MGH/HST Athinoula A. Martinos Center for Biomedical Imaging

MASSACHUSETTS GENERAL HOSPITAL

Harvard-MIT Health Sciences & Technology

rLe AT MIT

Boston Children's Hospital
Until every child is well

Improved spiral chemical shift imaging at 3 Tesla using a 32-channel integrated RF-shim coil array

Eren C. Kizildag[1], Jason P. Stockmann[2], Borjan Gagoski[2,3,4], Eva-Maria Ratai[2], Bastien Guerin[2,4], P. Ellen Grant[2,3,4], Lawrence L. Wald[2,4], Elfar Adalsteinsson[1,2]

[1] Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, USA
[2]A. A. Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Charlestown, MA, USA
[3]Boston Children's Hospital, Boston, MA, USA
[4]Harvard Medical School, Boston, MA, USA

INTERNATIONAL SOCIETY FOR ISMRM MAGNETIC RESONANCE IN MEDICINE
ONE COMMUNITY FOR CLINICIANS AND SCIENTISTS
24th Annual Meeting & Exhibition • 07–13 May 2016
SMRT 25th Annual Meeting • 07–08 May
SINGAPORE
www.ismrm.org • www.smrt.org

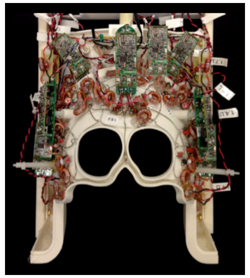
Declaration of Financial Interests or Relationships

Speaker Name: **Eren Kizildag**

I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.

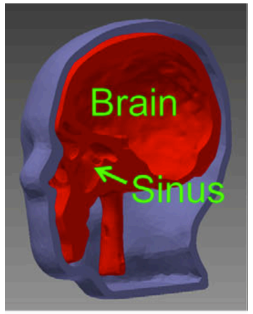
❑ Motivation :

- ❖ Chemical shift imaging and shimming
- ❖ Multi-coil shim array



❑ Experimental methods

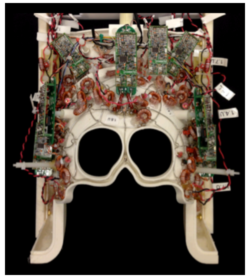
- ❖ Phantom
- ❖ Shimming
- ❖ Acquisition



❑ Results

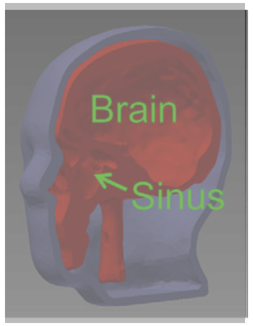
❑ Motivation :

