Aalto University
School of Science

Dept. of Biomedical Engineering
and Computational Science

New Methods for Brain Imaging and Stimulation

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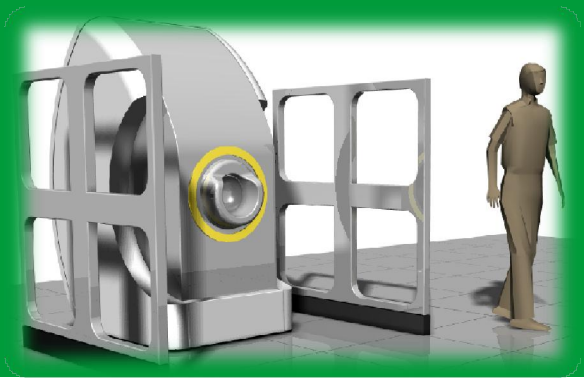
Dept. Biomedical Engineering and Computational Science (BECS)
Aalto University (2006–

BioMag Laboratory (1994–2003)
Nexstim (2000-2005)



The burden of brain diseases

1) Human suffering

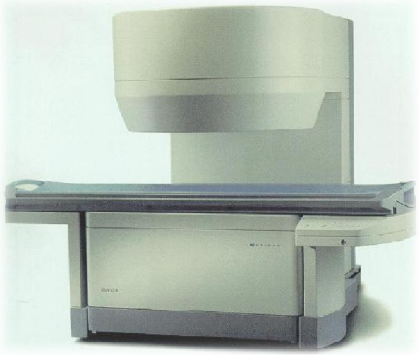
- Depression: 150 million patients
- Schizophrenia: 25 million
- Dementias: 40 million
- Epilepsy: 40 million
- Stroke: 40–100 million

2) Cost to society: 350 billion € / year in Europe alone

The burden is increasing with the aging population

Brain imaging developed in Helsinki

MRI



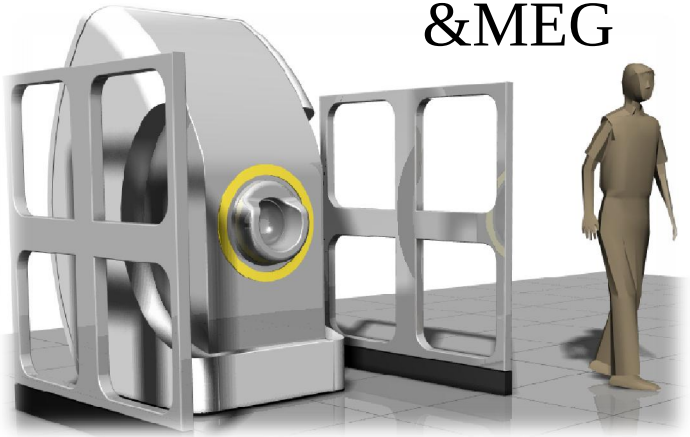
EEG

NIRS

MEG

Navigated TMS

Ultra-Low-Field MRI &MEG



Brain imaging developed in Helsinki

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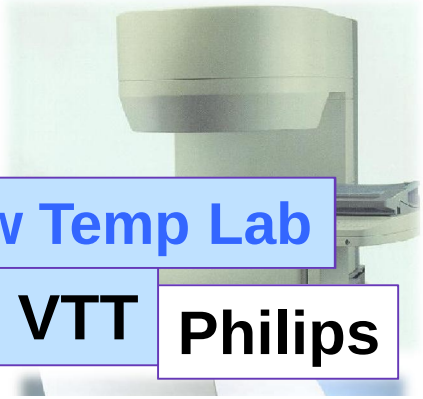

Low Temp Lab

VTT

Philips

EEG

Elekta

BioMag

Nexstim

NIRS

BECS

BioMag

MEG

Low Temp Lab

BioMag

Elekta

Navigated TMS

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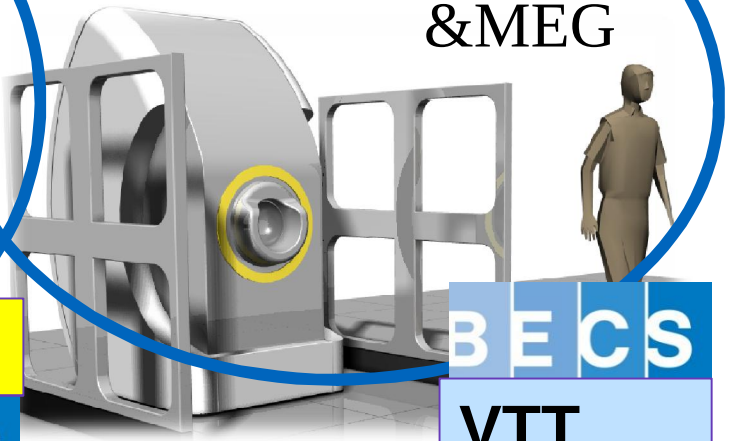
Ultra-Low-Field MRI &MEG



