Assessing Ultra-Low-Field MRI-Derived Head Models
for Electric Field Simulation in TMS, ECT, and tDCS

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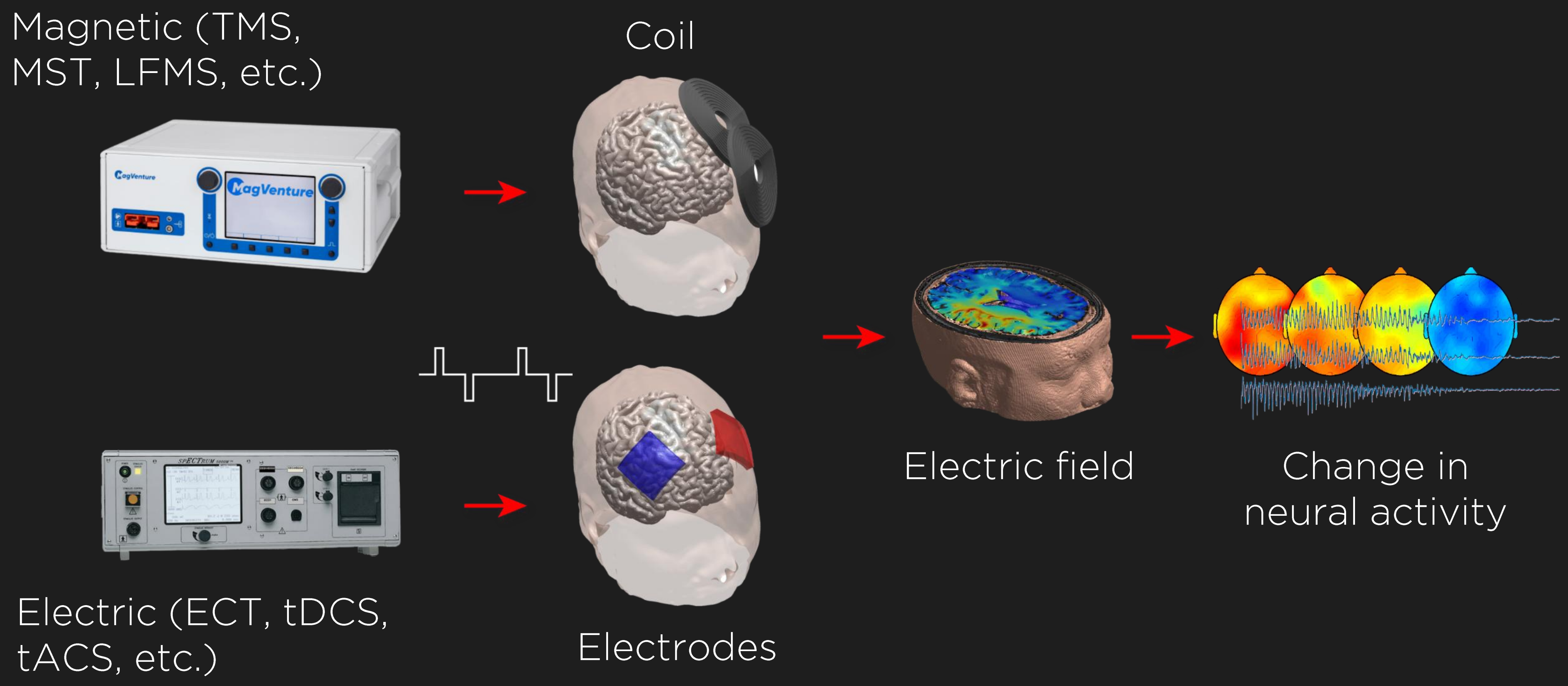
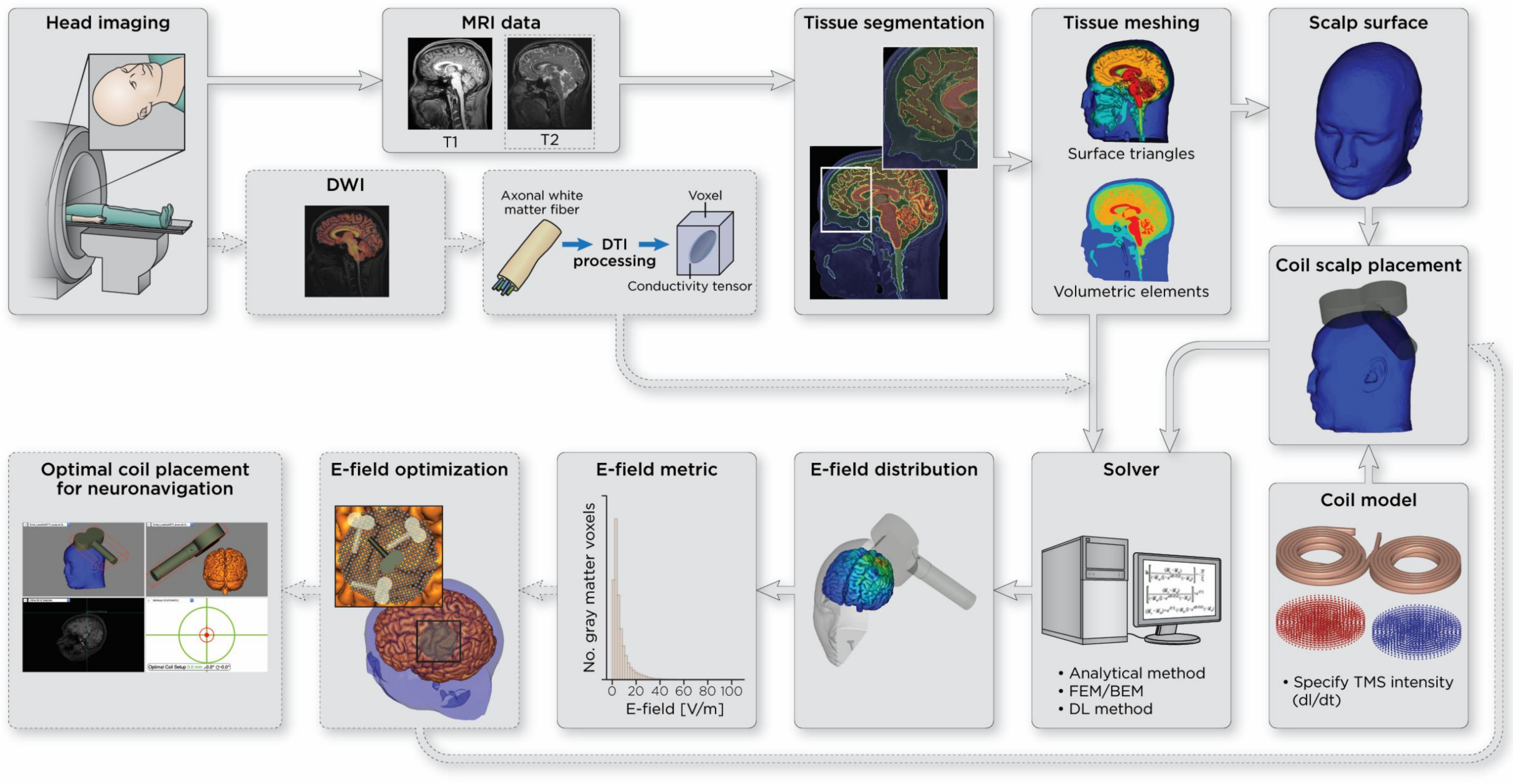
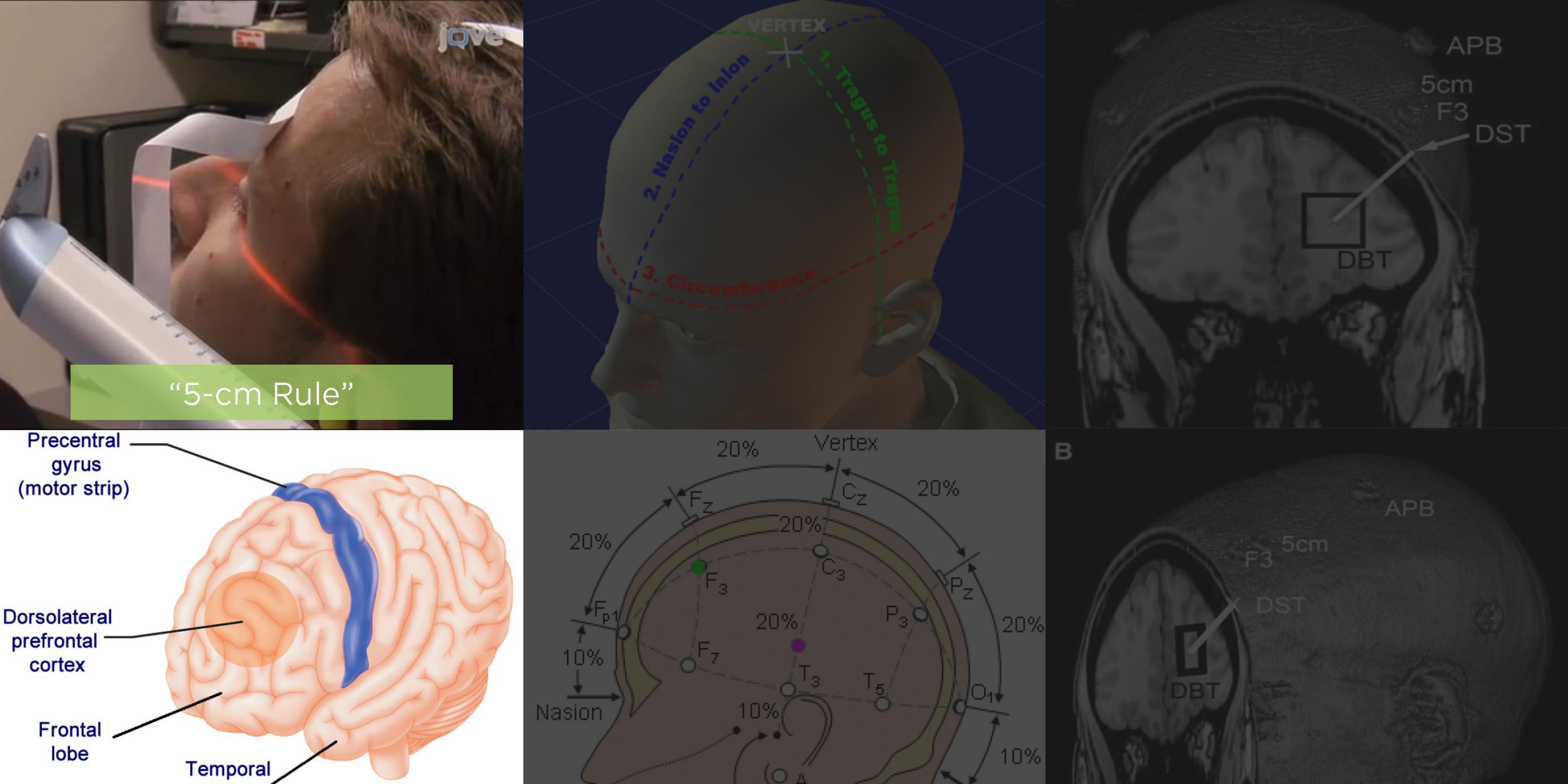
Transcranial brain stimulation: Magnetic vs electric



