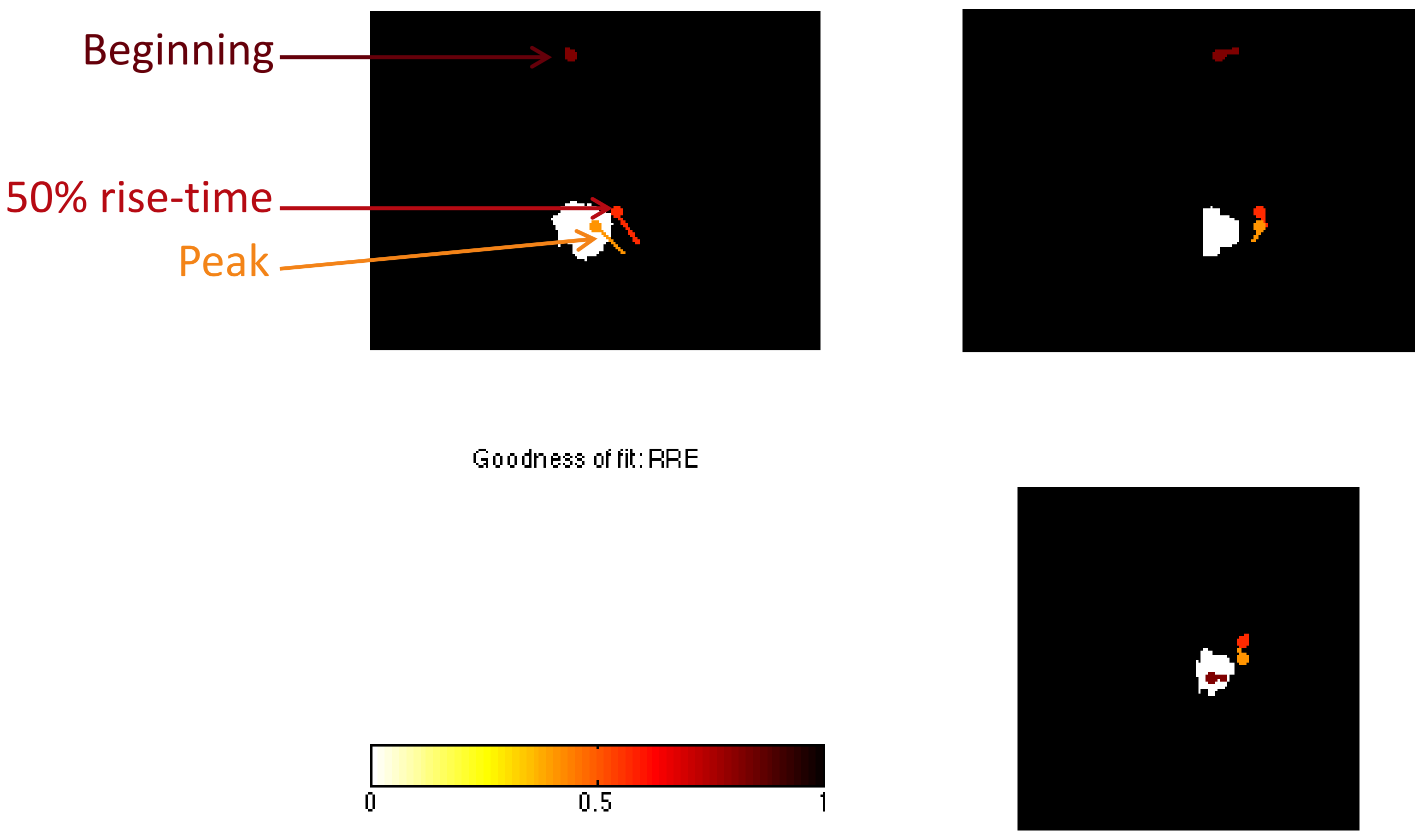
# 3-layered versus 4-layered head models

Case study: epilepsy – dipole localization at 3 time points of spike



# 3-layered versus 4-layered head models

Case study: epilepsy – dipole localization at 3 time points of spike



# 3-layered versus 4-layered head models

Case study: epilepsy – dipole localization

| Time point | Sample | Residual energy | Distance to resected zone |
|---|---|---|---|
| Beginning | 120 | 0.8271 | 76.01 mm |
| Peak | 129 | 0.4182 | 8.29 mm |
| 50% rise-time | 125 | 0.5733 | 16.45 mm |