BECS

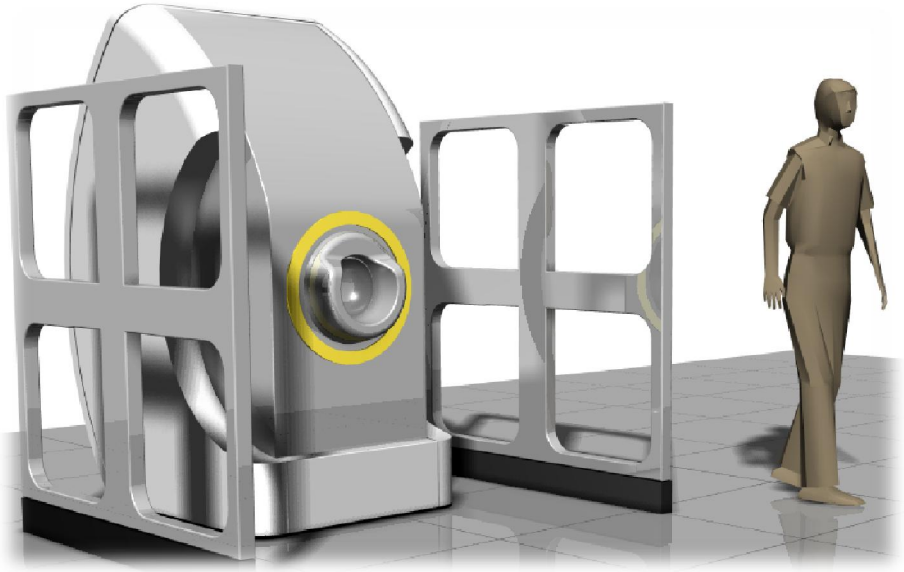
VTT

Elekta

Aivon

Aalto U School

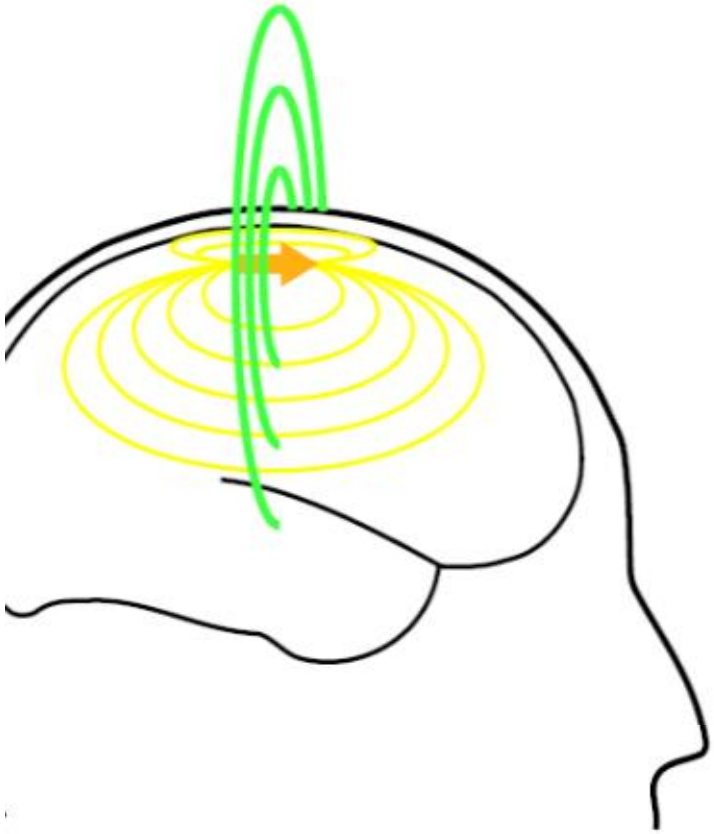
1) Hybrid MEG and MRI (MEGMRI)



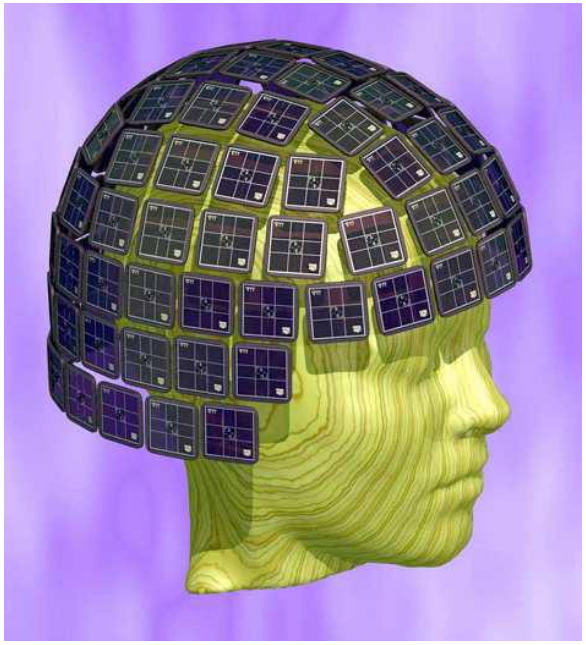
MEGMRI

Magnetoencephalography (MEG)

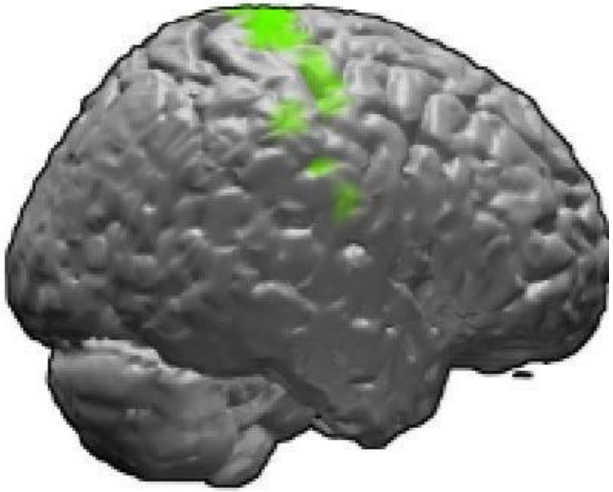
1. Neuronal currents produce a weak magnetic field (10^{-13} T)