- Chemical shift imaging and shimming
- Multi-coil shim array



❑ Experimental methods

- Phantom
- Shimming
- Acquisition

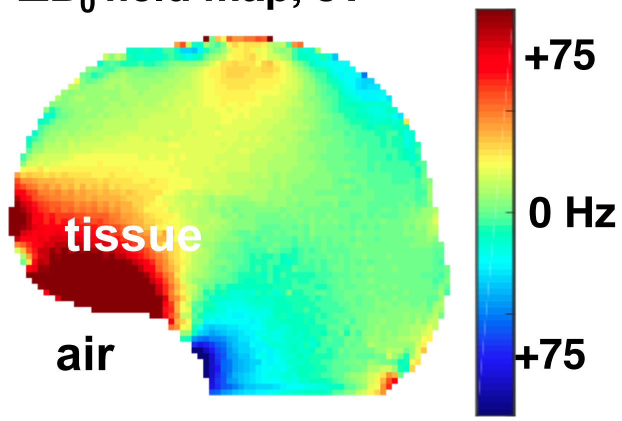


❑ Results

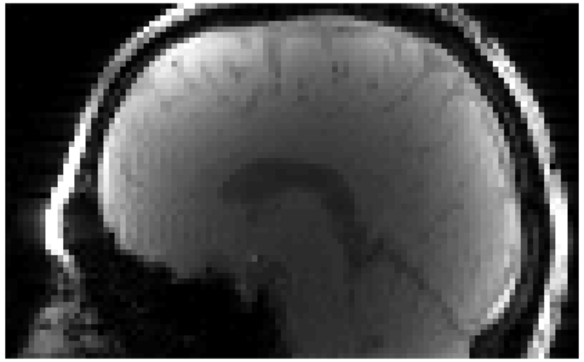
Motivation : Chemical Shift Imaging

- *In vivo* chemical shift imaging (CSI)
  - Enables to study brain metabolites
- Good B_0 shimming is critical
  - Linewidth
  - Chemical shift
  - Water and lipid suppression