Best data fit

# music.m function

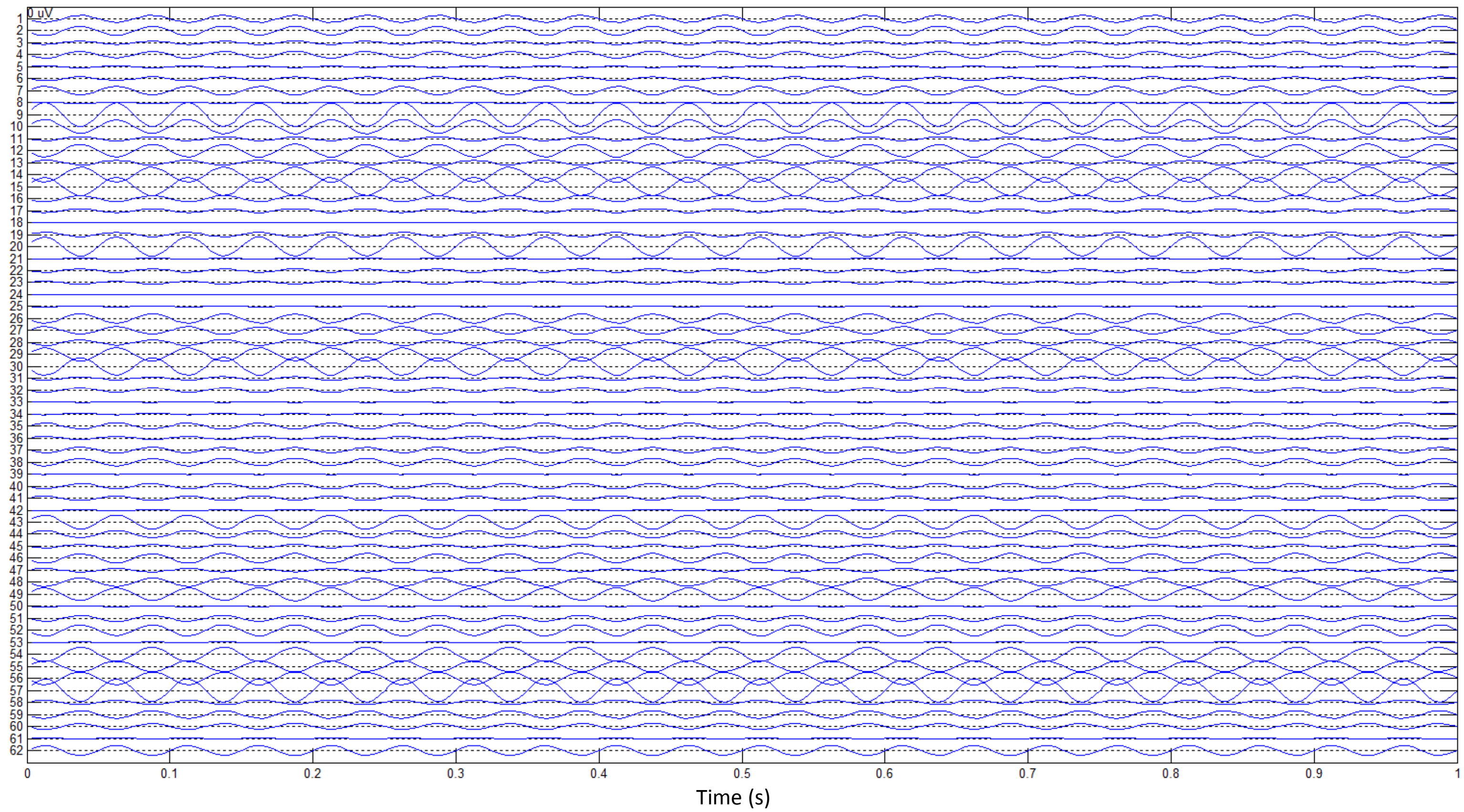
Change line 21 to

```
r=max(find(S>=S(1)/100));
```