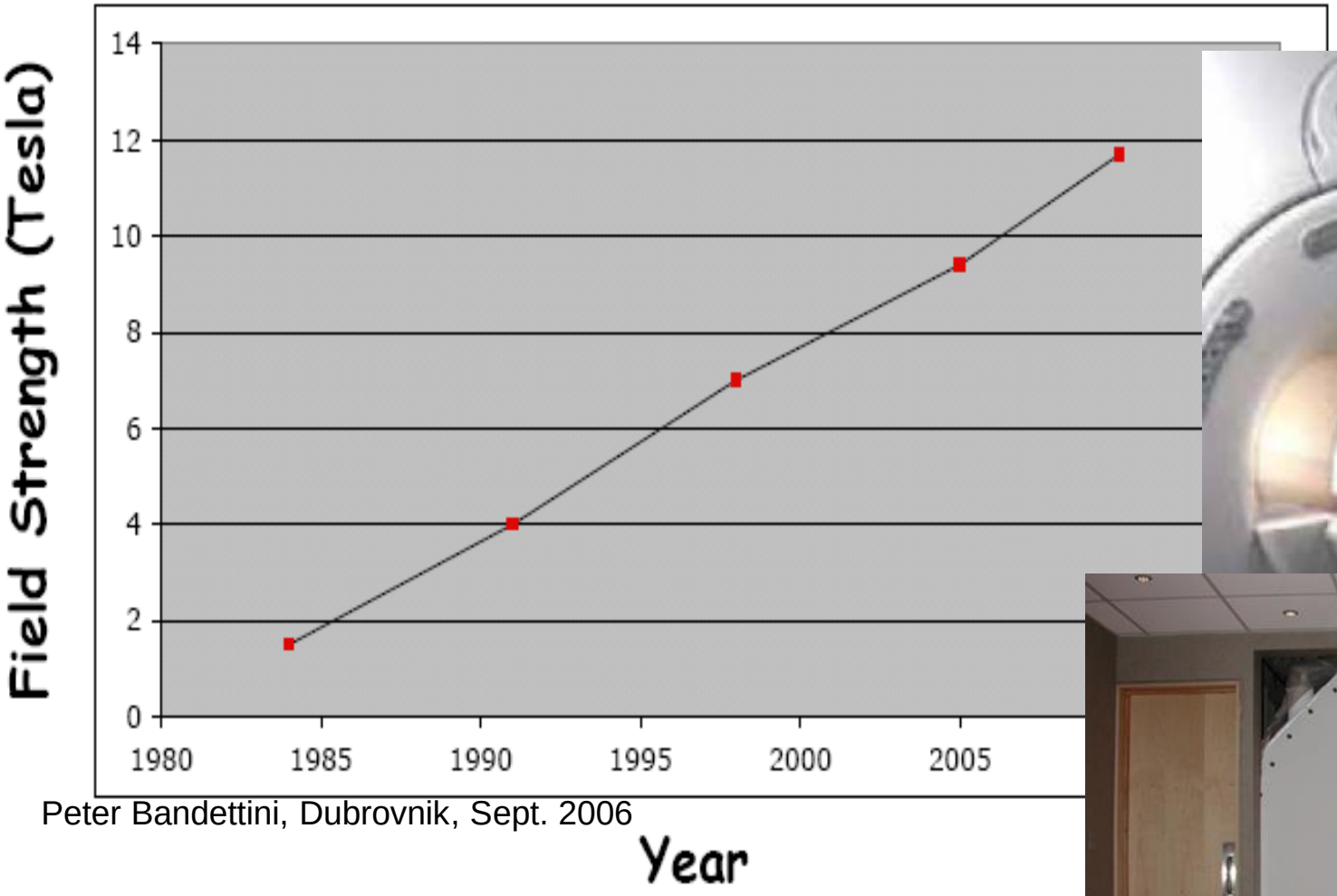
2. A sensor array detects the field



3. Reconstruction of the neuronal activity



Magnetic Resonance Imaging (MRI)



Peter Bandettini, Dubrovnik, Sept. 2006

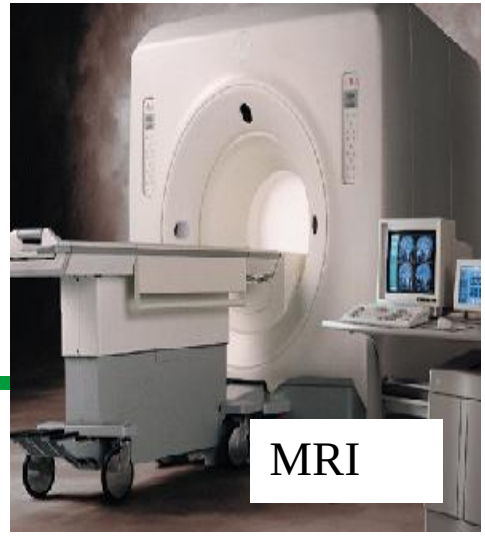
University of Illinois at Chicago

Goal in the MEGMRI project

A **hybrid brain scanner** that can measure **MEG and MRI** at the same time

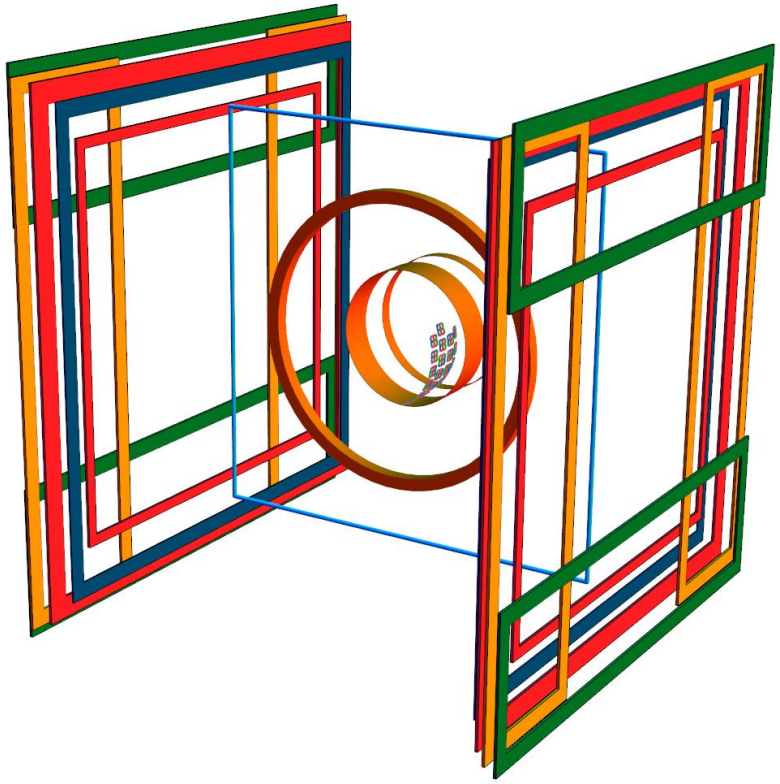
These techniques reveal information about the function and structure of the brain