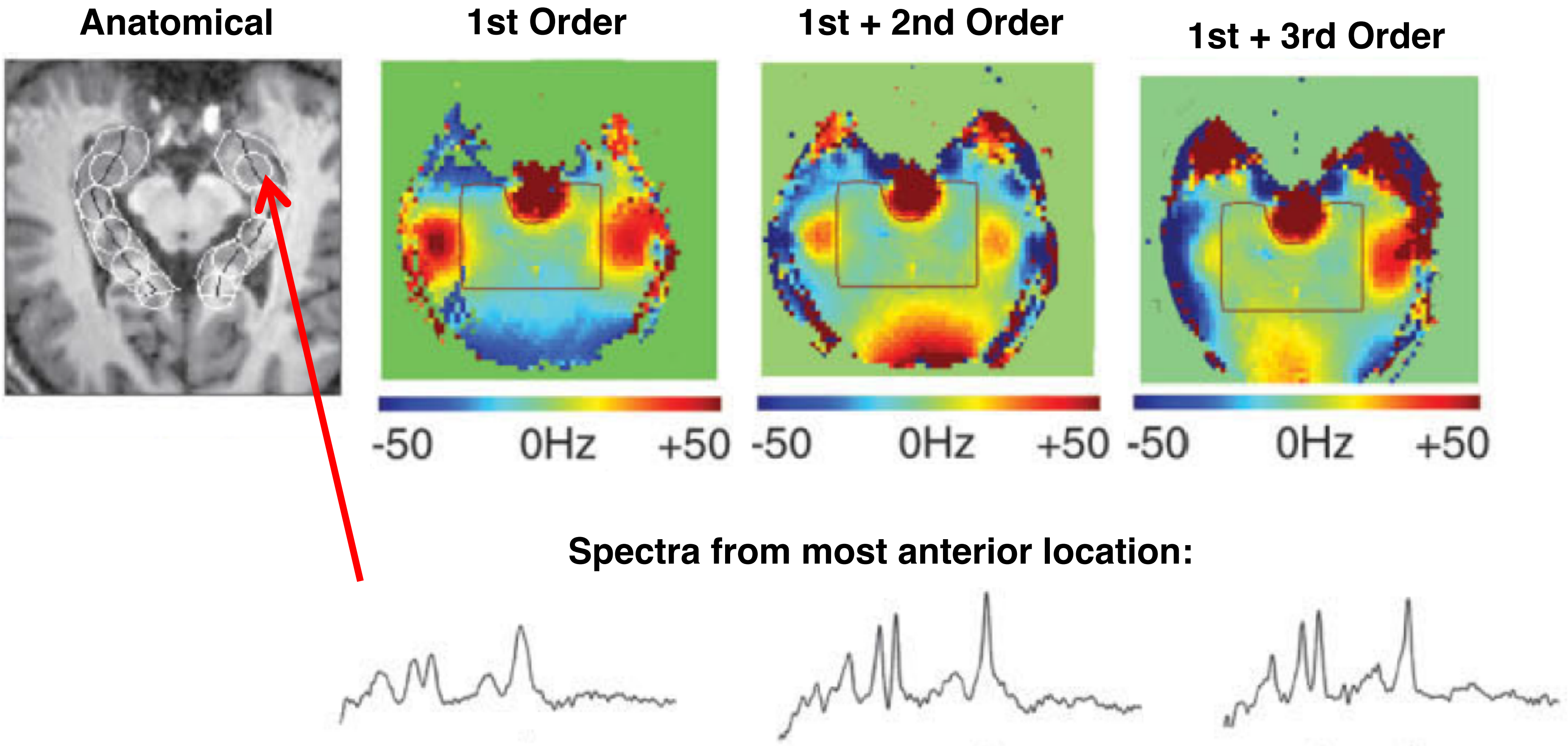
ΔB_0 field map, 3T



Anatomical Reference



Motivation : Shimming in Chemical Shift Imaging



Hetherington et al., MRM (2006)

Motivation : Multi-coil (MC) Shim Array

- Drawbacks of higher-order spherical harmonics

→ *Pan JW, MRM 68:1007–1017 (2012)*

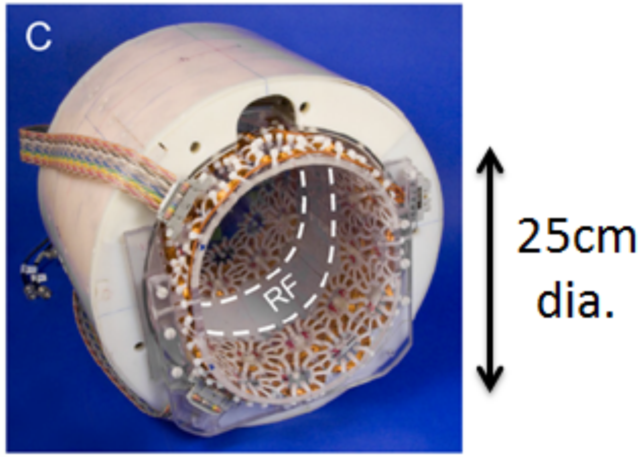
- *High inductance*
- *Eddy currents in cryostat; need pre-emphasis for dynamic shimming*
- *Lower efficiency at higher orders*
- *Expensive shim current drivers*

Source: Resonance Research, Inc.
http://www.rricorp.com

- Multi-coil shim arrays

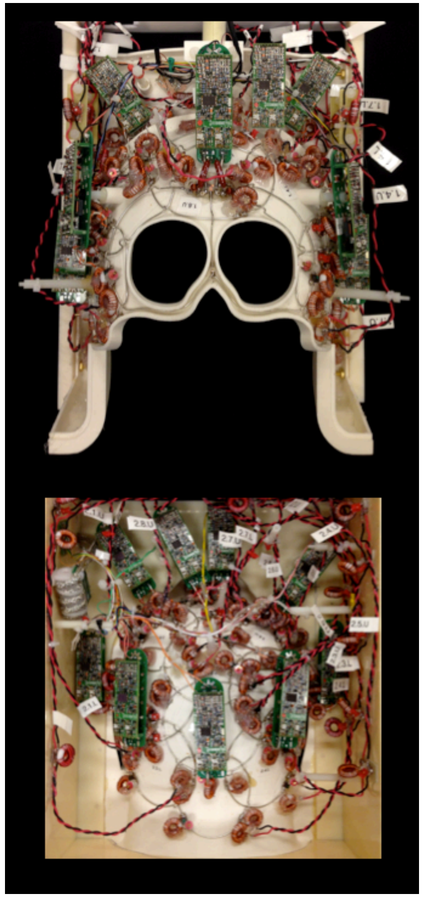
→ *Juchem C, JMR 212:280–288 (2011)*

- *Low inductance*
- *More efficient at generating higher-order fields*
- *Low-cost shim current supplies*
- *Little coupling to cryostat or gradient coils; no need for pre-emphasis*