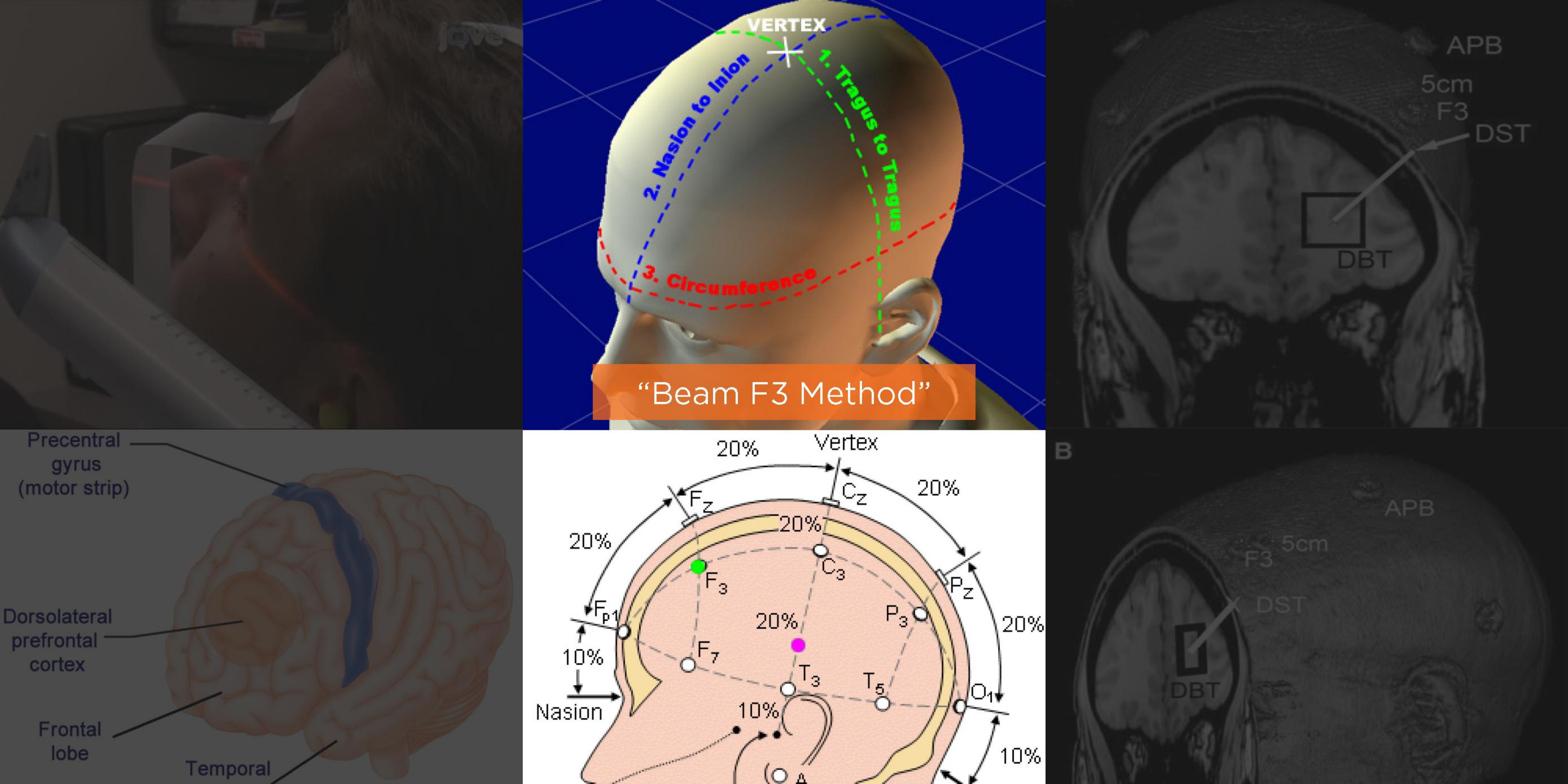
E-field modeling pipeline

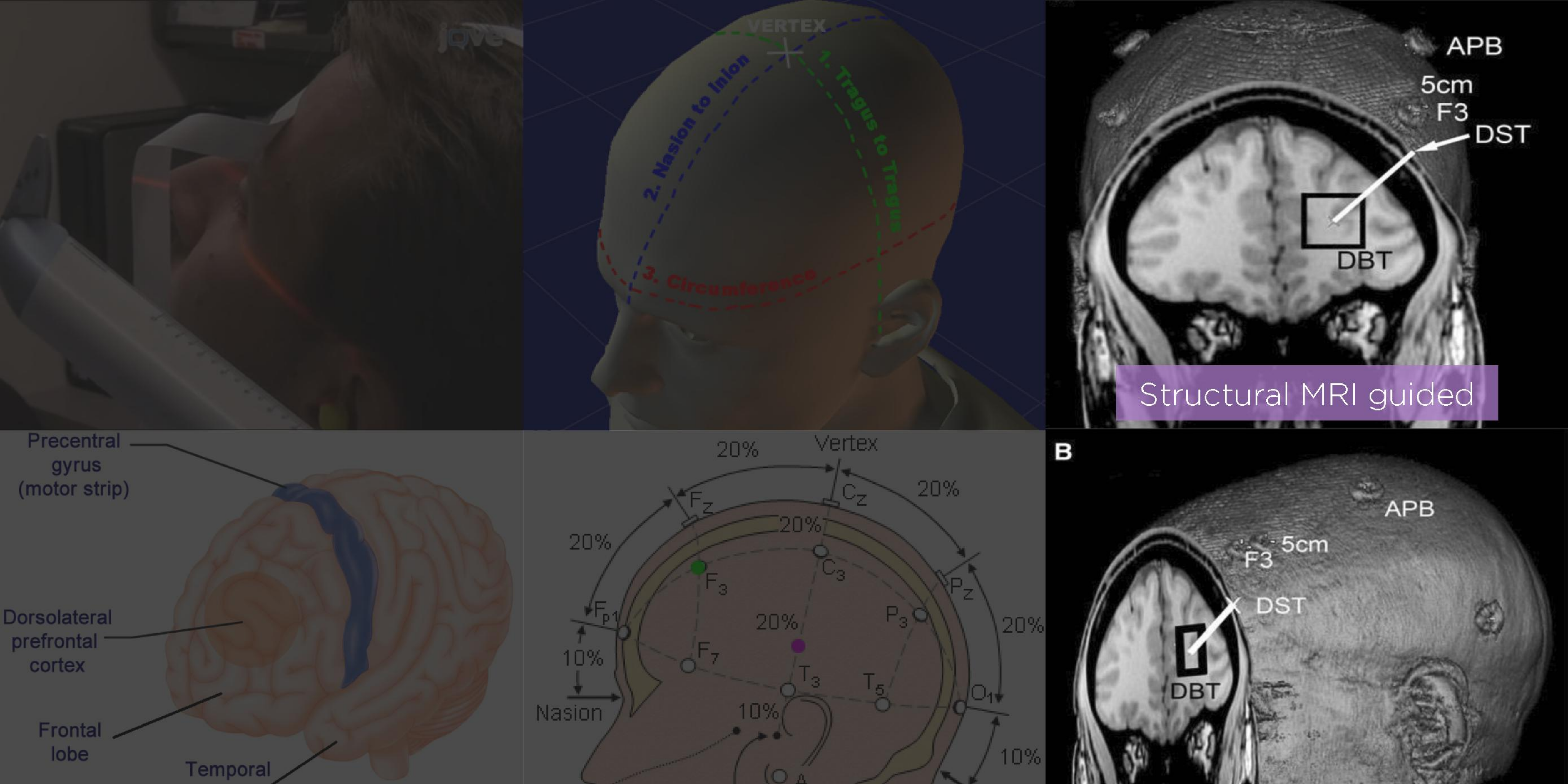


Dannhauer et al., *Biol Psychiatry*, 2025



"5-cm Rule"
VERTEX
2. Nasion to Inion
1. Tragus to Tragus
3. Circumference
APB
5cm
F3
DST
DBT
Precentral gyrus (motor strip)
Dorsolateral prefrontal cortex
Frontal lobe
Temporal
Vertex
20%
Cz
Fz
C3
F3
Fp1
F7
T3
T5
P3
Pz
O1
10%
Nasion
B
APB
5cm
F3
DST
DBT


VERTEX
2. Nasion to Inion
1. Tragus to Tragus
3. Circumference
"Beam F3 Method"
APB
5cm
F3
DST
DBT
B
APB
5cm
F3
DST
DBT
Precentral gyrus (motor strip)
Dorsolateral prefrontal cortex
Frontal lobe
Temporal
Vertex
20%
20%
20%
20%
20%
20%
10%
10%
10%
Fz
Cz
Pz
Fp1
F3
C3
P3
F7
T3
T5
O1
Nasion



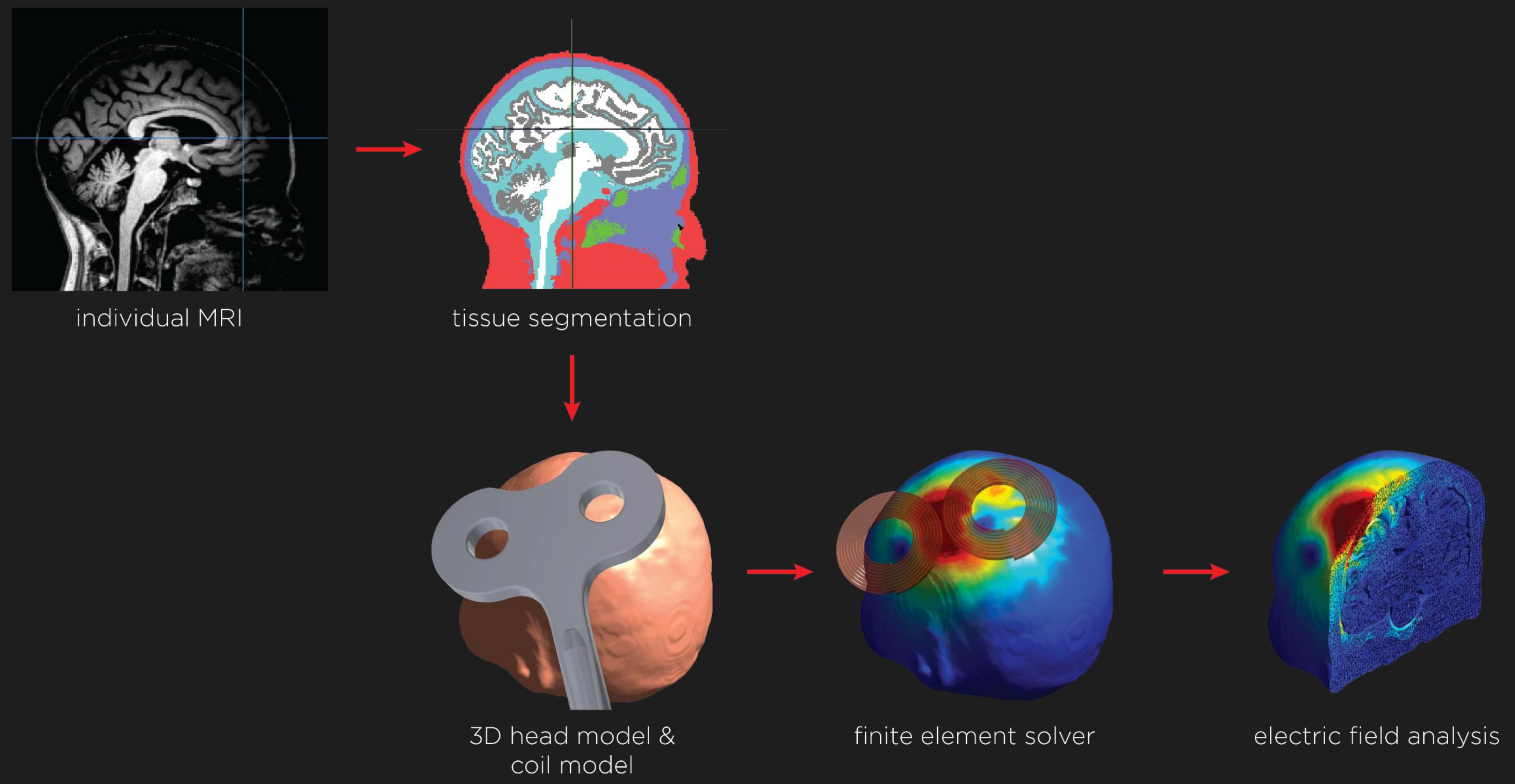
VERTEX
1. Tragus to Tragus
2. Nasion to Inion
3. Circumference
APB
5cm
F3
DST
DBT
Structural MRI guided
Precentral gyrus (motor strip)
Dorsolateral prefrontal cortex
Frontal lobe
Temporal
Vertex
20%
Fz
Cz
20%
20%
20%
C3
F3
Fp1
Pz
P3
20%
20%
10%
F7
T3
T5
O1
Nasion
10%
10%
B
APB
5cm
F3
DST
DBT