MEG

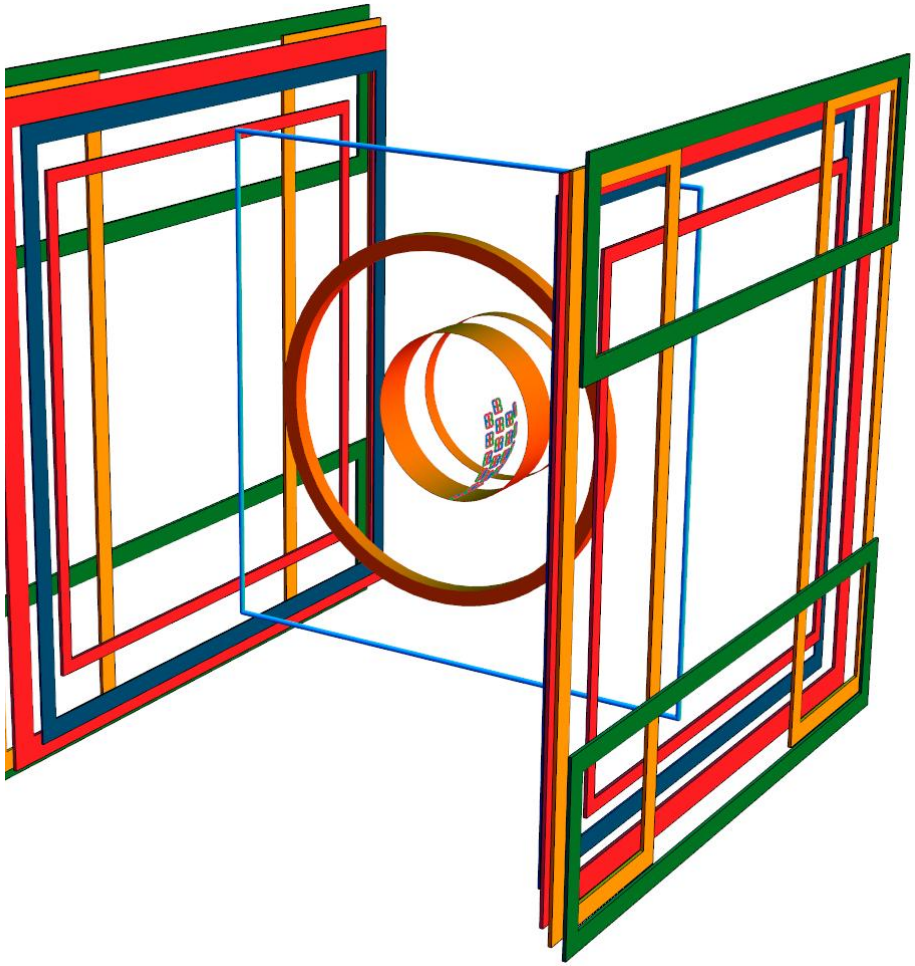

MRI

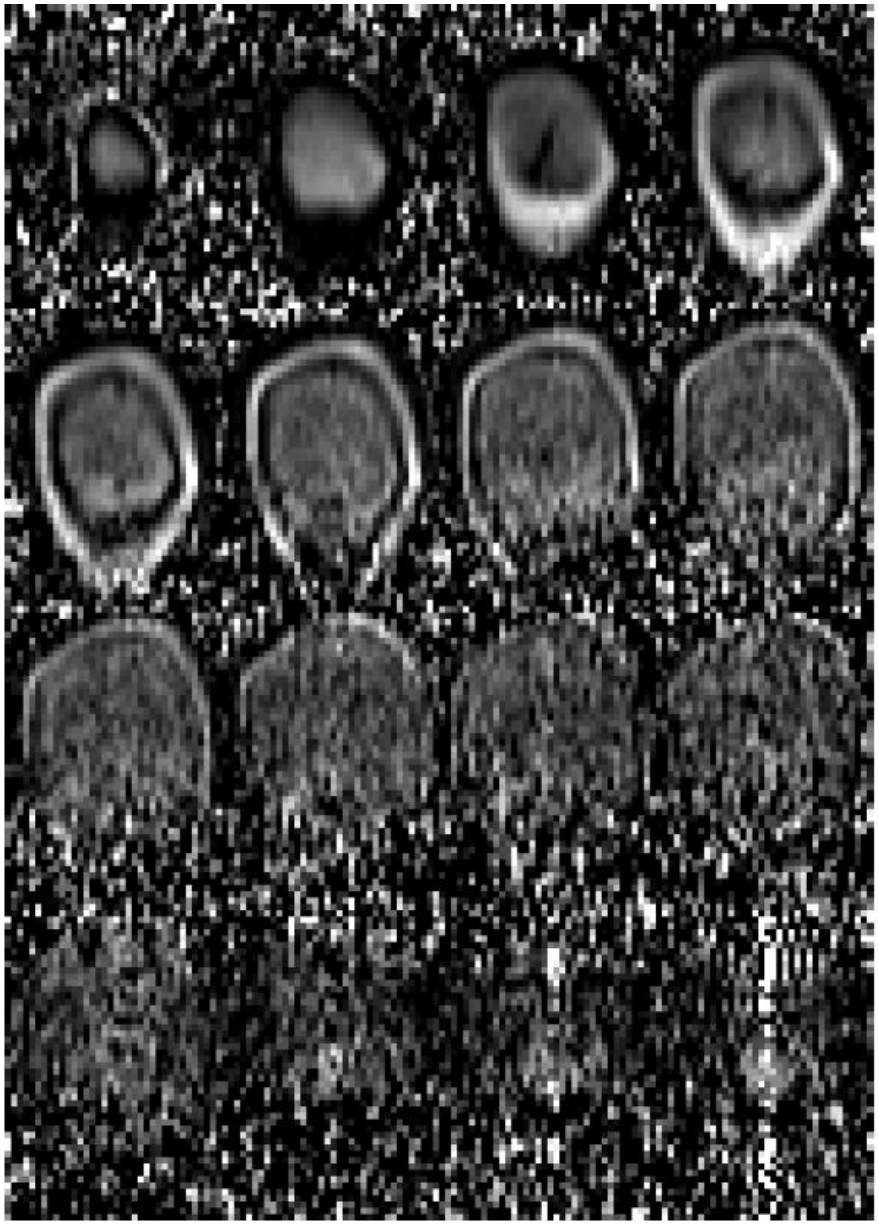
The whole-head MEG dewar

- 2011: 70 SQUIDs, later 306 SQUIDs
- Simultaneous MEG and MRI



First Images of the Brain (Nov. 2011)

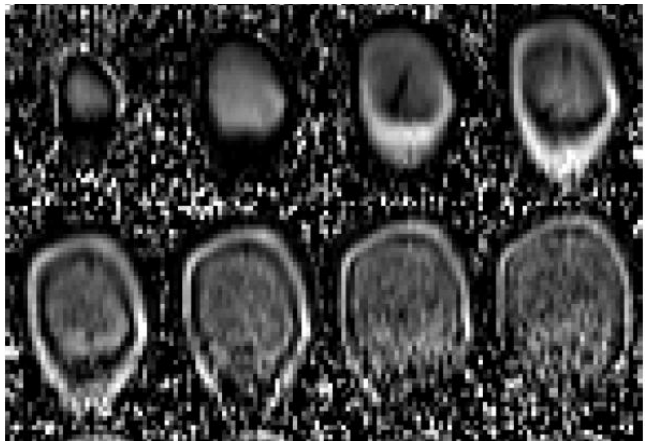




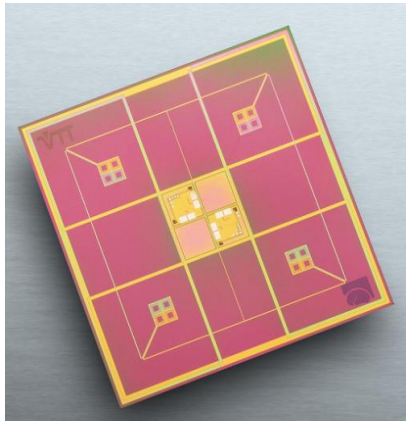
Benefits of ULF-MRI

- Safety
  - No projectile danger, safe with pacemakers
- Quiet and open structure
  - Better for infants and children
- Superior T1 contrast
- Simplicity, lower price
- Simultaneous MEG and MRI
  - Superb registration accuracy

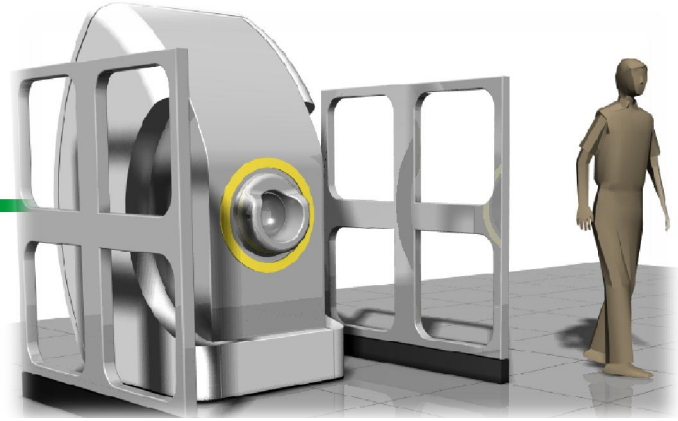
How to improve?