# Influence of the source space and inverse technique

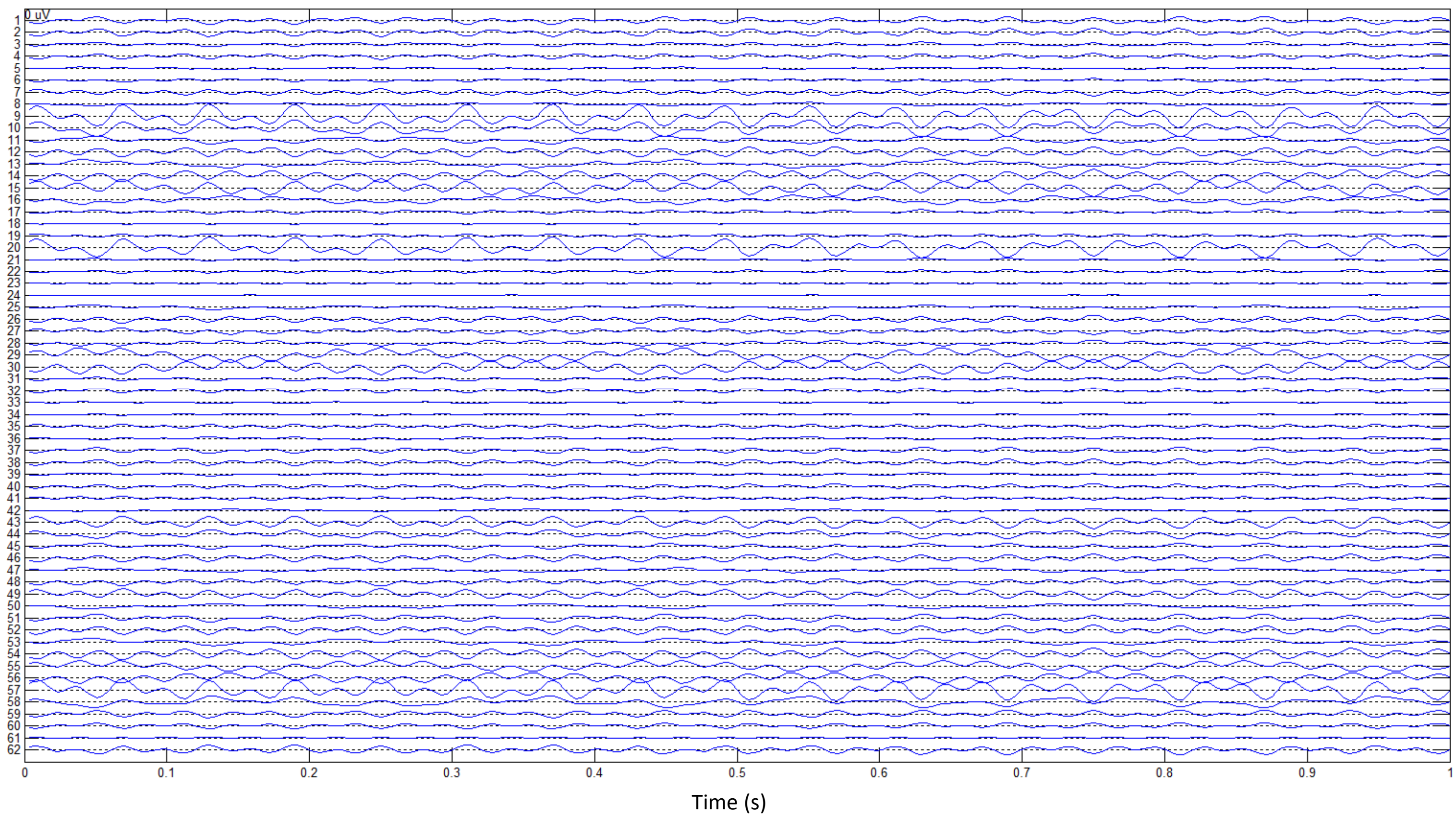
# Single, multiple and distributed dipole sources

Simulated EEG 1 oscillating dipole



# Single, multiple and distributed dipole sources

Simulated EEG 3 oscillating dipoles



# Single, multiple and distributed dipole sources

hm_4lay_DS

hm_4lay_DS <1x1 struct>

| Field | Value | Min | Max |
|---|---|---|---|
| MRI | <186x225x192 double> | <To... | <To.. |
| segmentation | <186x225x192 double> | <To... | <To.. |
| conductivities | [0.3300,0.0220,1.7900,0.3300] | 0.02... | 1.79. |
| dipole_loc | <7002x3 double> | 24 | 197 |
| QG | <7002x7002 sparse double> | <To... | <To.. |
| leadfields | <62x7002 double> | -0.0... | 0.00. |
| elec | <1x1 struct> | | |