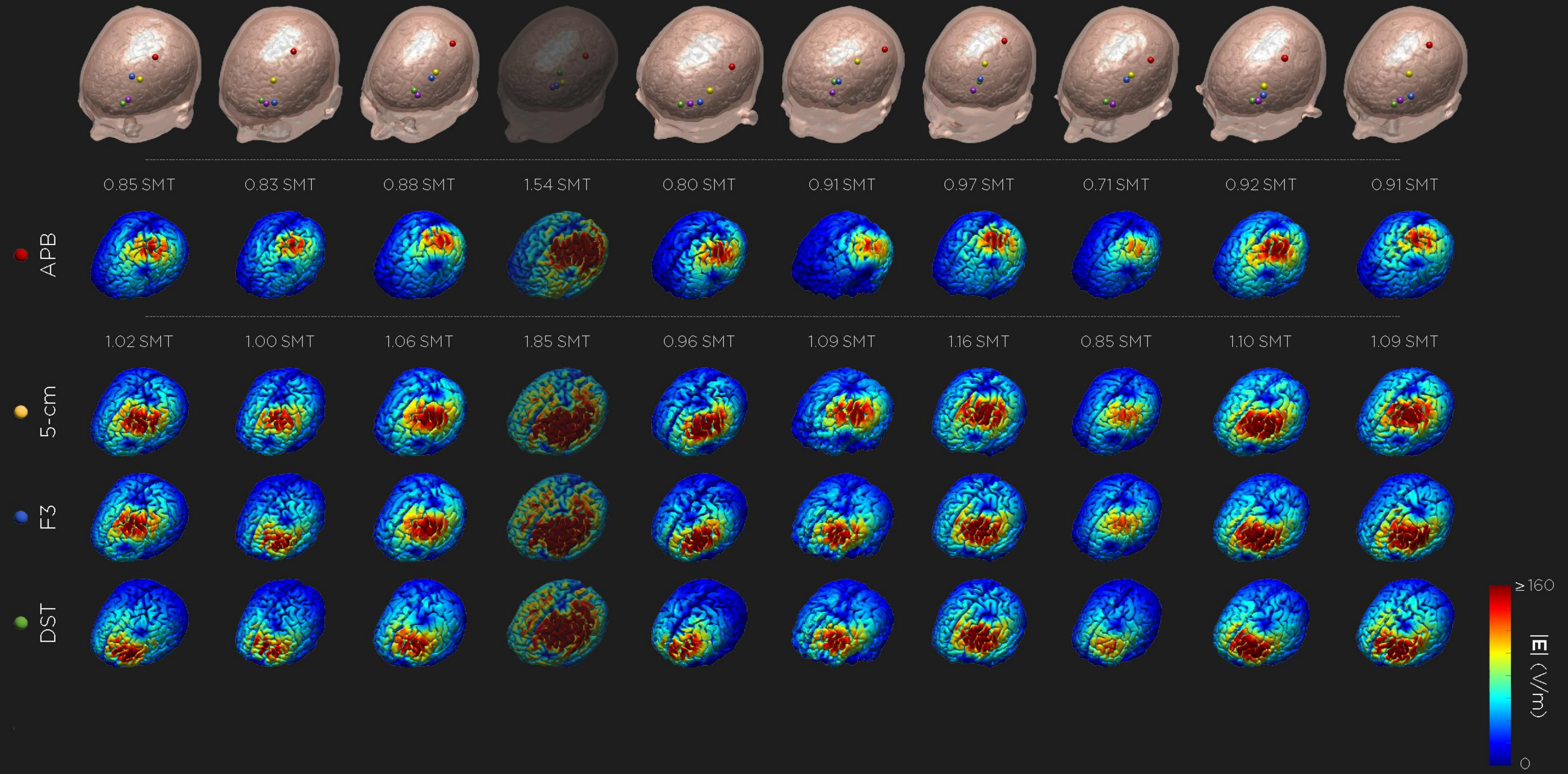
§ Individual left DLPFC target localized using structural MRI (DLPFC Scalp Target: DST)

§ 10-Hz rTMS delivered using NeuroStar Therapy System, at intensity of 120% Standard Motor Threshold

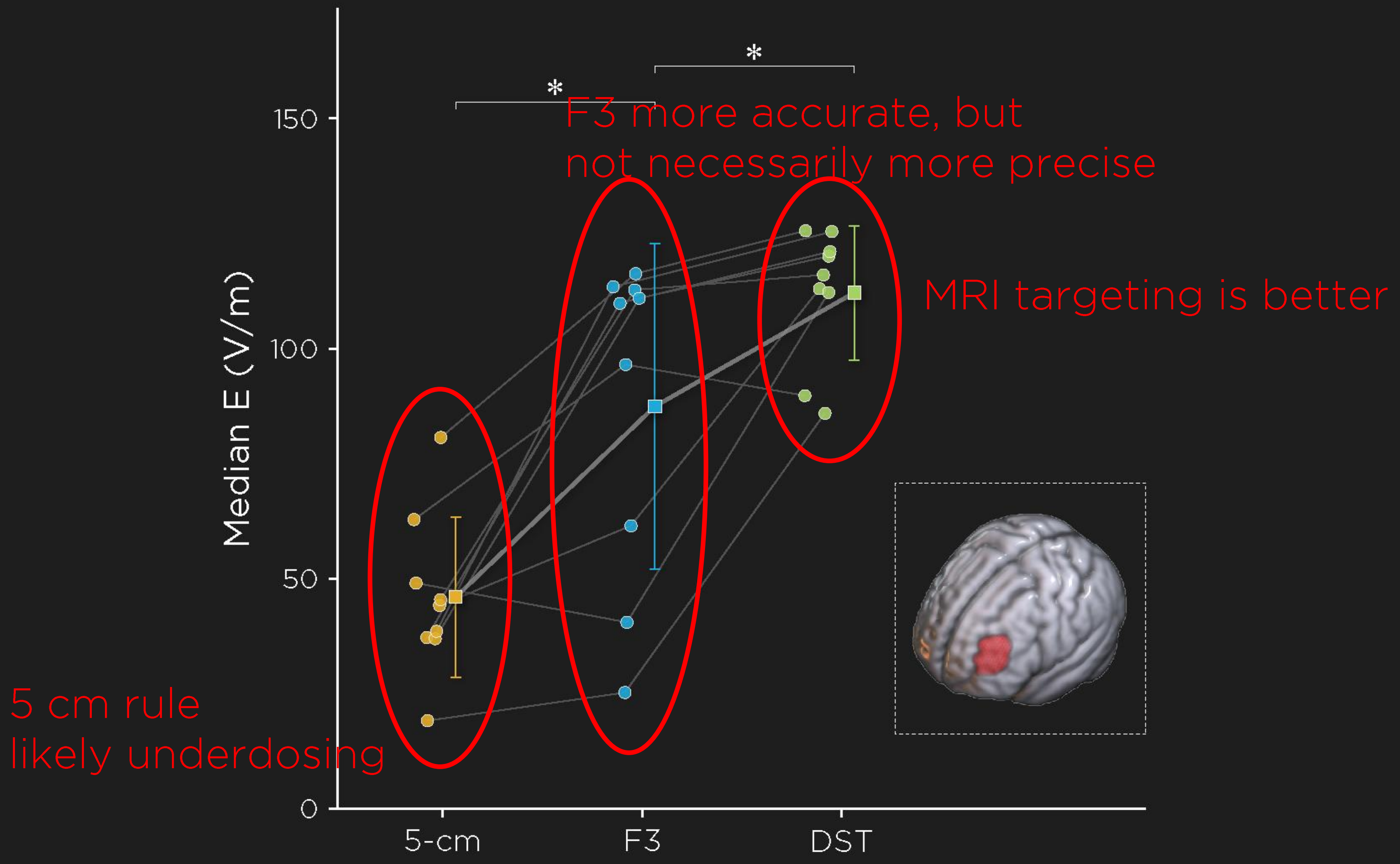
§ 5 days per week, over 6–8 weeks, up to 30 sessions

§ Computational electric field modeling...


individual MRI
tissue segmentation
3D head model &
coil model
finite element solver
electric field analysis



Deng et al., *Biomedicines*, 2023



Deng et al., *Biomedicines*, 2023

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Electric field distribution predicts efficacy of accelerated intermittent theta burst stimulation for late-life depression

Davin K. Quinn[1]*, Joel Upston[1], Thomas R. Jones[1], Benjamin C. Gibson[2], Tessa A. Olmstead[1], Justine Yang[1], Allison M. Price[3], Dorothy H. Bowers-Wu[1], Erick Durham[4], Shawn Hazlewood[1], Danielle C. Farrar[1], Jeremy Miller[1], Megan O. Lloyd[1], Crystal A. Garcia[1], Cesar J. Ojeda[1], Brant W. Hager[1], Andrei A. Vakhtin[5] and Christopher C. Abbo

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Introduction: Repetitive transcranial magnetic stimulation (rTMS) is a pro intervention for late-life depression (LLD) but may have lower rates of res and remission owing to age-related brain changes. In particular, rTMS in electric field strength may be attenuated by cortical atrophy in the pre cortex. To identify clinical characteristics and treatment parameters asso with response, we undertook a pilot study of accelerated fMRI-guided interr