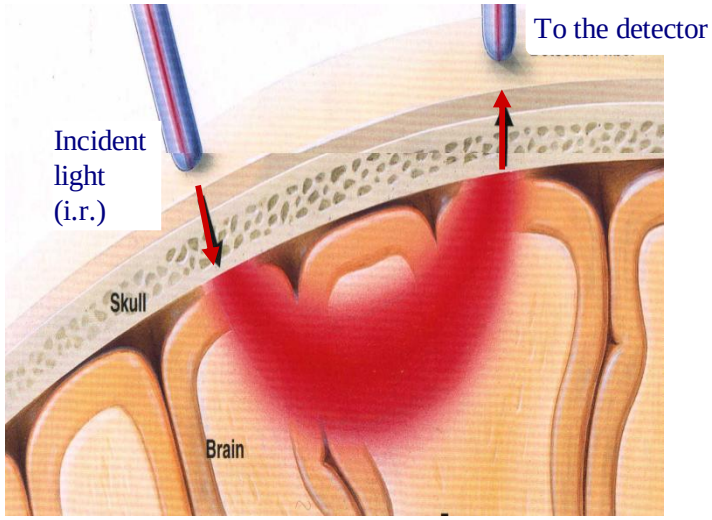
- SQUID noise down by a factor of 10 (to 0.5 fT)
- Prepolarization field up by a factor of 6 (to 120 mT)
- Number of SQUIDs up by a factor of 5 (to 306)



=> Data rate up by a factor of 10000 (by 2017?)

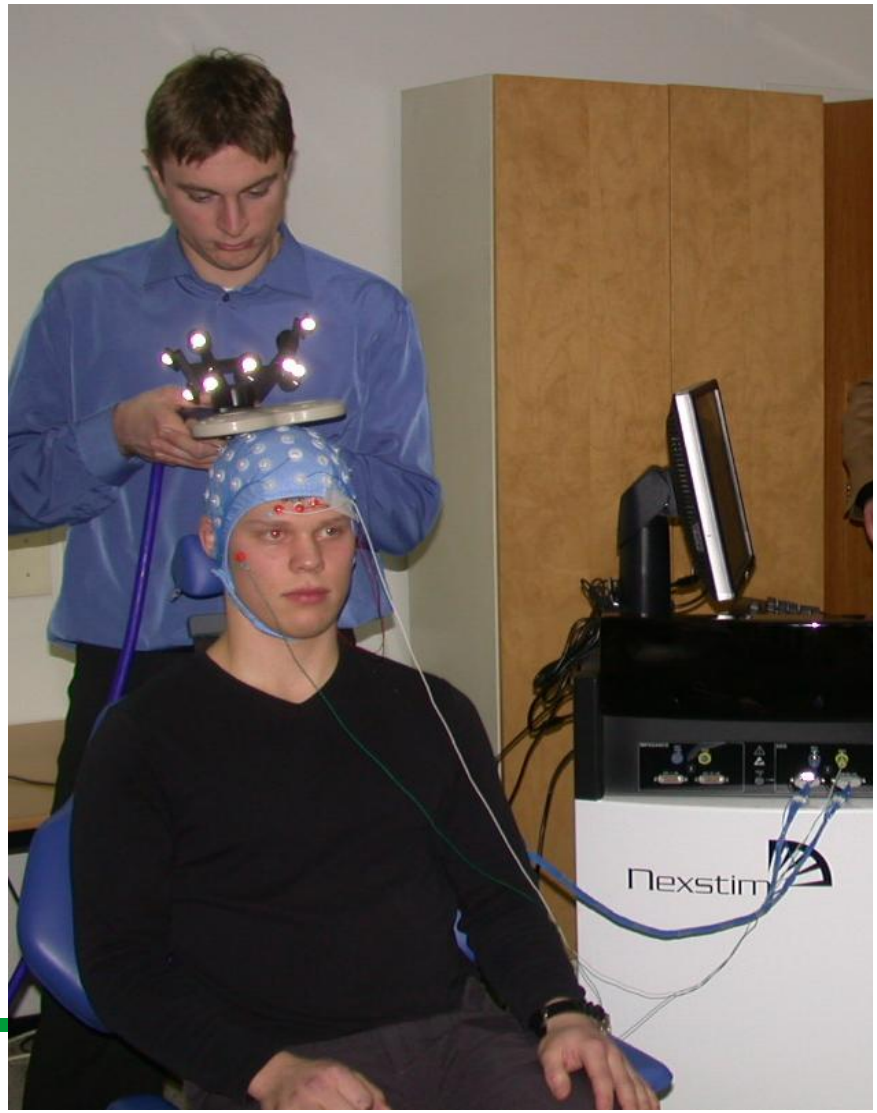


2) Near-Infrared Spectroscopy (NIRS)



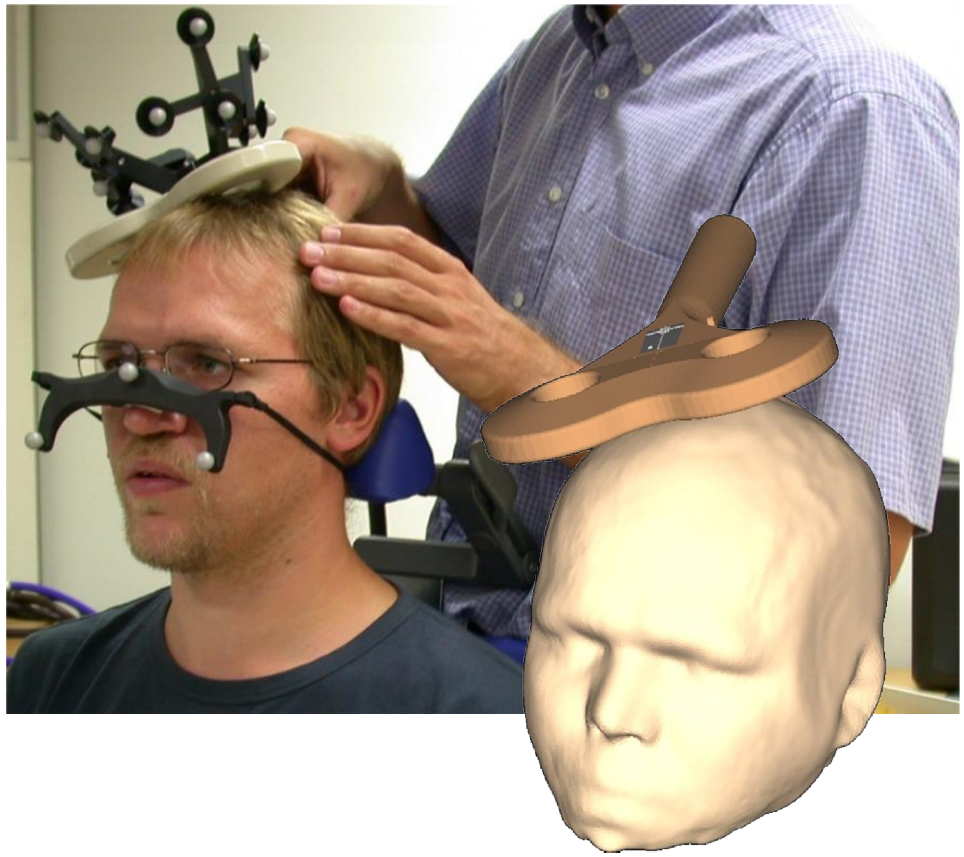
3) Transcranial Magnetic Stimulation (TMS)