hm_4lay

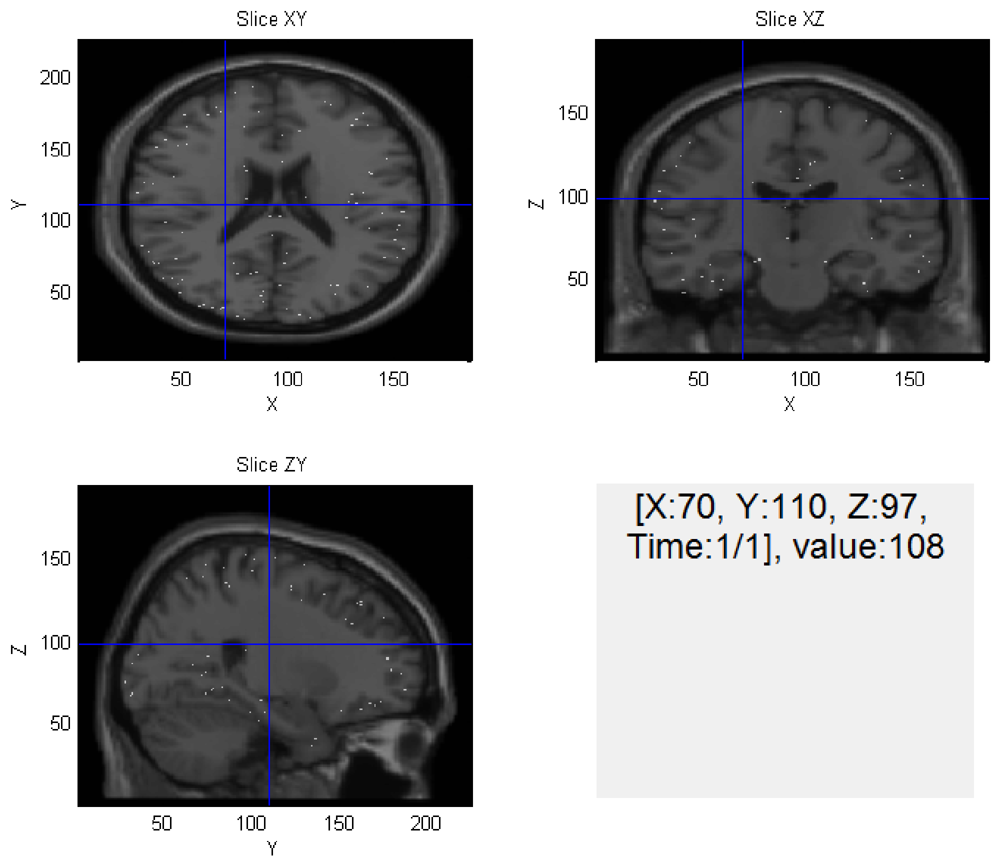
hm_4lay <1x1 struct>

| Field | Value | Min | Max |
|---|---|---|---|
| dipole_loc | <53178x3 double> | 7 | 196 |
| MRI | <186x225x192 double> | <To... | <To.. |
| segmentation | <186x225x192 double> | <To... | <To.. |
| conductivities | [0.3300,0.0220,0.3300,1.7900] | 0.02... | 1.79. |
| leadfields | <62x159534 double> | <To... | <To.. |
| lead | <1x1 struct> | | |
| elec | <1x1 struct> | | |

- Only 7002 possible dipole locations vs. 53178: only on cortical surface
- Matrix QG contains information on interconnections between dipoles
- Leadfields have as many columns as there are dipoles. The orientation of the dipoles is already incorporated (orthogonal to the cortical surface)

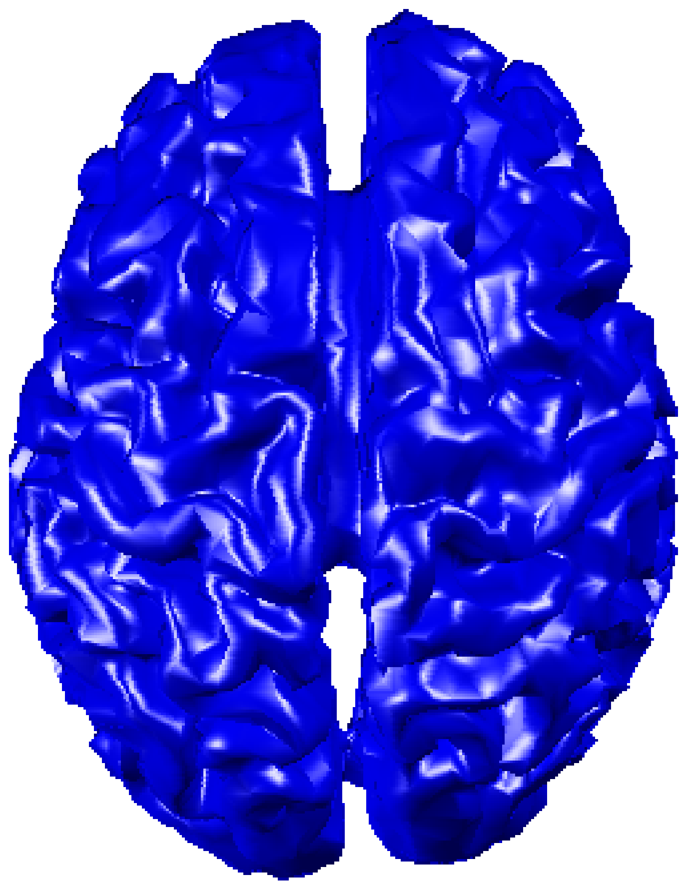
# Single, multiple and distributed dipole sources