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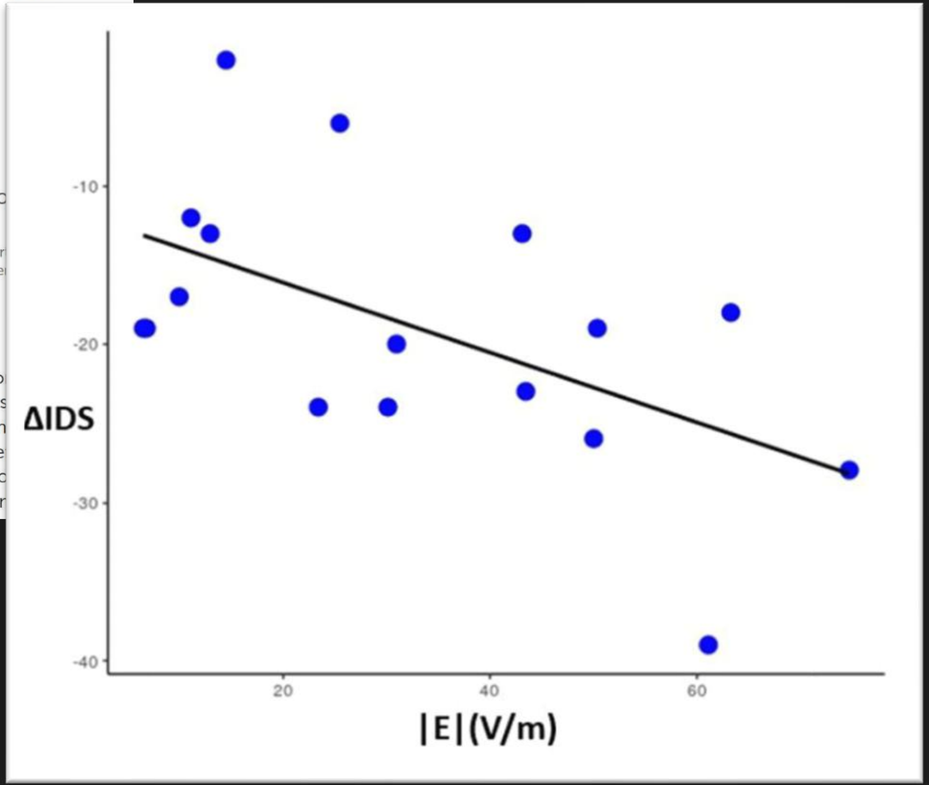
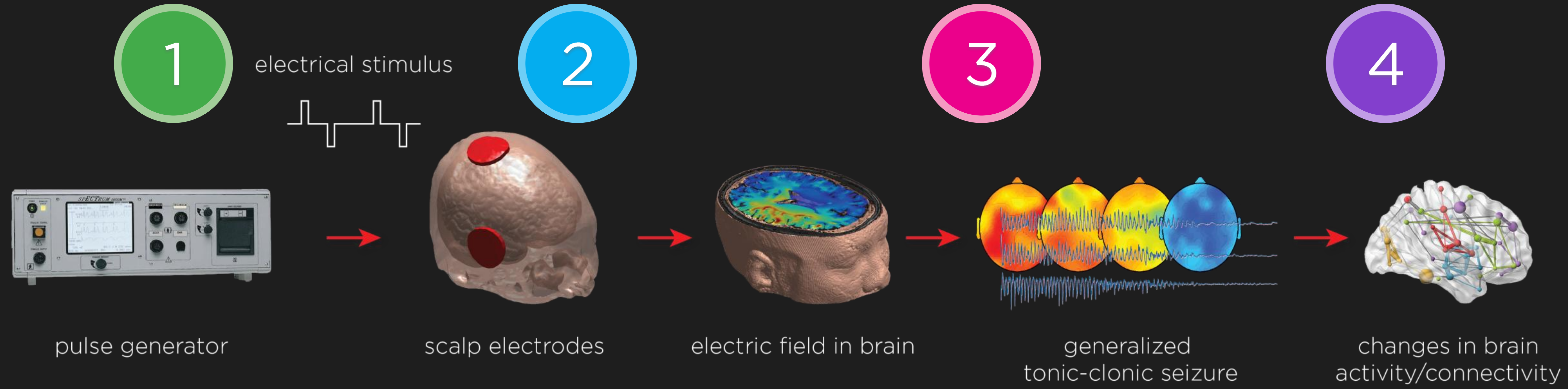
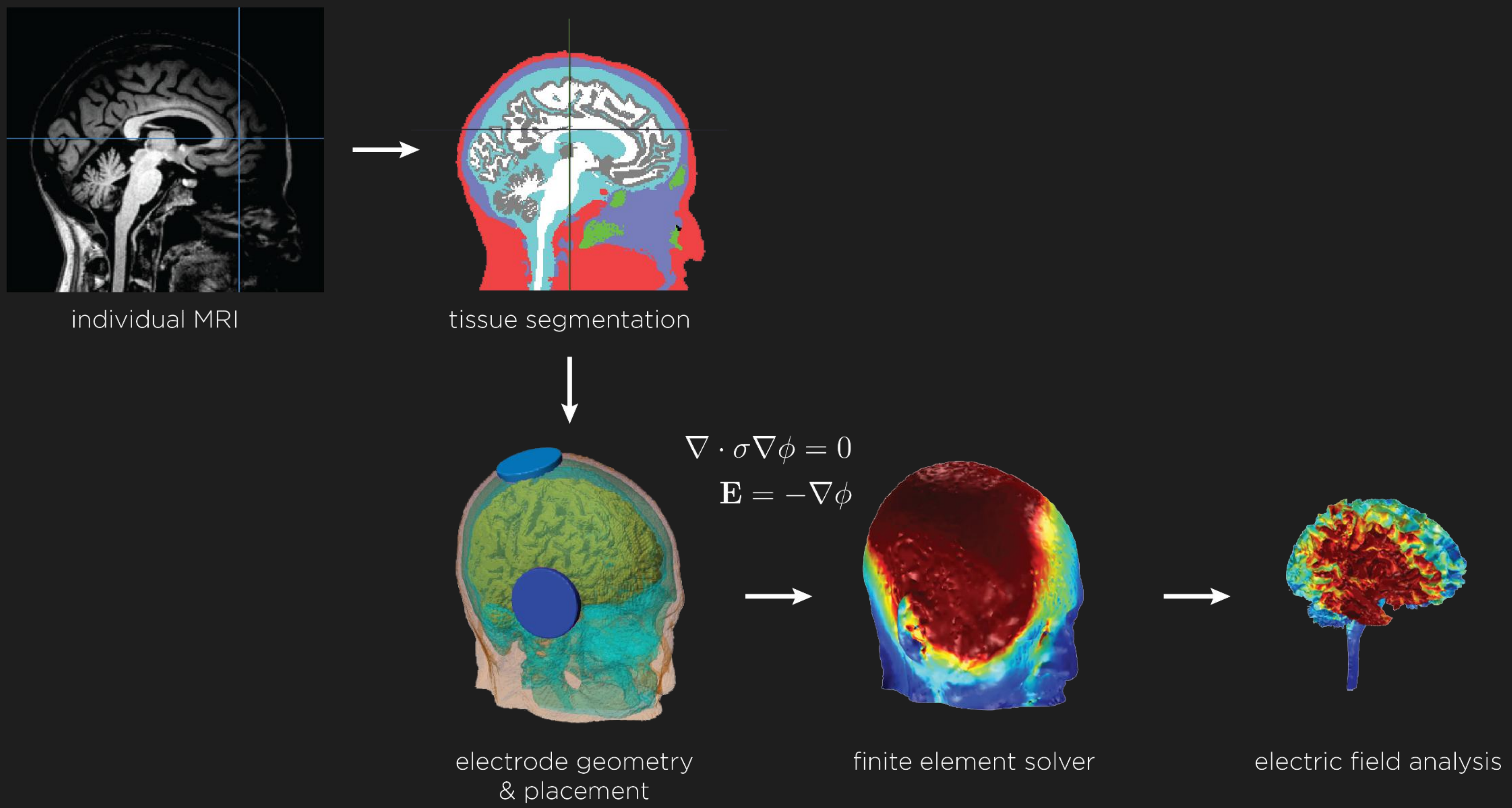


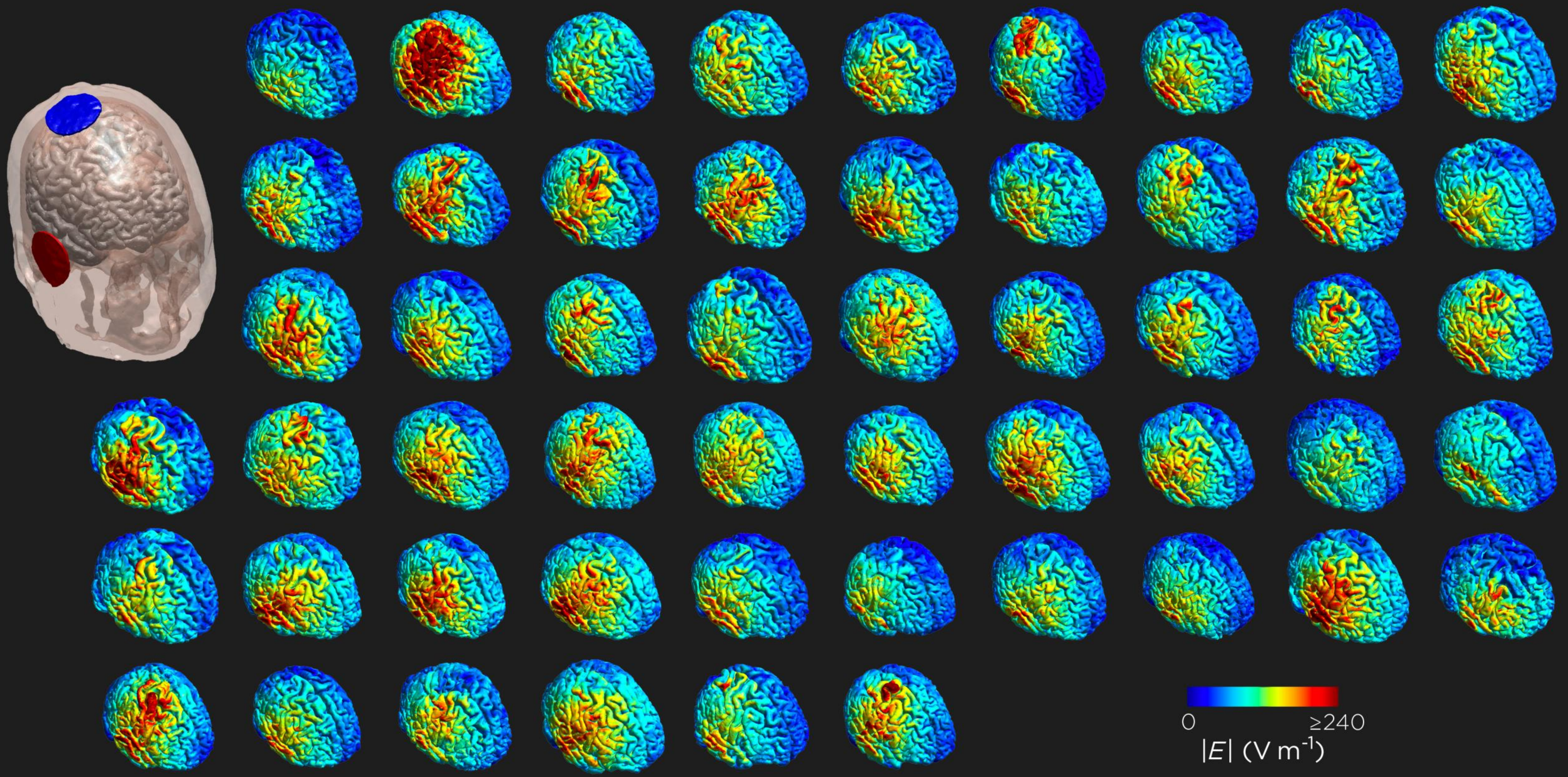
Deng et al., *Biomedicines*, 2023

Electroconvulsive therapy (ECT)



E-field modeling in ECT





0
≥240
|E| (V m-1)