Source: Juchem C, JMR 2011

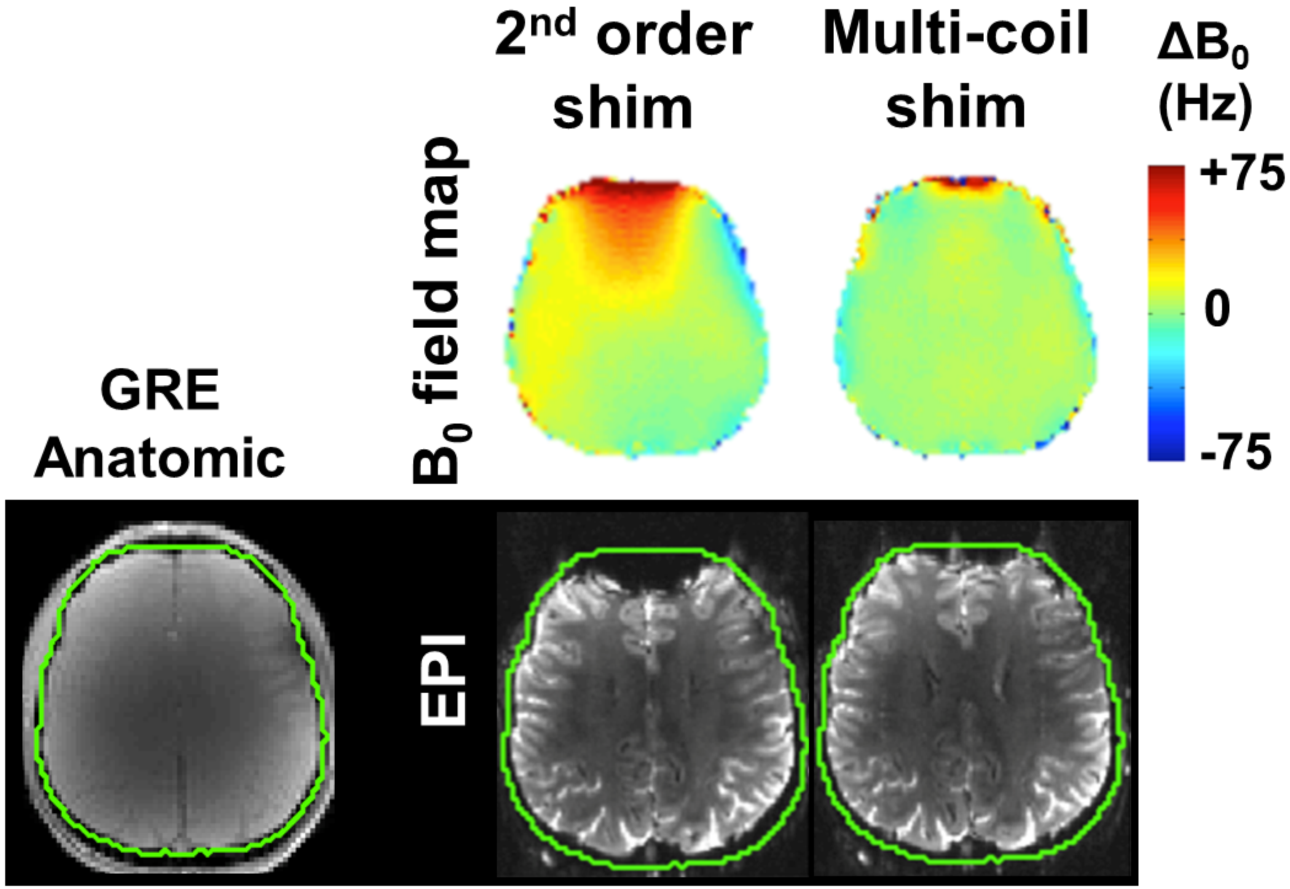
Integrated Multi-coil (MC) Shim Array



A 32-channel integrated RF-shim coil uses the same close-fitting array of loops for RF signal detection and B_0 shimming