Dipole locations



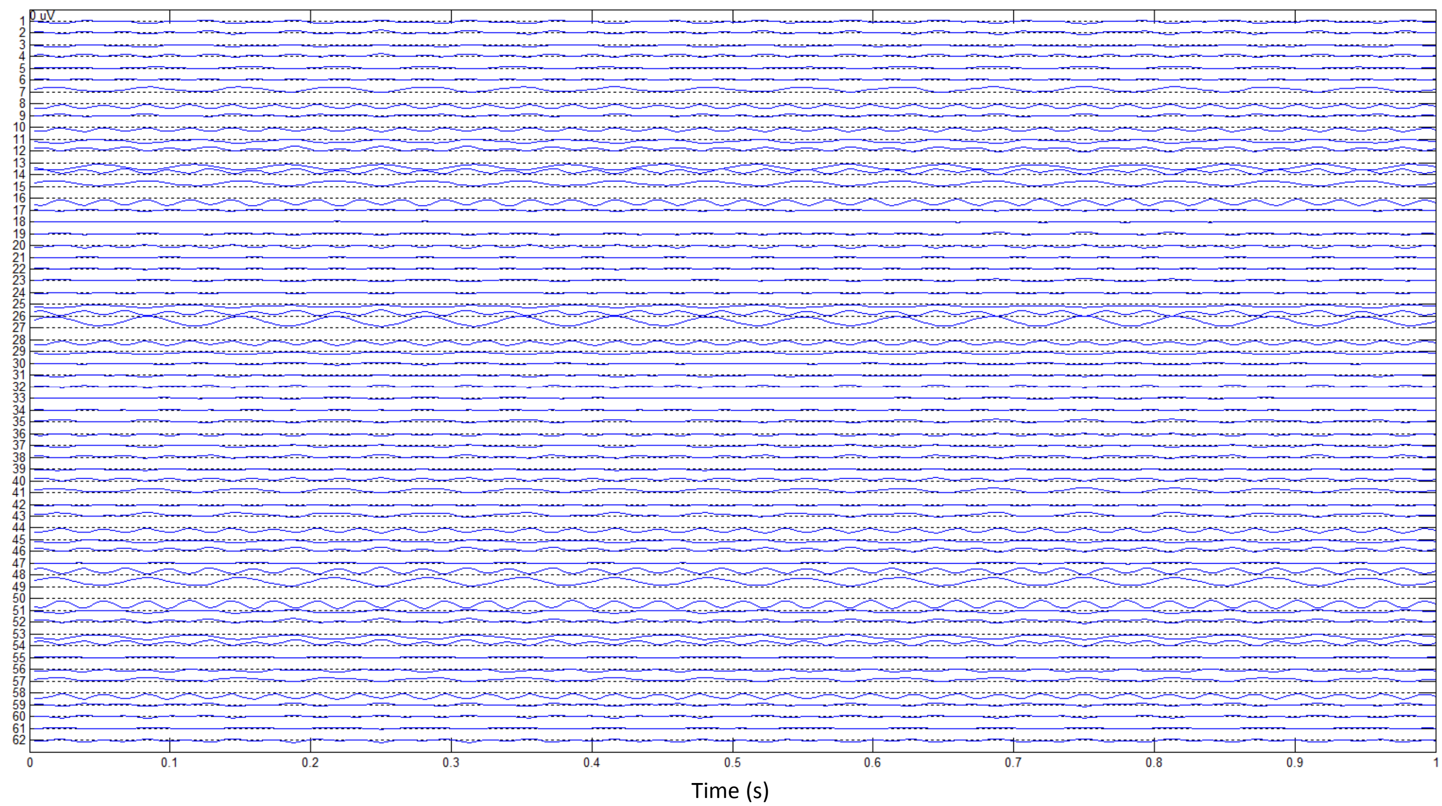
# Single, multiple and distributed dipole sources

Cortical surface



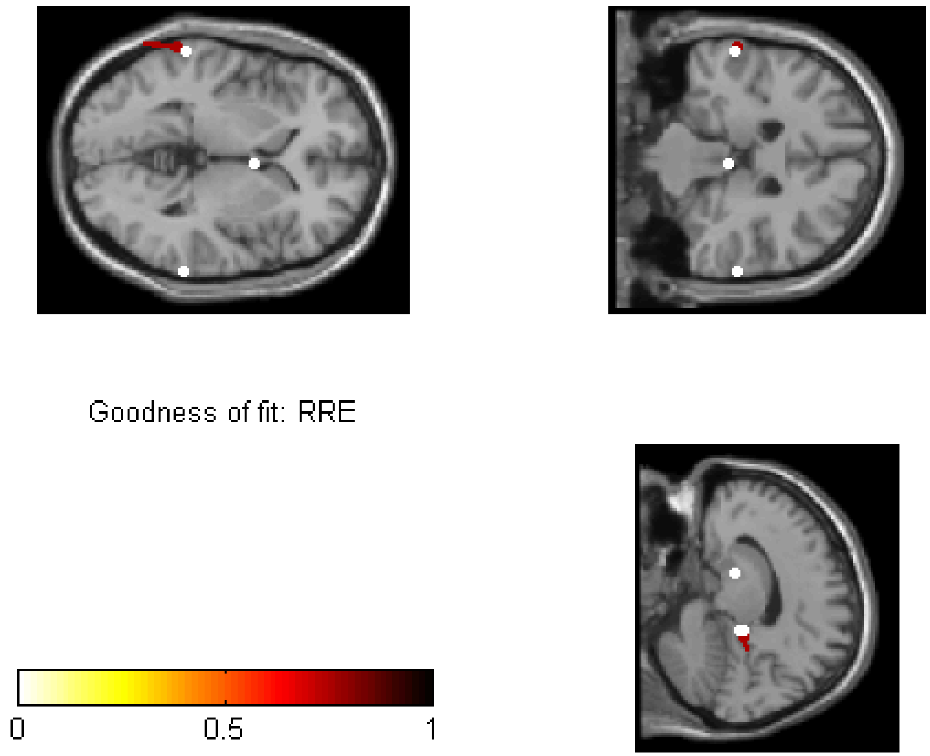
# Single, multiple and distributed dipole sources