Why accurate E-field modeling matters in ECT

Dose is variable, not the dial you set

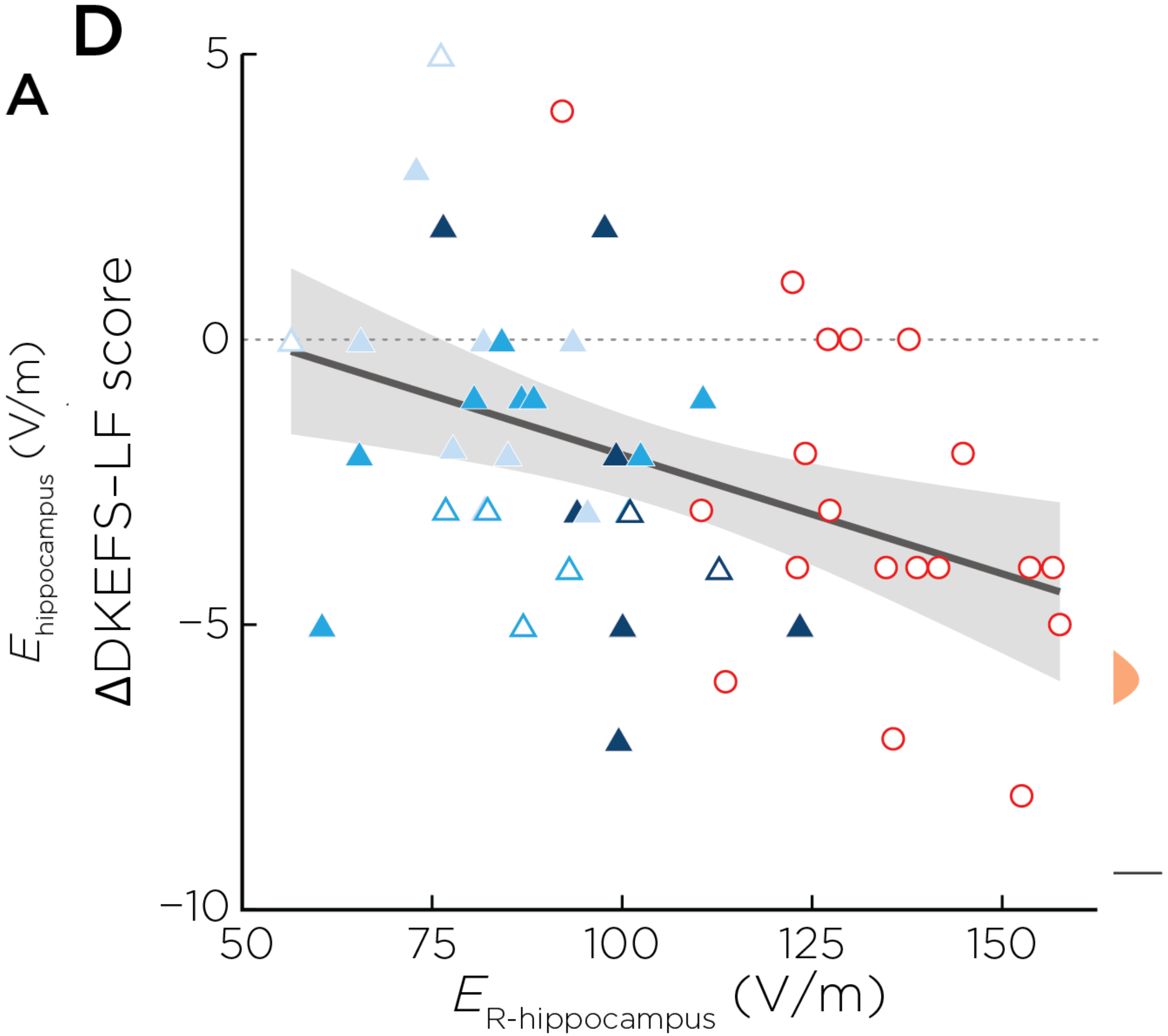
Despite fixed 100 mA difference between groups, hippocampal E-field strength varied widely within each arm, enough to mask group differences (Deng et al., 2022).

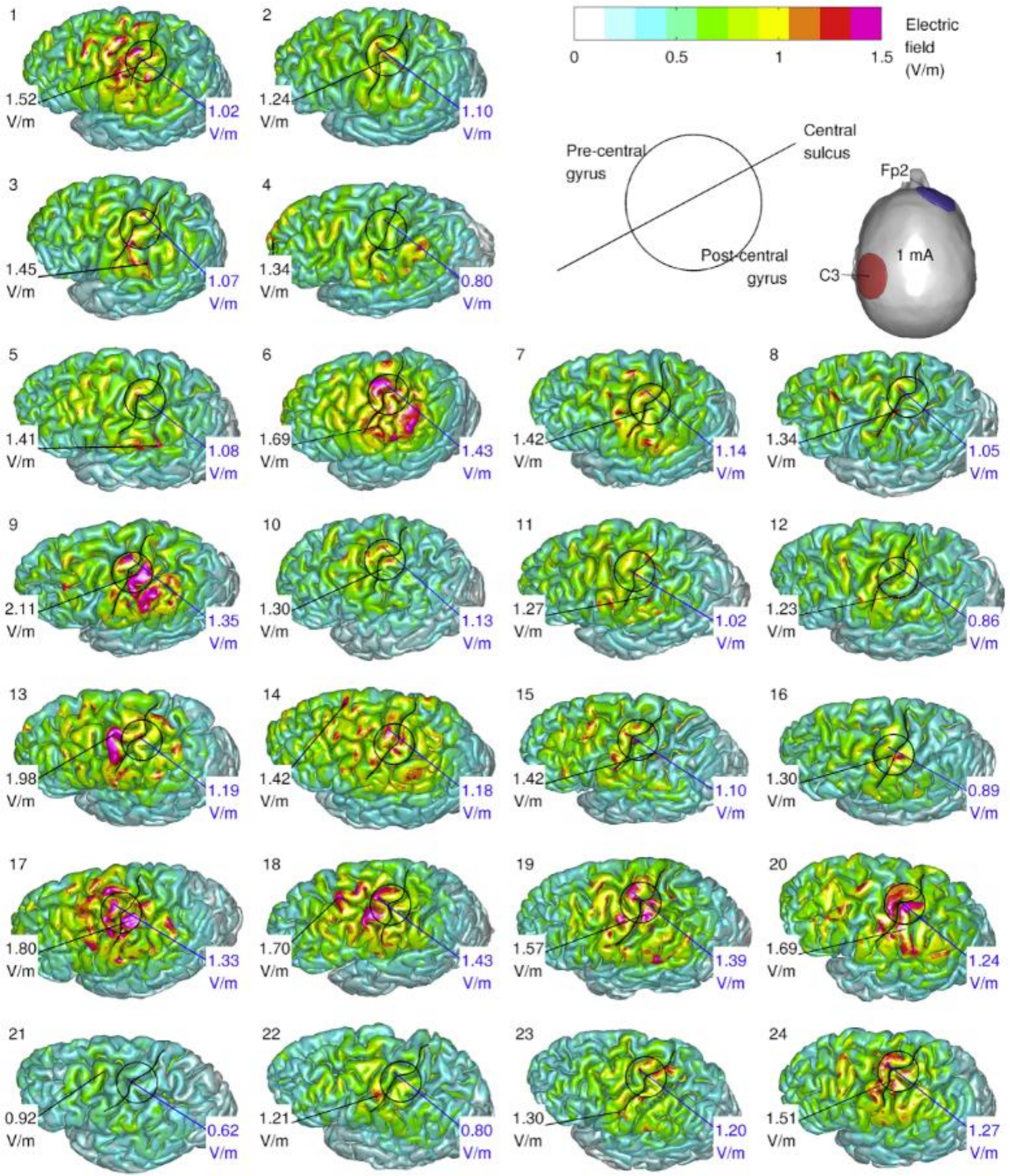
Field → neuroplasticity → antidepressant response

Hippocampal E-field is linearly related to its volumetric change, this neuroplasticity in turn mediates antidepressant response (Argyelan et al., 2019).

Same field also drives cognitive side effects

Higher E-field is directly linked to phonemic-fluency decline. ~112.5 V/m marks the ceiling for cognitive safety.

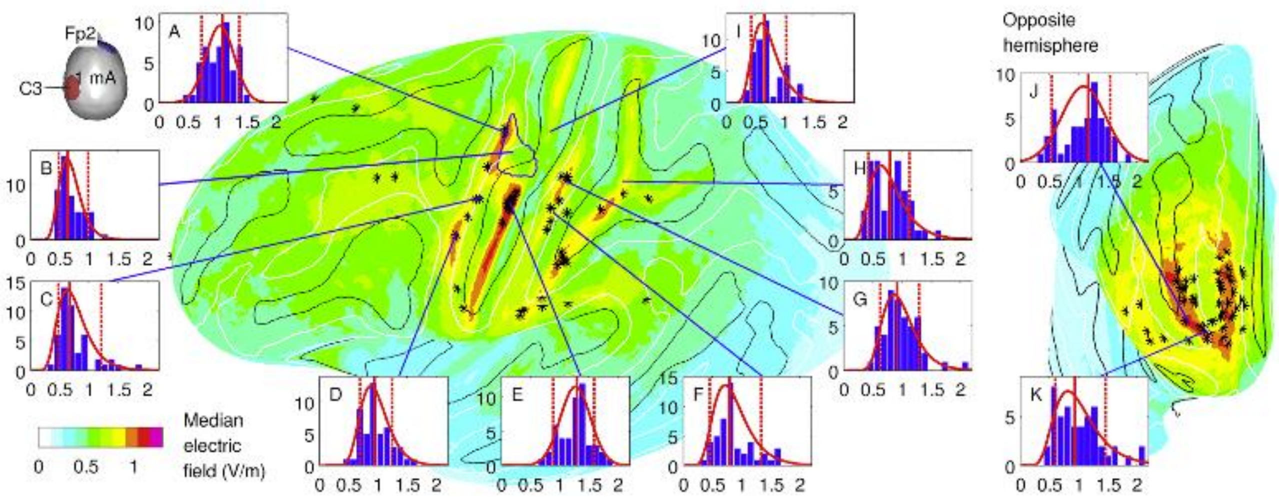




Modeling in tDCS

- 24 males, age 38.6 +/- 11.2
- Individual FEM models of motor tDCS (C3 anode, Fp2 cathode)
- Large differences in each individual's E-field distribution

Laakso et al., *Brain Stimul*, 2015



Inter-subject variability in tDCS

- Variations in E-field in hand motor area could be characterized by normal distribution with **standard deviation of approximately 20% of the mean**
- **CSF thickness** was primary factor influencing an individual's E-field, thereby explaining 50% of inter-individual variability

Laakso et al., *Brain Stimul*, 2015

THE TRADE-OFF

Lower magnetic fields yield fundamentally lower Signal-to-Noise Ratios (SNR) and resolution. Can they provide reliable quantitative data?