Stockmann et al., MRM (2014)

- 32-channel, integrated RF-shim coil array
- Performances of both systems maintained

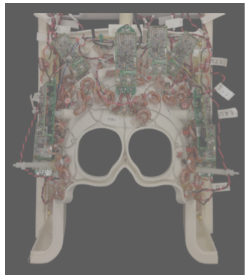


Reduced geometric distortion in EPI scans (1mm in-plane, 1.11ms echo spacing, GRAPPA R=1)

Outline

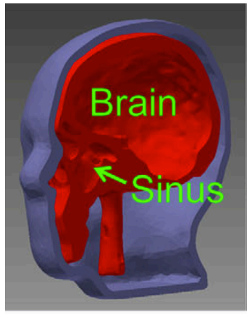
Motivation :

- Chemical shift imaging and shimming
- Multi-coil shim array



Experimental details

- Phantom
- Shimming
- Acquisition



Results

Experimental Details : Phantom

- *Realistic head phantom*

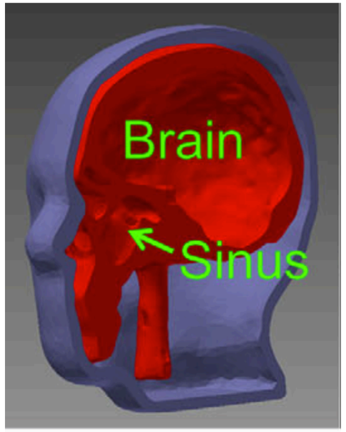
  → *Guerin et al., MRM 2015*

  - Brain compartment filled with *'Braino'* solution
    - NAA
    - Cr
    - Cho
    - Glutamate
    - GABA
    - Myo-inocitol

  - 5x typical *in vivo* concentration

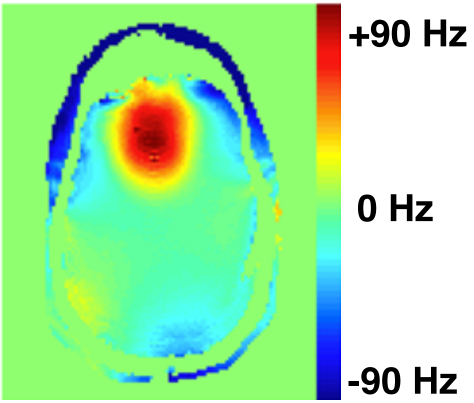
  - Realistic ΔB_0 patterns observed in frontal lobes *in vivo*

  - 3D models available at phantoms.martinos.org



Phantom : 3D-printed, antropomorphic head phantom

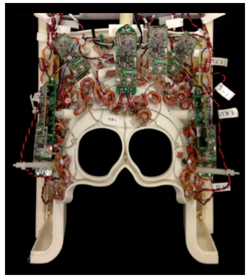
B_0 field map, 3T



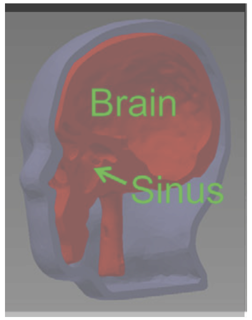
GRE experiment : axial B_0 field map, indicates indeed realistic frontal lobe B_0 profile