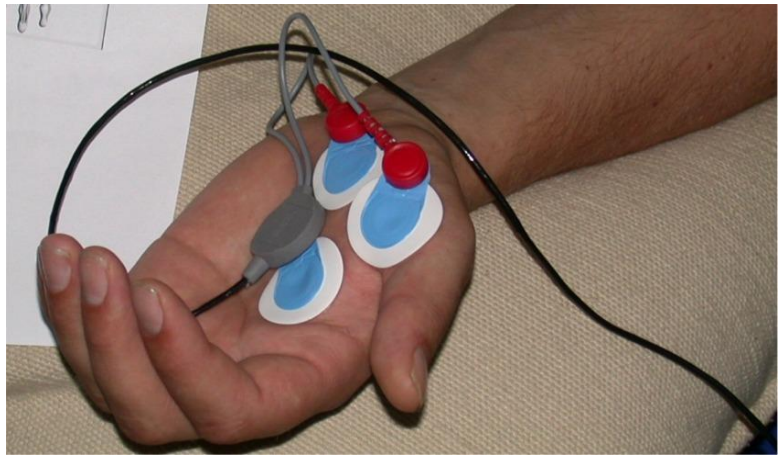
- Magnetic field:
  From zero to 2 tesla in 100 microsecond!
- Induced current in the brain:
  0.1 mA/mm^2
- Membrane depolarization:
  10–100 mV

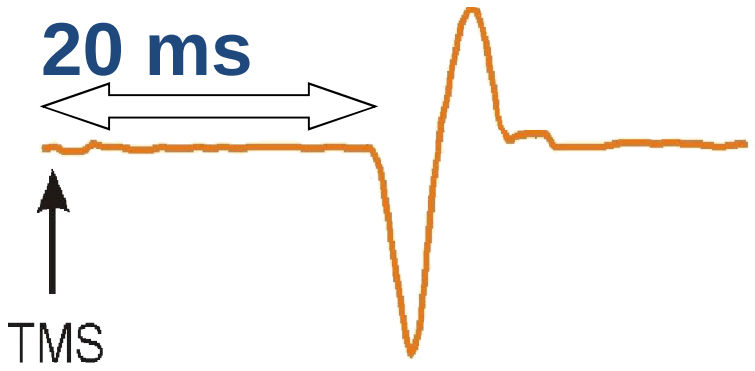


Measuring cortical excitability

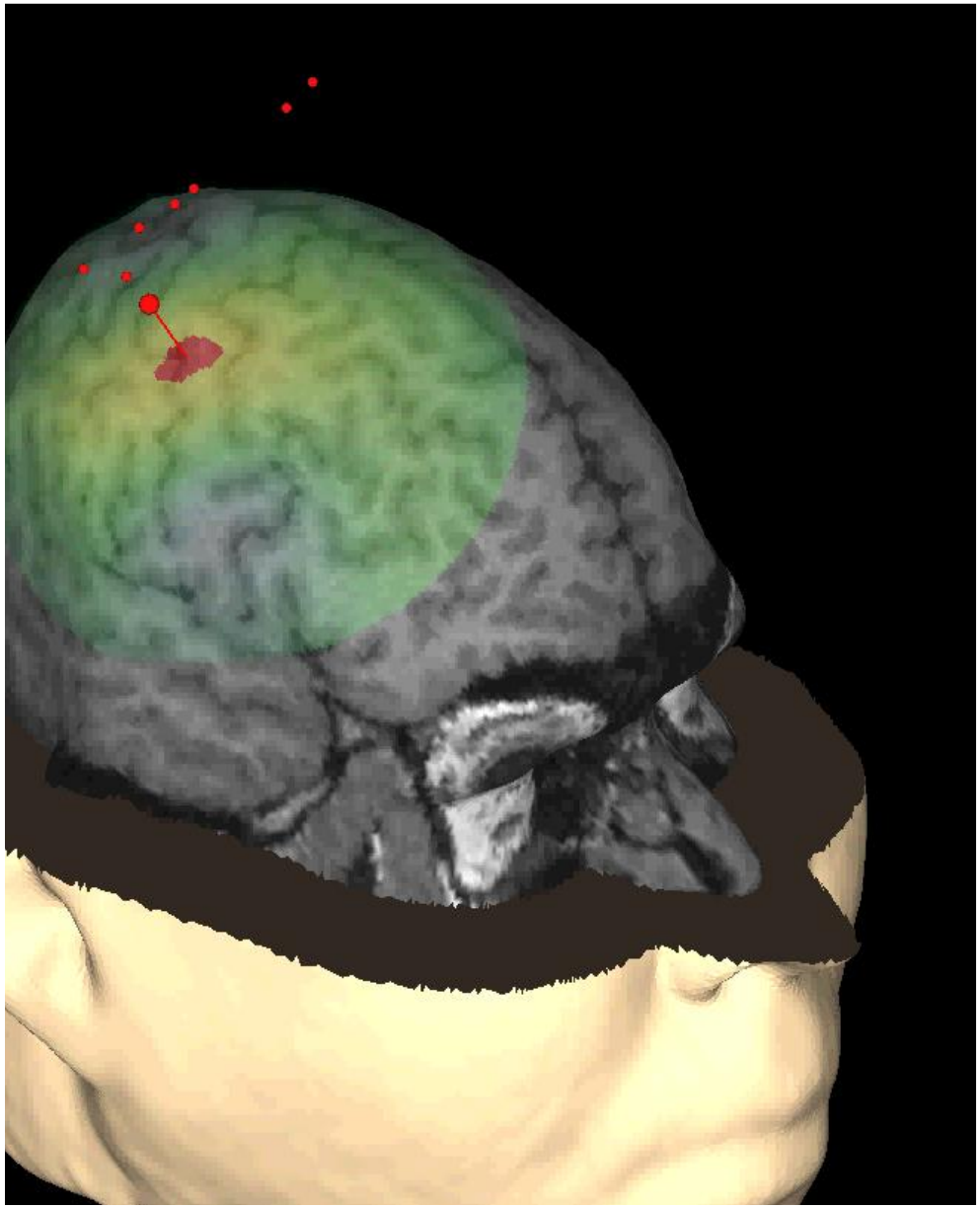
Motor evoked potential (MEP)