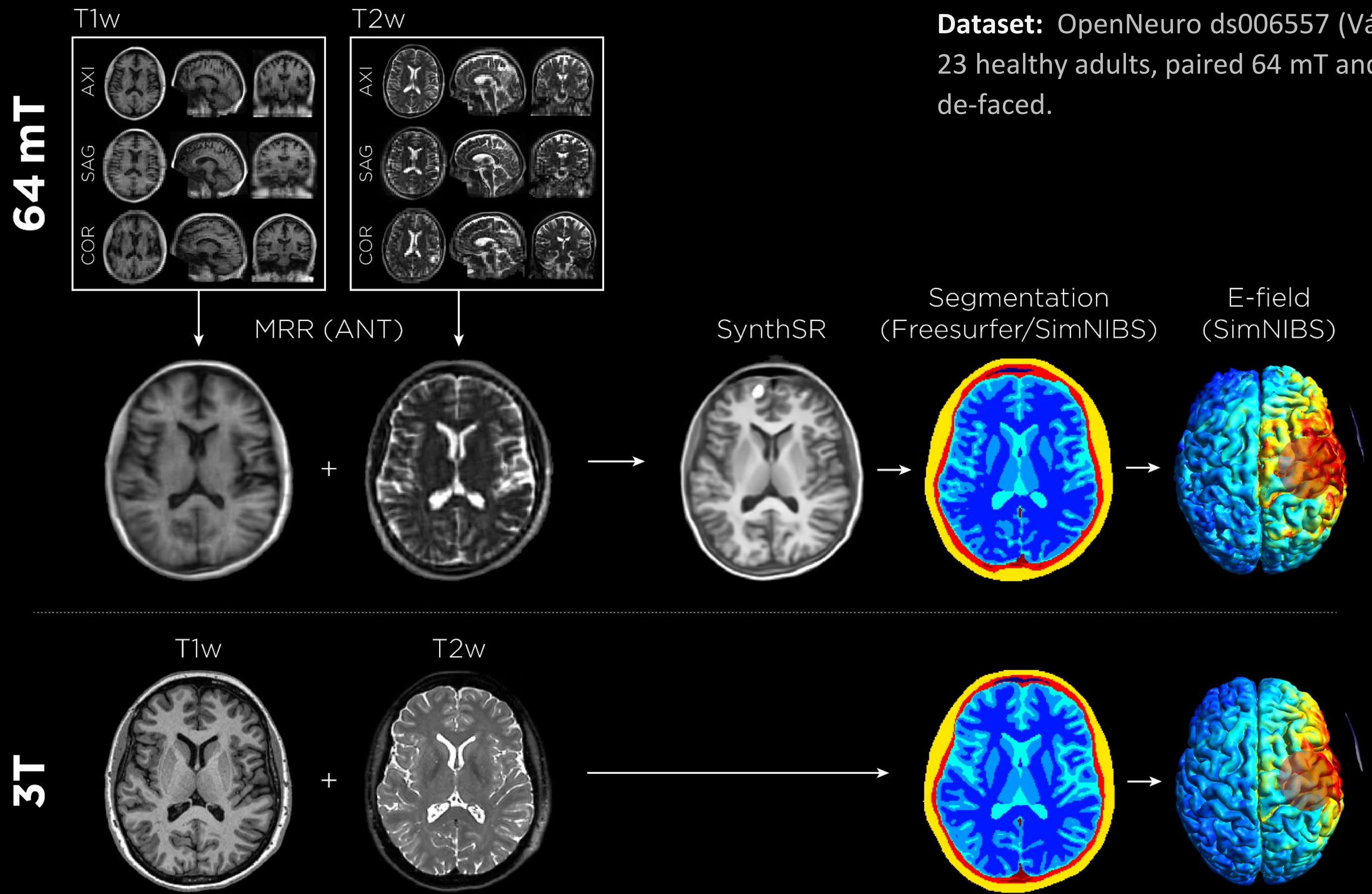
THE GOLD STANDARD

- 1.5–3.0 Tesla
- High spatial resolution (1mm isotropic)
- Massive infrastructure (cooling, Faraday cages)
- High capital and operational costs
- Severe siting constraints

THE CHALLENGER

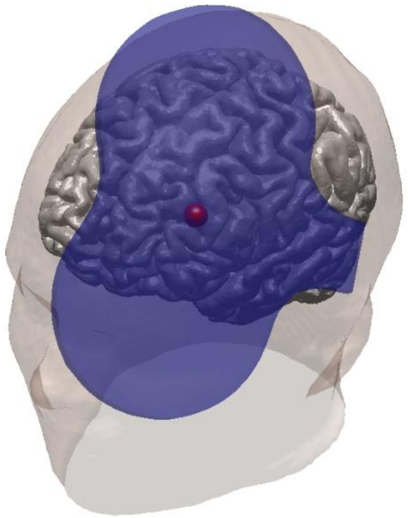
- < 0.1 Tesla (e.g., 64mT)
- Portable (plugs into standard wall outlets)
- Negligible operational costs
- Deployed at bedside and remote locations

Dataset: OpenNeuro ds006557 (Váša et al., 2025)
23 healthy adults, paired 64 mT and 3 T, T1w + T2w, de-faced.

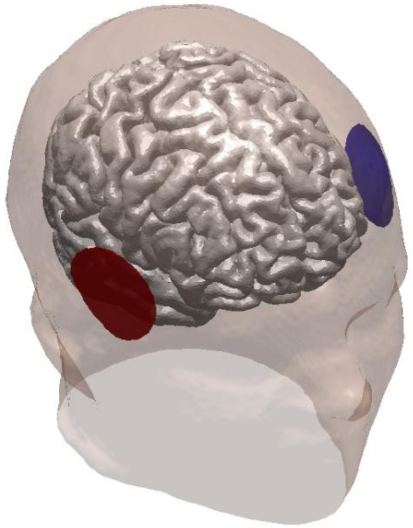


Simulated modalities

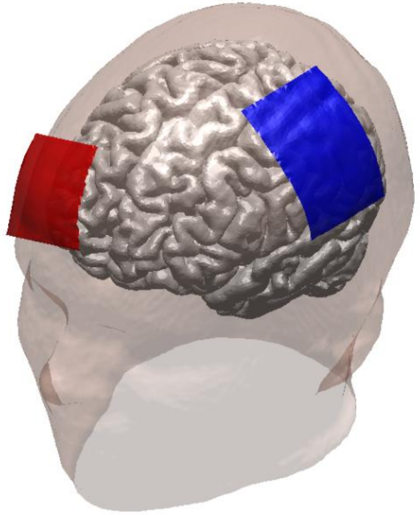
TMS-F3
(75 A/ μs)



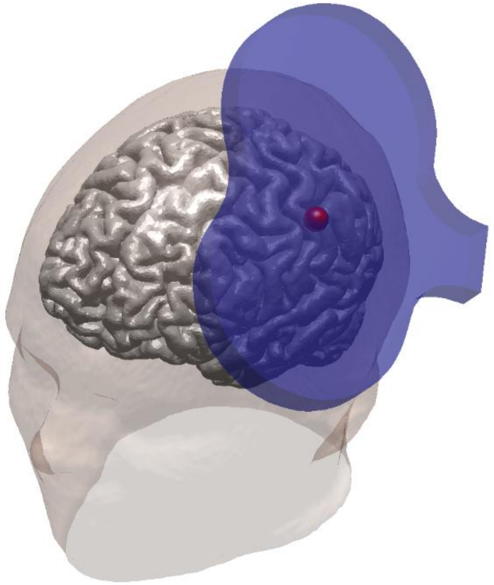
ECT-BL
(FT7/FT8,
800 mA)



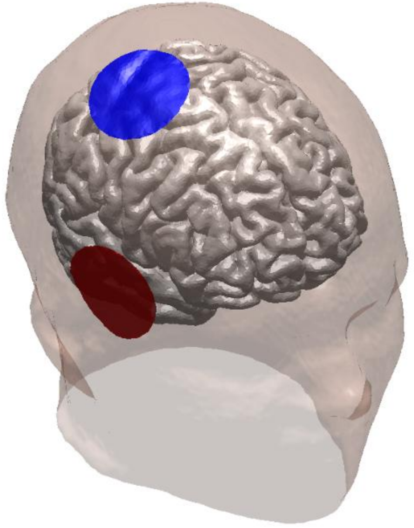
tDCS-M1SO
(C3/AF4, 2 mA)



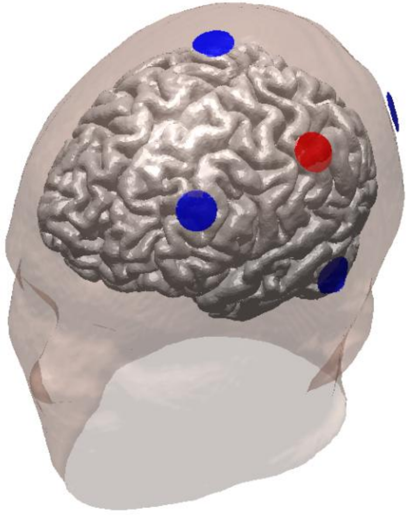
TMS-C3
(75 A/ μs)



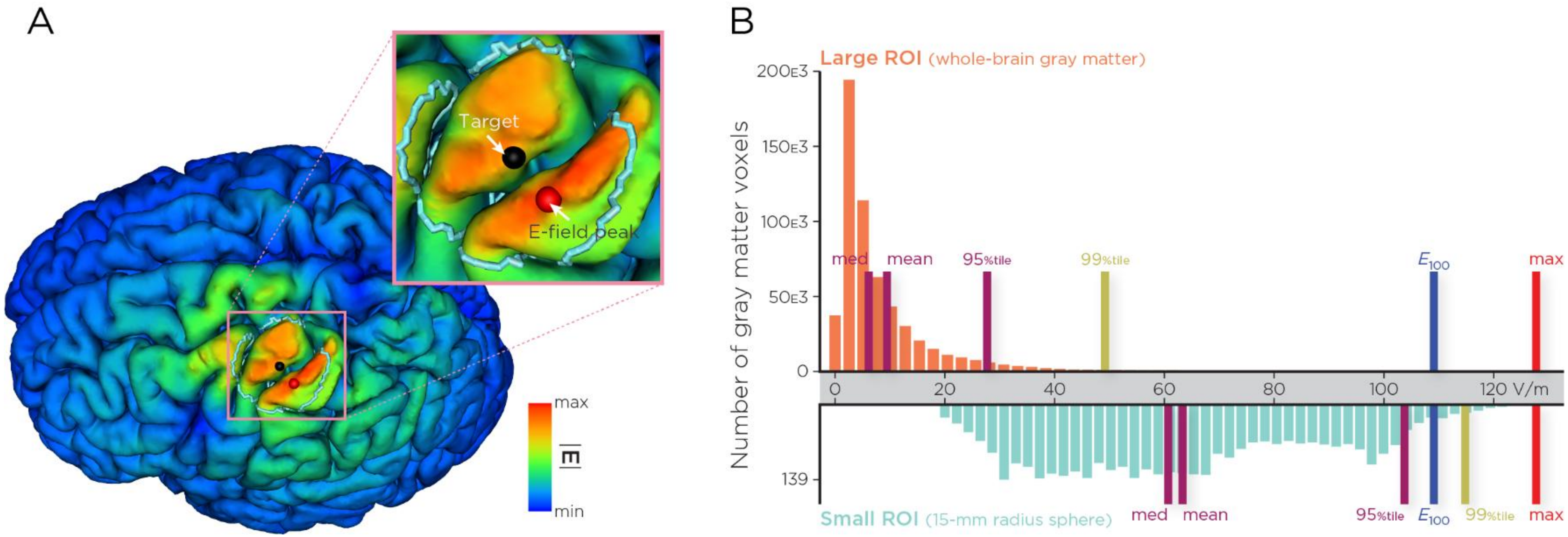
ECT-RUL
(C2/FT8,
800 mA)