Outline

- Motivation :
  - Chemical shift imaging and shimming
  - Multi-coil shim array



- Experimental details
  - Phantom
  - Shimming
  - Acquisition



- Results

Experimental Details : Shimming

- Optimal currents computed by solving

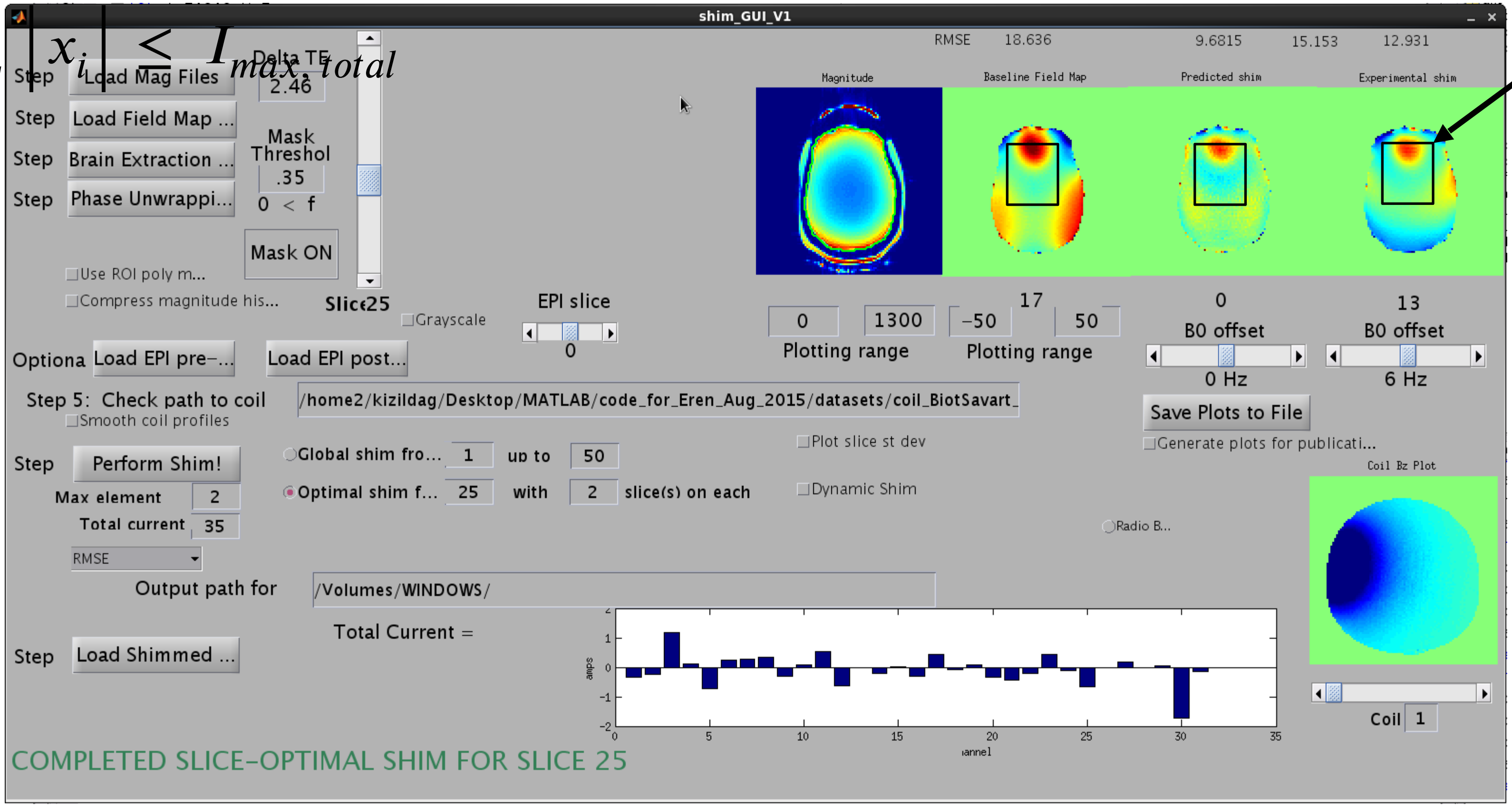
$$\min_x \left\| B_0 - Ax \right\|_2^2$$