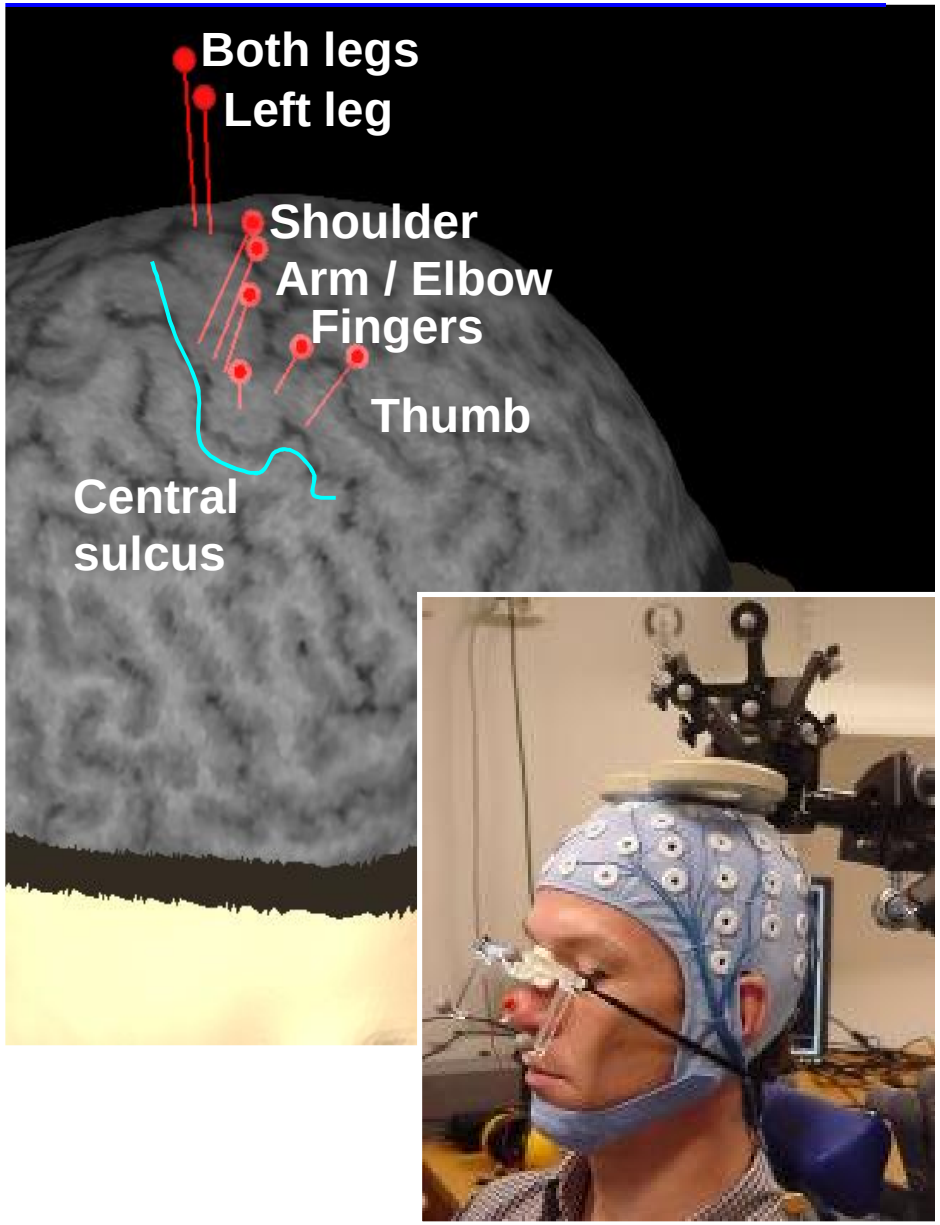




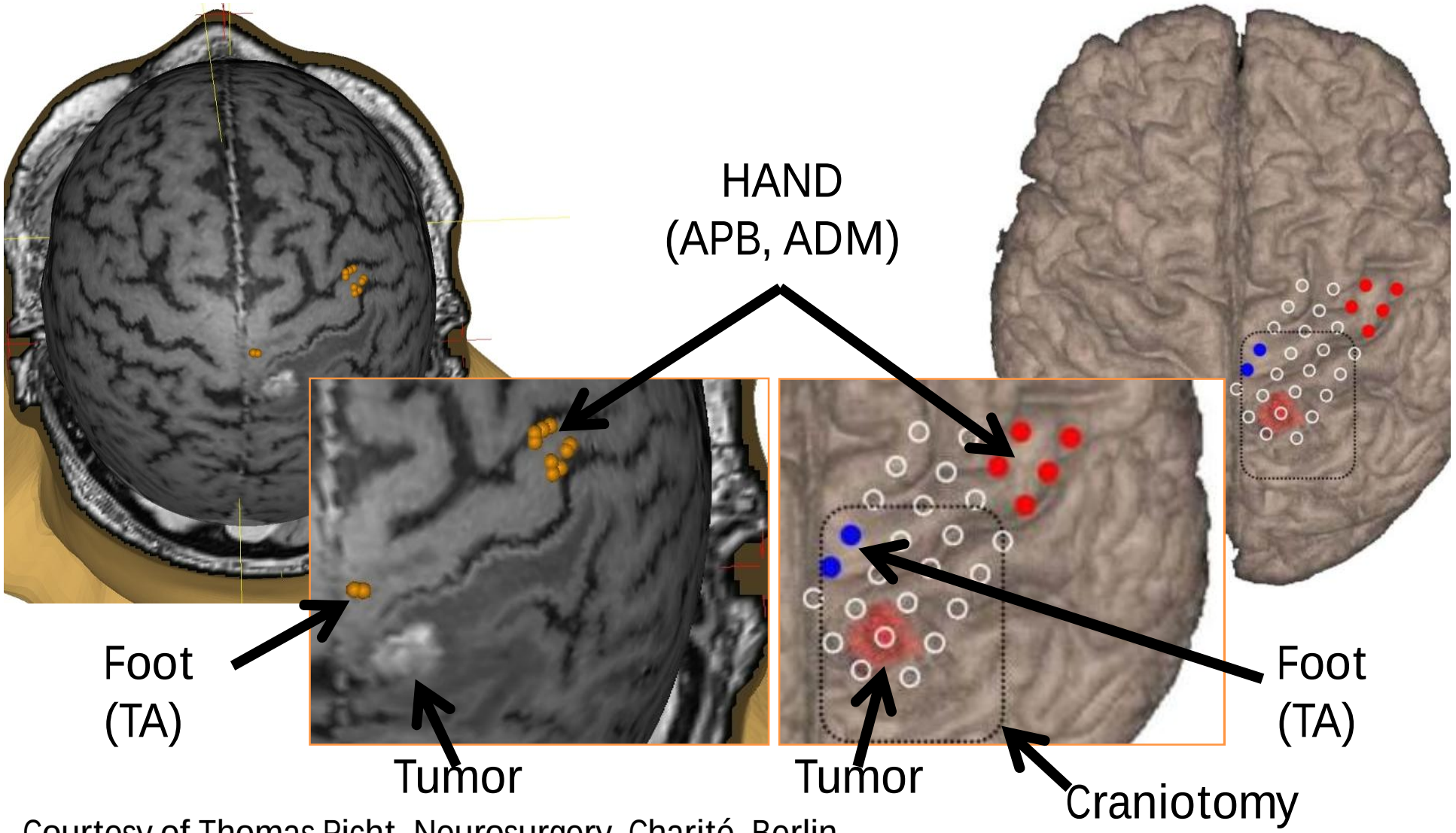


Navigated Brain Stimulation (NBS)