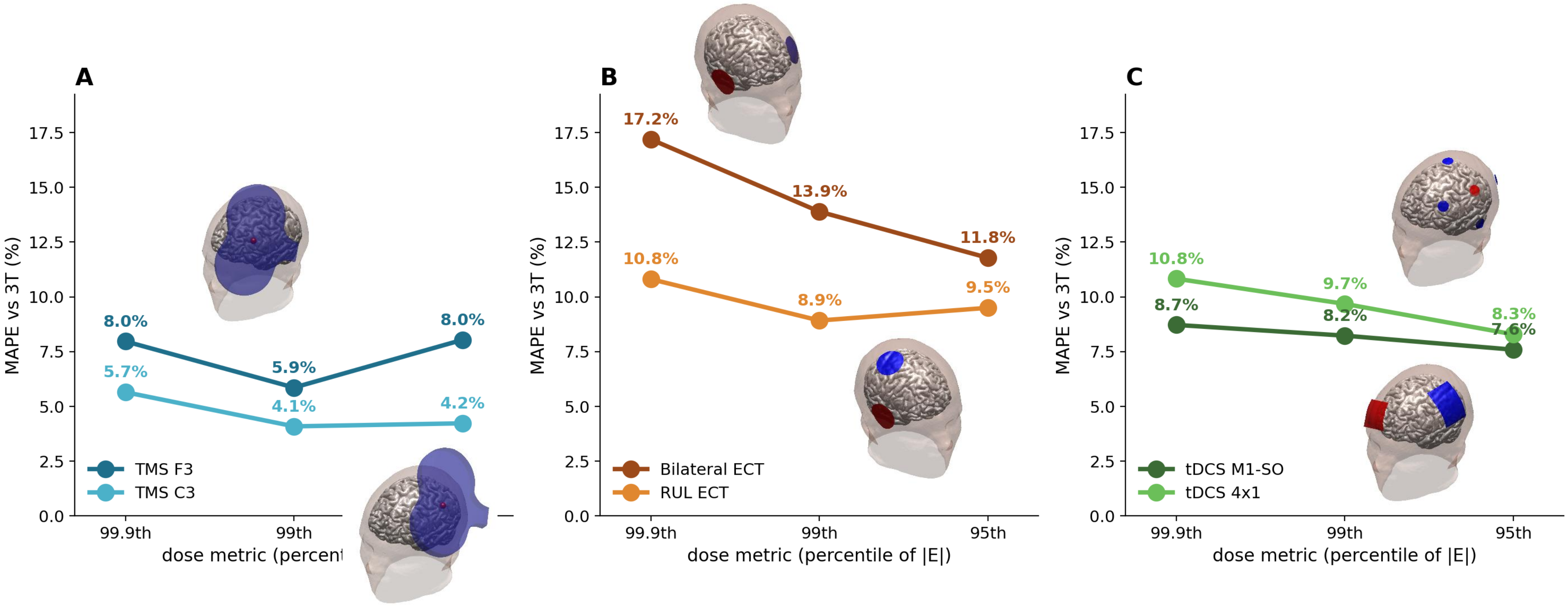
tDCS-4x1
(C3/T7, F3, Cz,
P3, 2 mA)



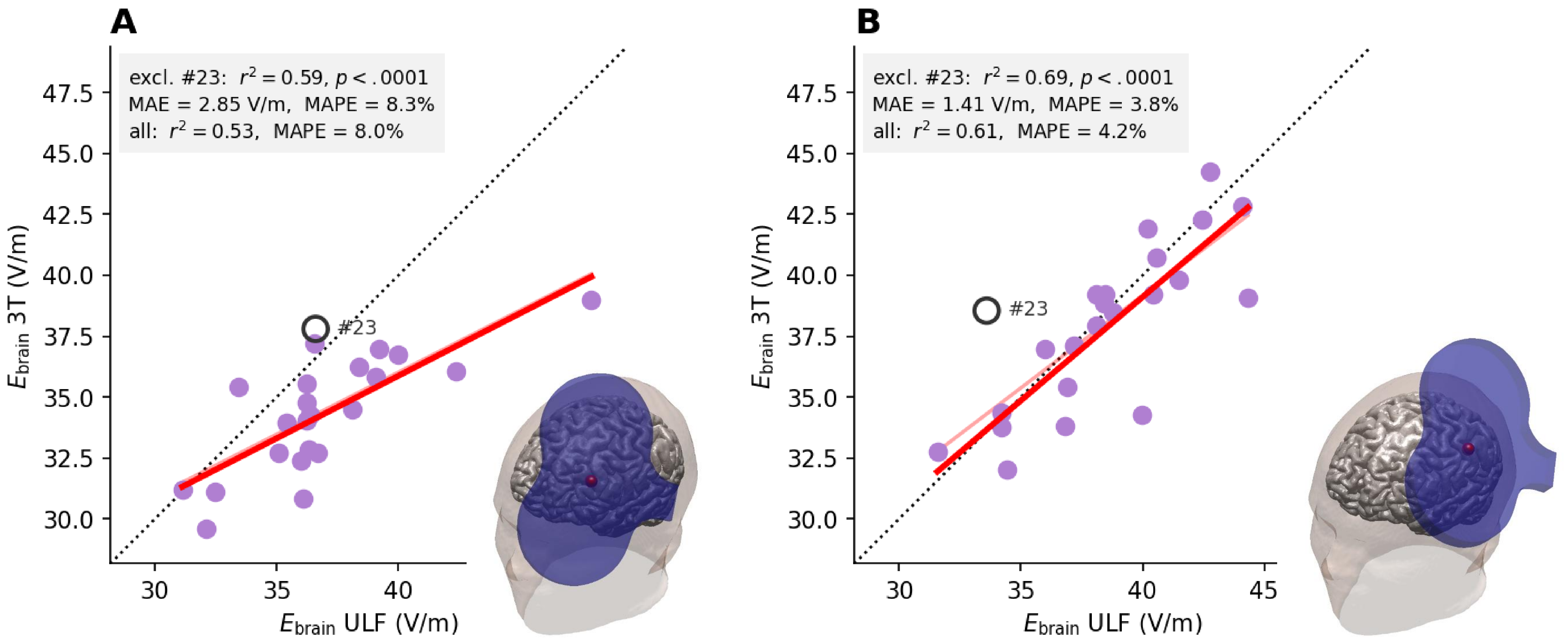
How to compare E-field?



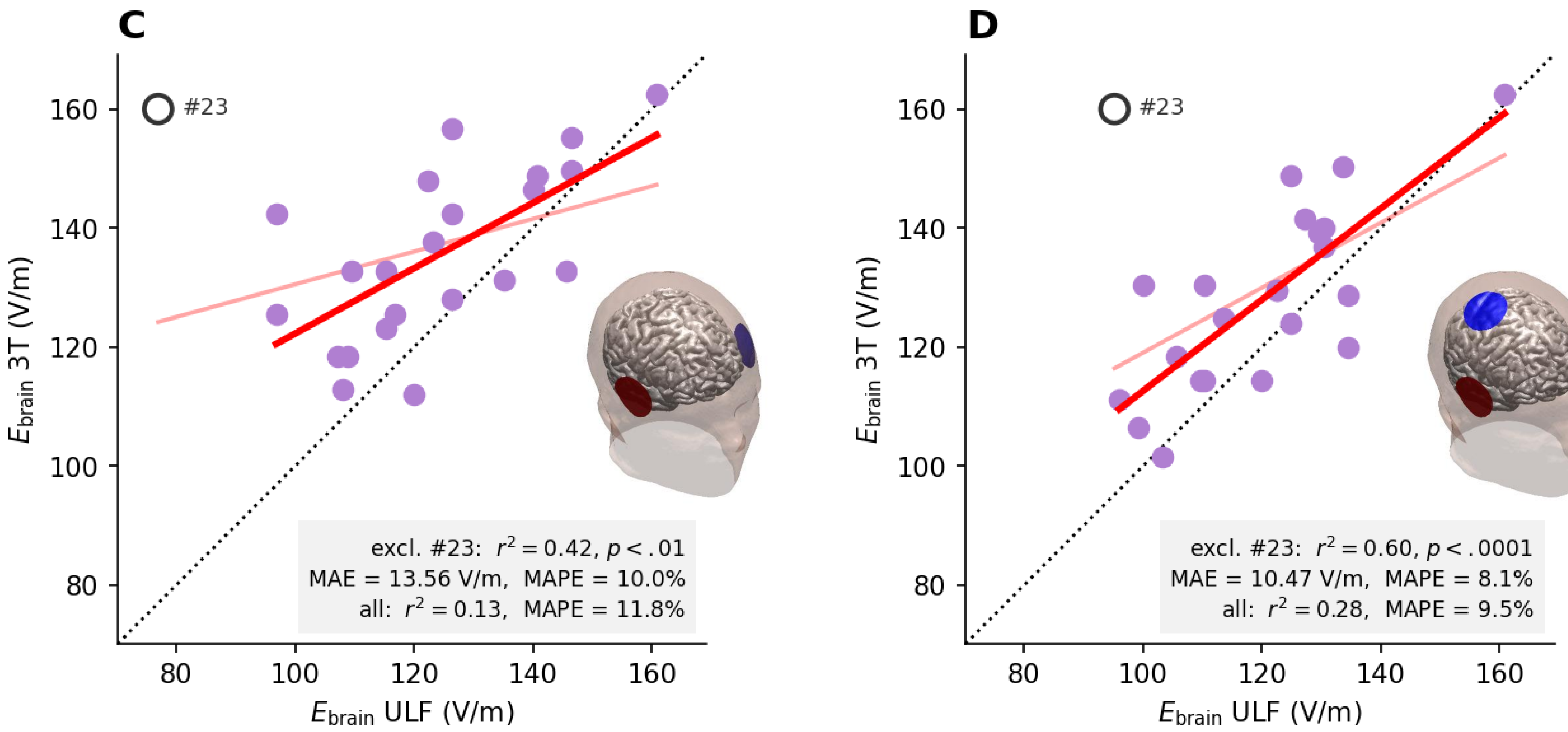
95th or 99th percentile more robust than 99.9



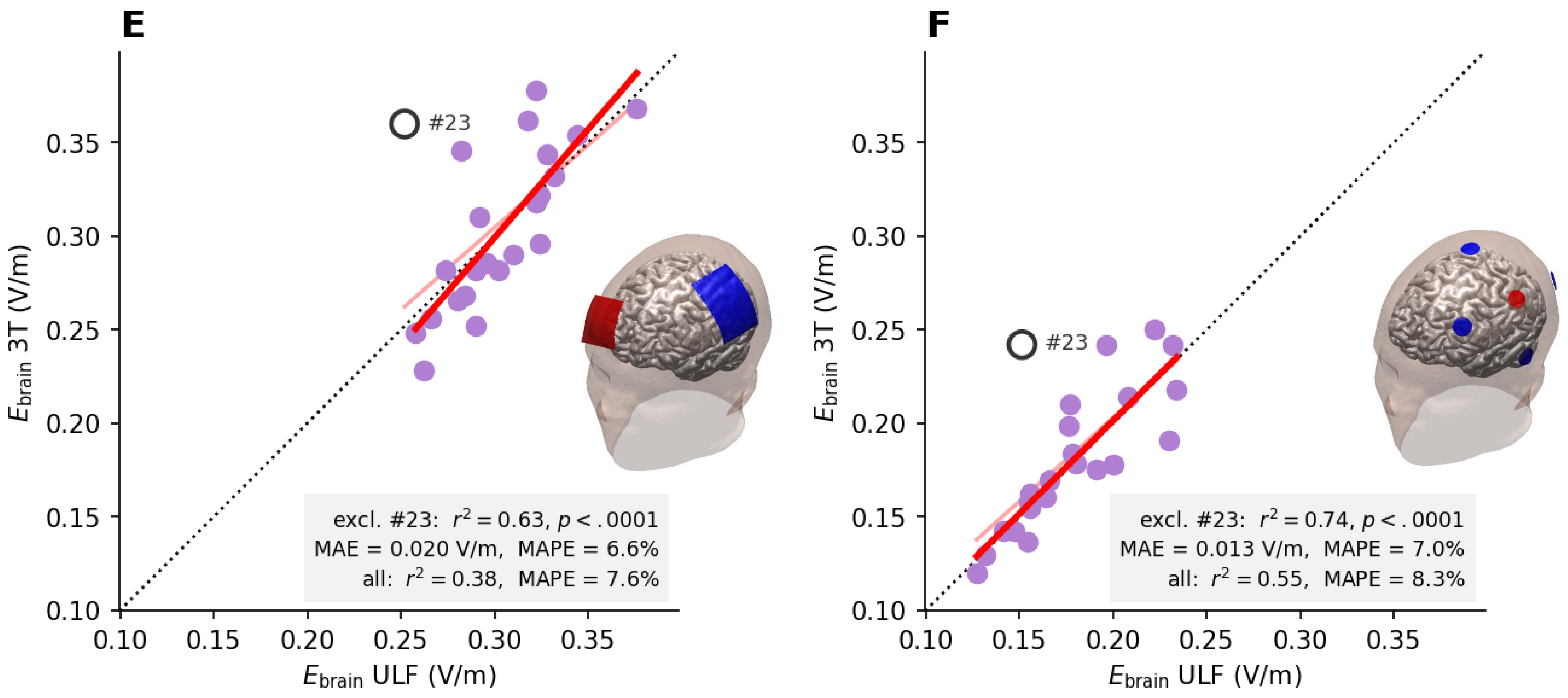
E-field correspondence between ULF and 3T: TMS