Simulated patch, ind = [10 3500 7000], fo = [15 17 33], SNR = 10 dB



# Single, multiple and distributed dipole sources

Single dipole fit



# Single, multiple and distributed dipole sources

Single dipole fit – distance to center of patches:

patch 1 (dip 10 [27 89 79]): 134.09 mm

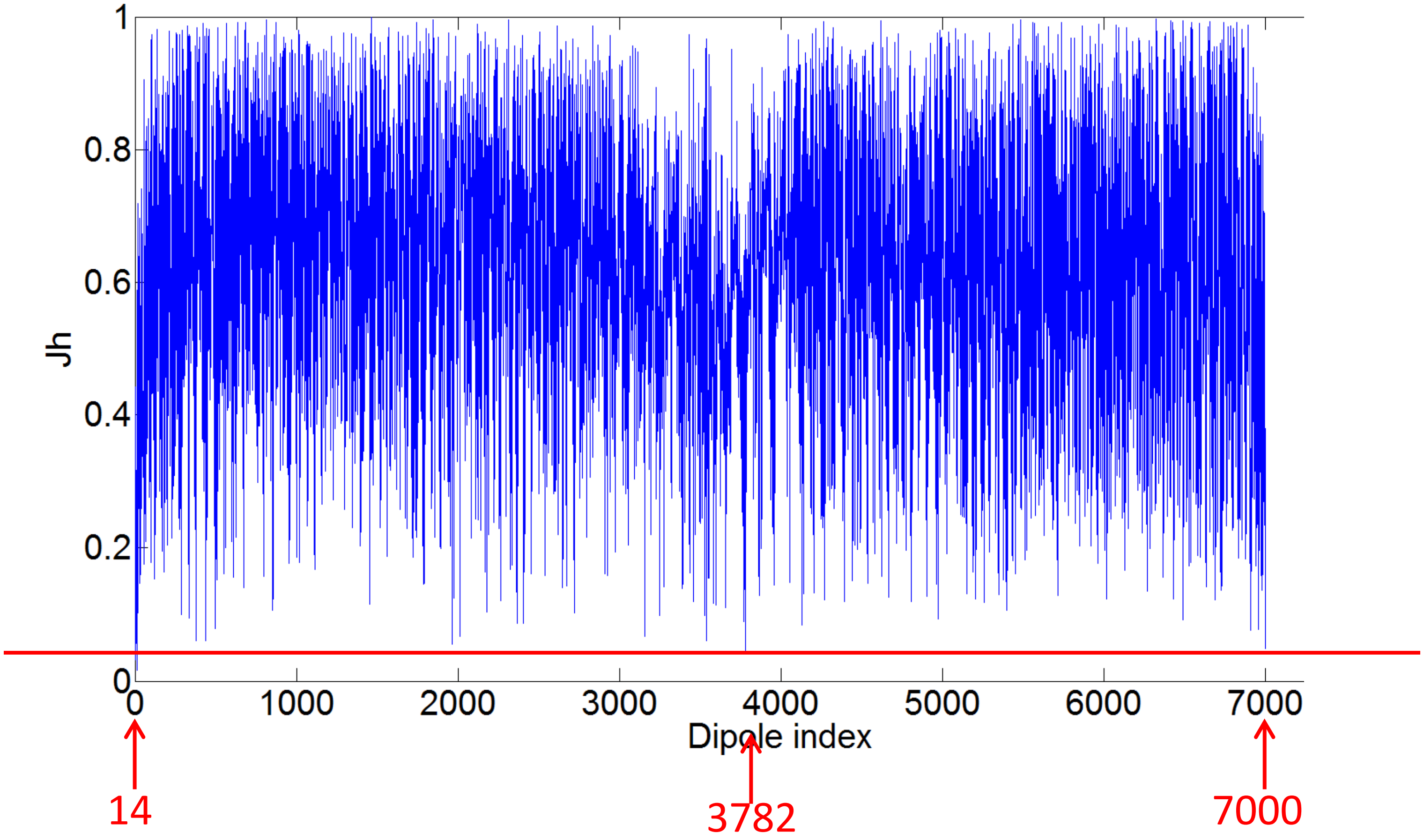
patch 2 (dip 3500 [92 132 73]): 84.27 mm