Preoperative mapping of eloquent areas:
TMS versus Direct Cortical Stimulation



Courtesy of Thomas Picht, Neurosurgery, Charité, Berlin

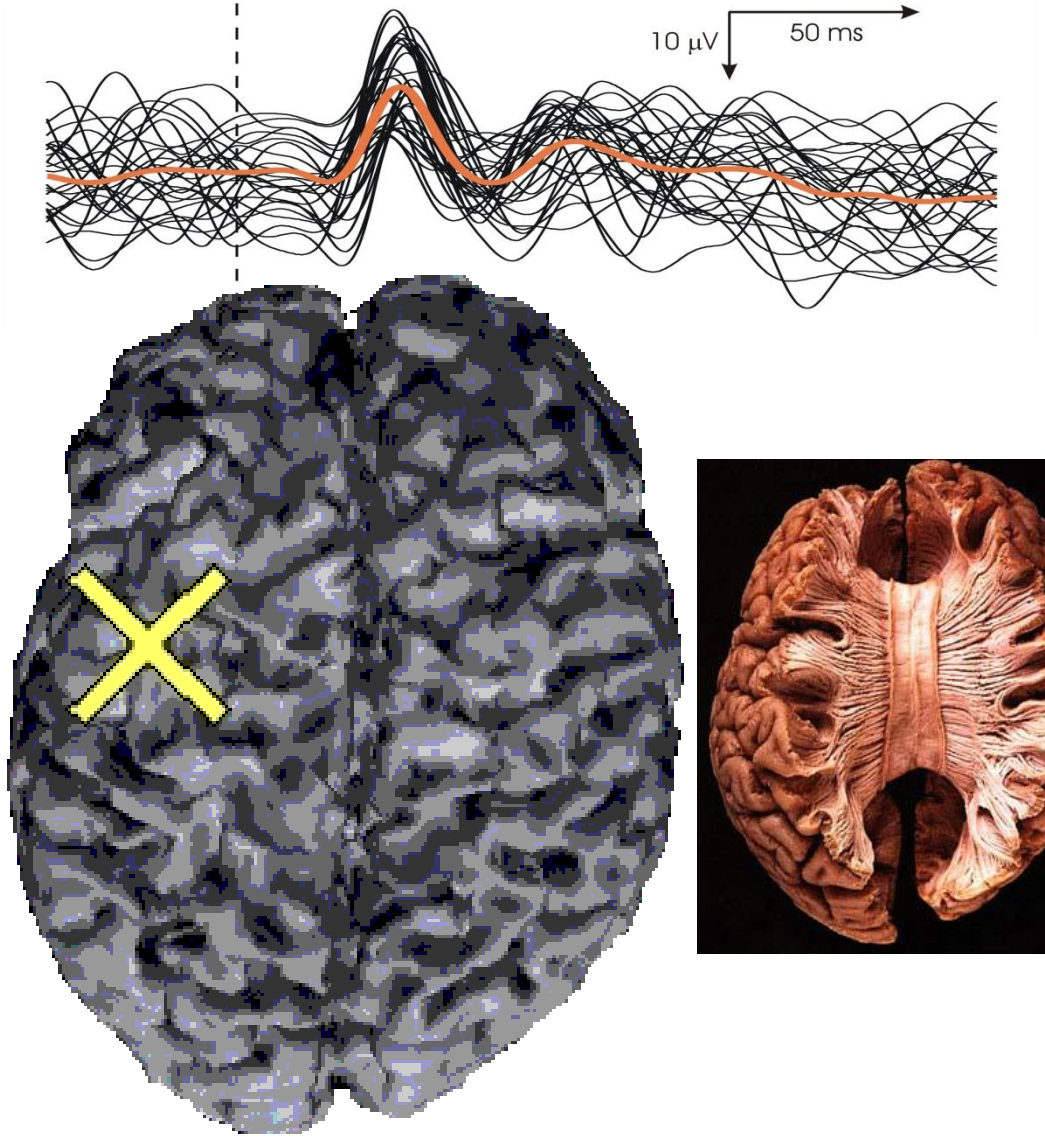
Mapping of language areas (video)

TMS combined with EEG

- Cortical excitability
- Functional connectivity
- State of the cortex!

Ilmoniemi *et al*. NeuroReport 1997
Kähkönen *et al.* NeuroImage 2001
Komssi *et al.* Clin. Neurophysiol. 2002
Nikulin *et al*. Eur. J. Neurosci. 2003
Komssi *et al.* Hum. Brain Mapp. 2004
Kähkönen *et al.* Clin. Neurophysiol. 2004
Bender *et al.* Ann. Neurol. 2005
Massimini *et al.* Science 2005
Ilmoniemi & Kicic Brain Topogr. 2010
Mäki & Ilmoniemi NeuroImage 2011

TMS–EEG: Excitability and Connectivity



Applications of TMS

- Presurgical evaluation
  - Determination of motor and language areas
- Possible therapy
  - Depression, tinnitus, hallucinations, chronic pain, migraine, stroke, epilepsy, coma
- Pharmaceutical studies
  - Excitability, functional connectivity
- Neuroscience
  - Probing of functional areas
  - Measurement of brain state
  - Connectivity

Thank you for your attention!

Thanks to colleagues and co-workers:

MEGMRI: Panu Vesanen, Koos Zevenhoven, Juhani Dabek, Sarianna Alanko, Andrey Zhdanov, Mika Pollari, Fa Hsuan-Lin, Jaakko Nieminen,Tuomas Hirvonen, Juha Simola, Lauri Parkkonen, Antti Ahonen, Juho Luomahaara, Juha Hassel, Jari Penttilä, Jyrki Mäkelä, Juha Montonen, and the MEGMRI consortium; megmri.net

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NIRS: Ilkka Nissilä, Kalle Kotilahti, Tiina Näsi, Petri Hiltunen, Jaakko Virtanen, Tommi Noponen, Pekka Meriläinen