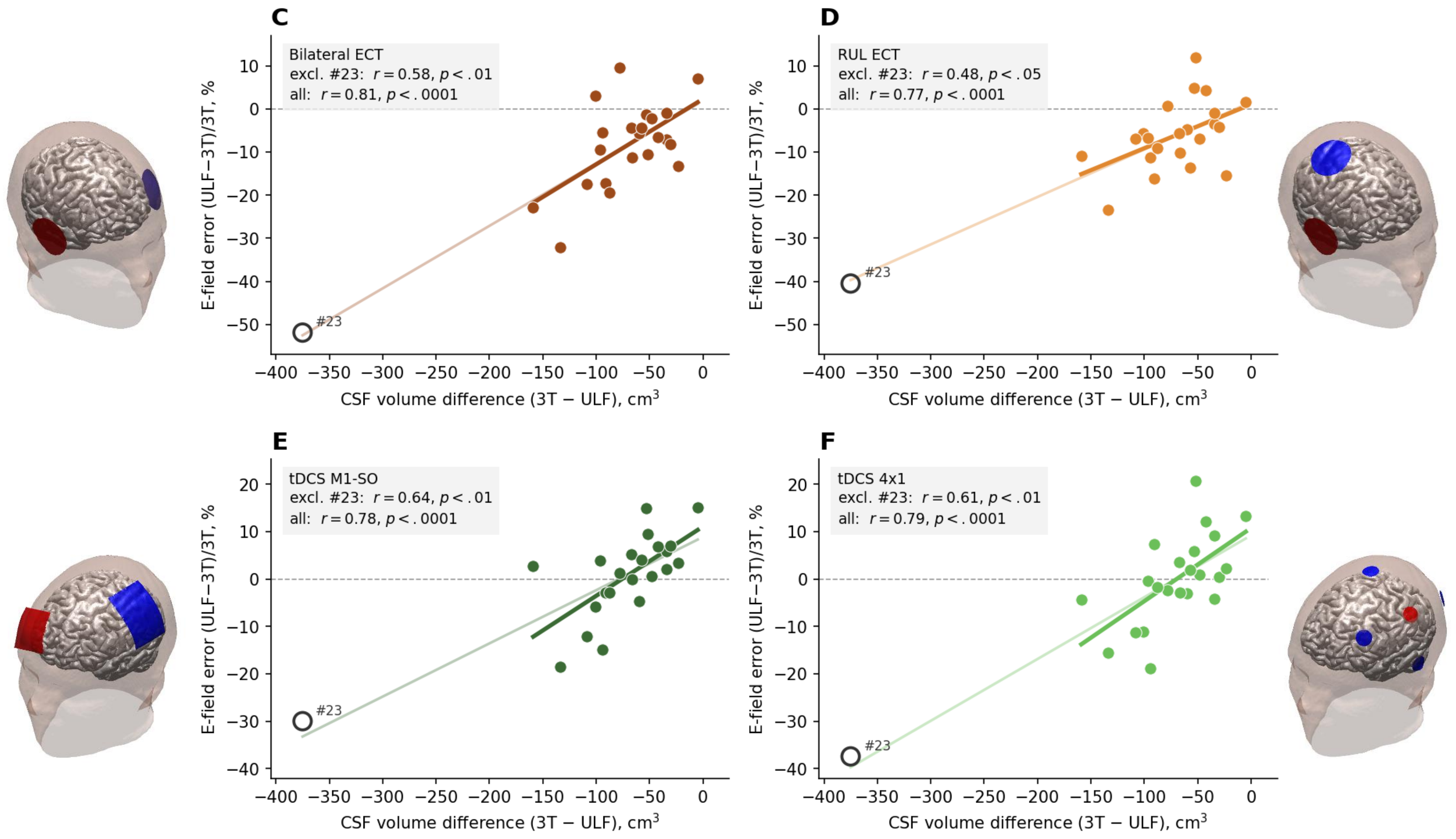
E-field correspondence between ULF and 3T: ECT



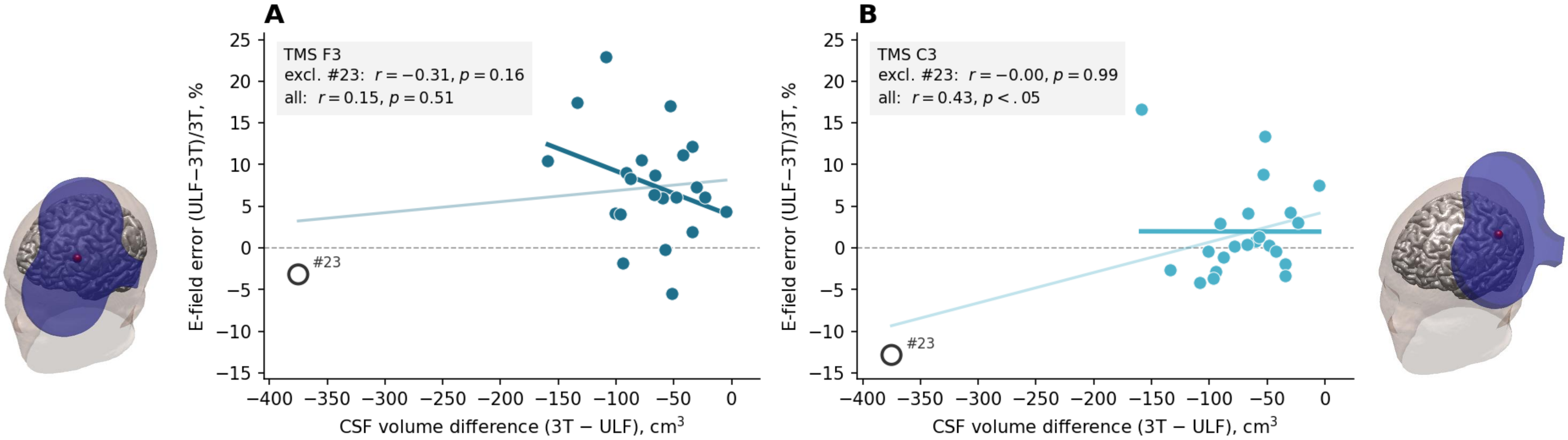
E-field correspondence between ULF and 3T: tDCS

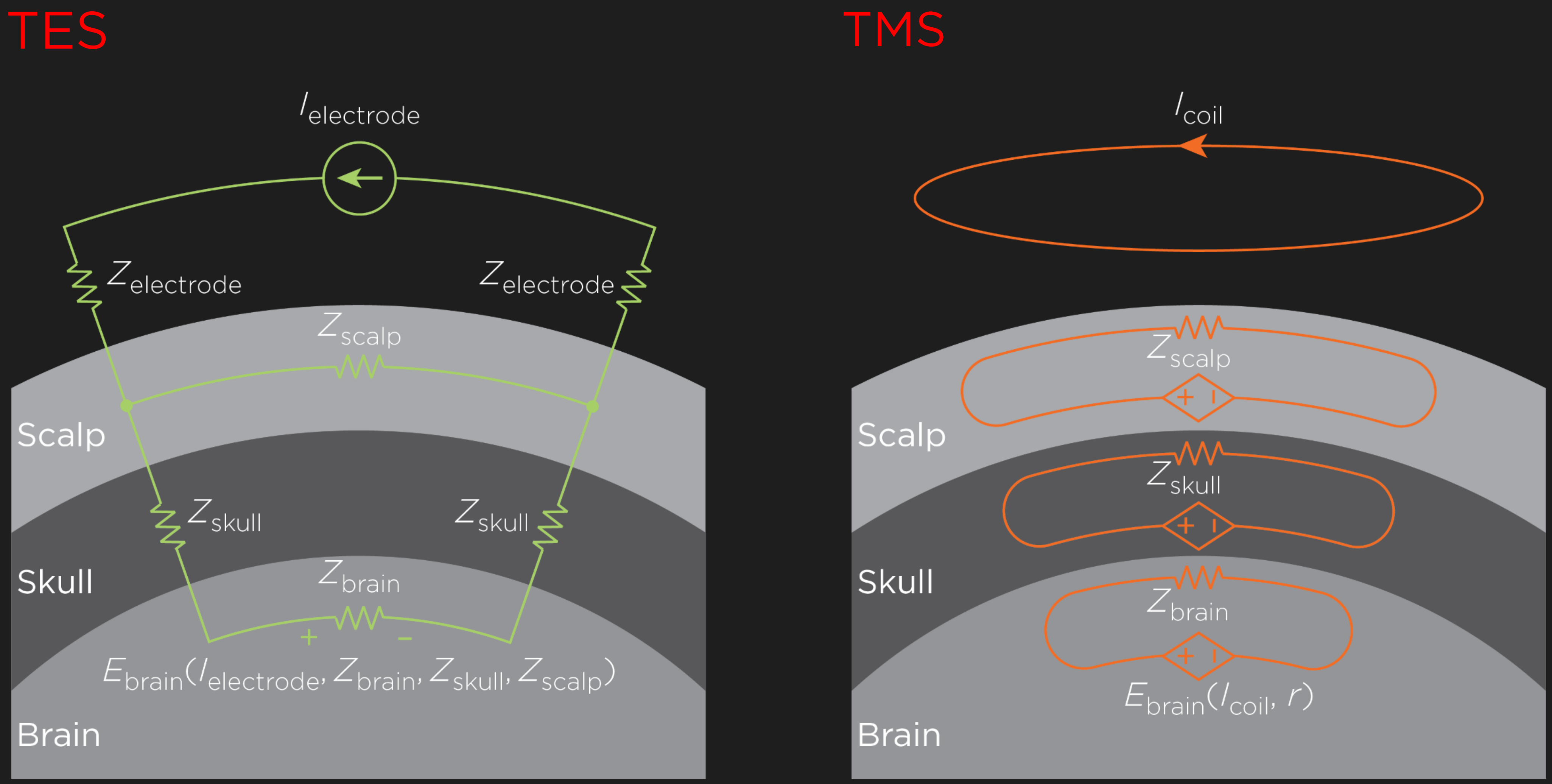


Source of error for TES: CSF oversegmentation



Doesn't affect TMS





TES
TMS
$I_{electrode}$
$Z_{electrode}$
$Z_{electrode}$
Z_{scalp}
Scalp
Z_{skull}
Z_{skull}
Skull
Z_{brain}
+ −
$E_{brain}(I_{electrode}, Z_{brain}, Z_{skull}, Z_{scalp})$
Brain
I_{coil}
Z_{scalp}
Scalp
Z_{skull}
Skull
Z_{brain}
$E_{brain}(I_{coil}, r)$
Brain

Takeaways

- E-field modeling using ULF scans is feasible
  - ULF MRI + super-resolution reconstruction + standard E-field modeling
- Moderate-to-strong agreement with 3T
  - Within 10% error across TMS, ECT, tDCS
- CSF segmentation is a *systematic* source of error for TES
  - Over-segmentation in all subjects, correctable to some degree
- Report a robust dose percentile
  - The 99.9%-tile peak is too unstable

Future work

- Improve CSF segmentation
  - Correction U-Net / SynthSR fine-tuning
- What about fMRI?
  - At 64 mT, BOLD effects are vanishingly small
- Clinical translation
  - Integrate ULF into bedside dose planning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