patch 3 (dip 7000 [159 90 77]): 6.64 mm

→ One of the 3 patches reconstructed

# Single, multiple and distributed dipole sources

Multiple dipole fit: MUSIC

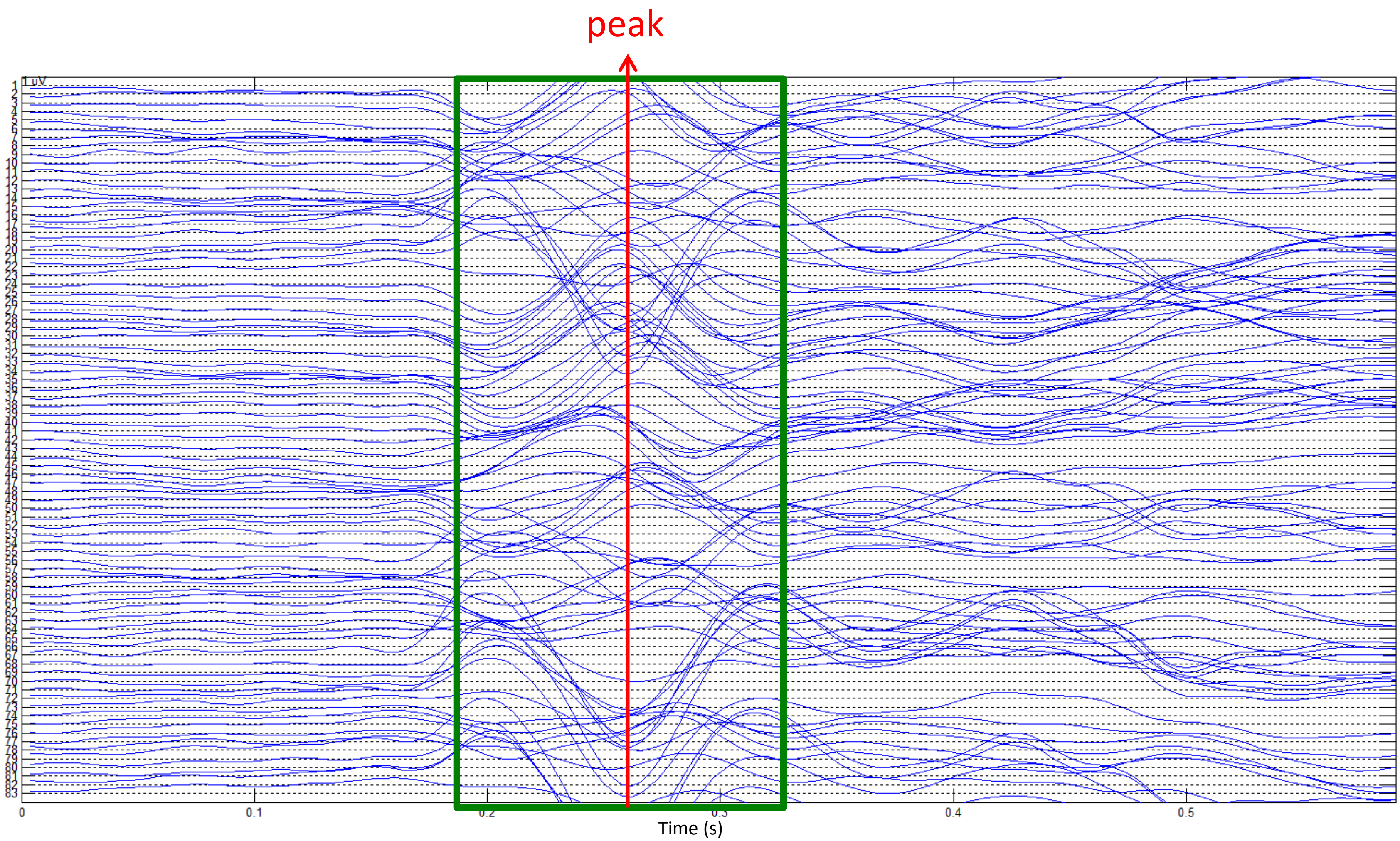


# Single, multiple and distributed dipole sources

Multiple dipole fit: MUSIC

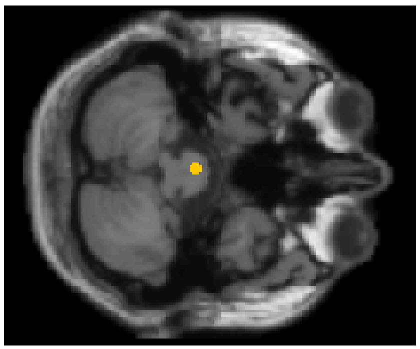
| | Reconstructed dipole 1 | Reconstructed dipole 2 | Reconstructed dipole 3 |
|---|---|---|---|
| Patch 1 | **10.34 mm** | 79.01 mm | 132.02 mm |
| Patch 2 | 80.06 mm | **20.02 mm** | 79.18 mm |
| Patch 3 | 131.3 mm | 69.24 mm | **0.0 mm** |

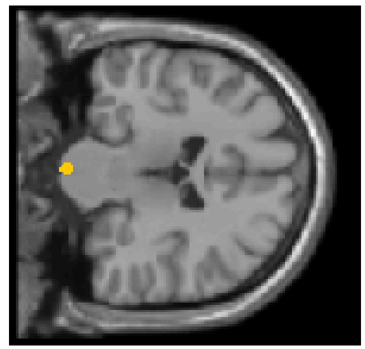
# Reconstruction of realistic ERP data



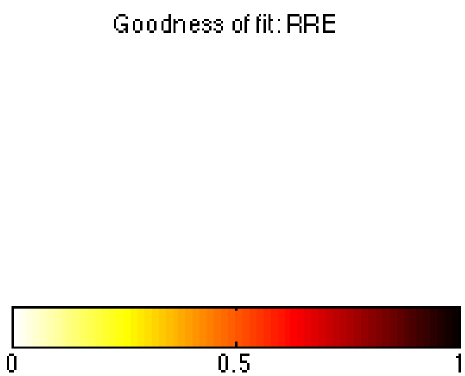
# Reconstruction of realistic ERP data

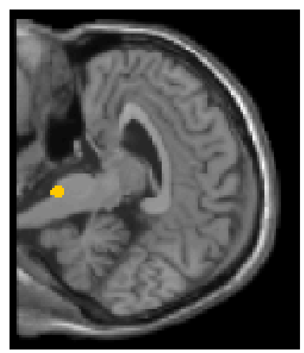
Single dipole fit





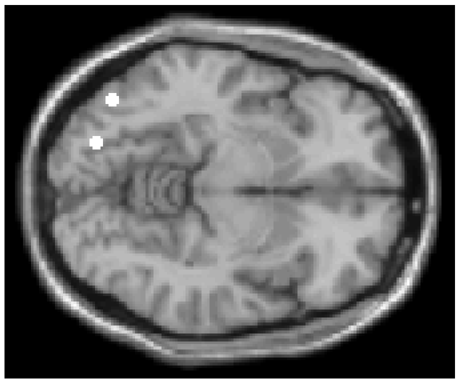
Fitted dipole not in fusiform face area

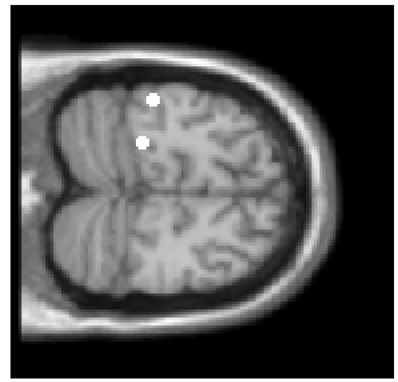


# Reconstruction of realistic ERP data

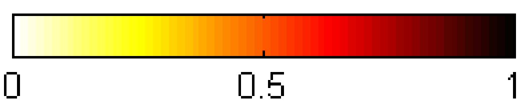
Multiple dipole fit - MUSIC

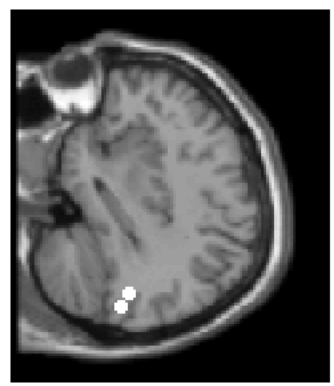




Fitted dipoles near left FFA

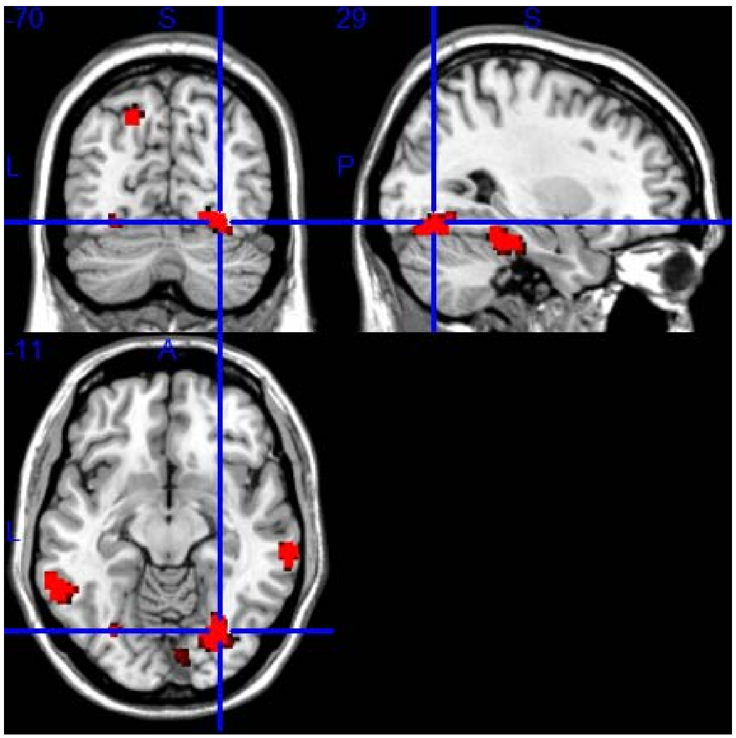
Goodness of fit: RRE



# Reconstruction of realistic ERP data

Distributed source model




Activation in left and right FFA, more expressed in right hemisphere