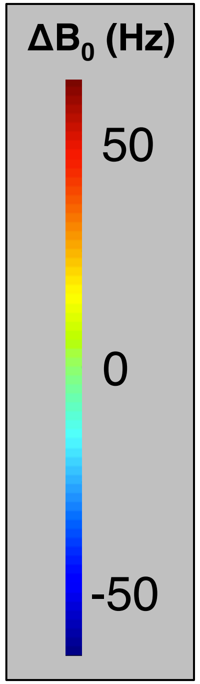
$$s.t \quad |x_i| \le I_{max,loop}$$

$$\sum_i |x_i| \le I_{max,total}$$

B_0 : Baseline profile
A : Basis set, corresponding to 1A/coil
$I_{max,loop}$: Maximum current per loop (2.5A)
$I_{max,total}$: Total current in the array (35A)
x : Unknown currents to be solved

Excitation volume

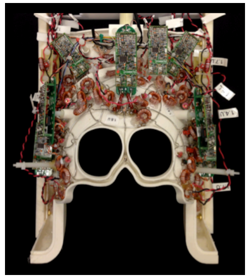




Outline

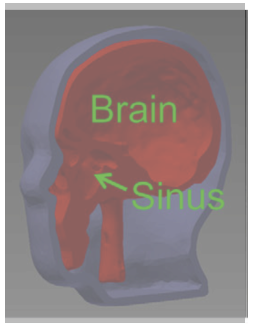
❑ Motivation :

- Chemical shift imaging and shimming
- Multi-coil shim array



❑ Experimental details

- Phantom
- Shimming
- Acquisition
  - ✓ Conventional Cartesian CSI



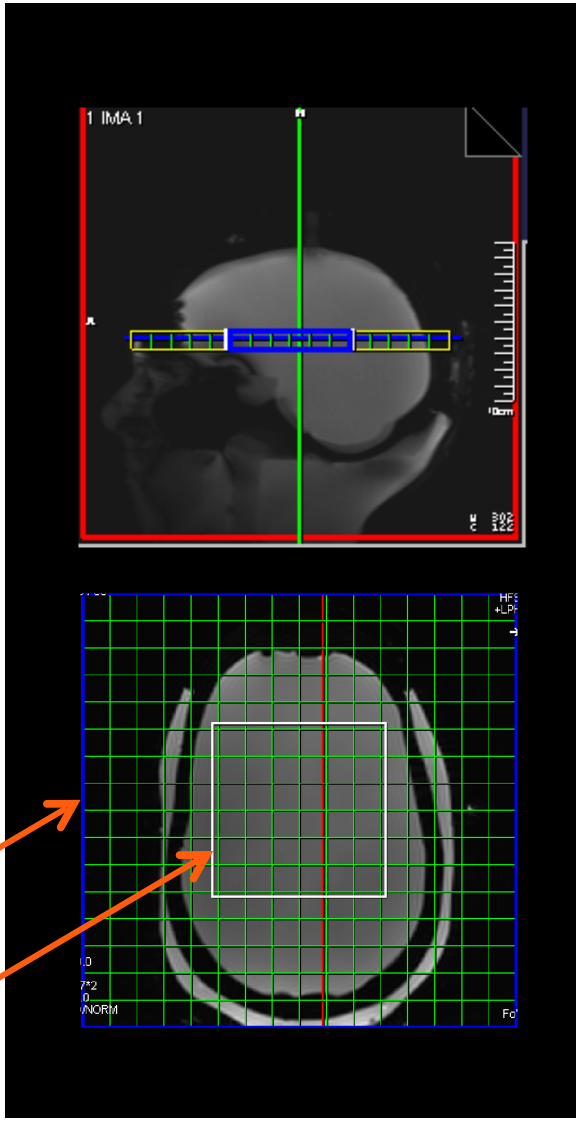
❑ Results

- Conventional Cartesian CSI

Acquisition – Cartesian CSI

- Details (**CSI Acquisition**)
  - **TR/TE :** 1400ms/144ms
  - **TA :** 03:30
  - **Voxel :** [12.5x12.5x12]mm **(2cc)**
  - **VOI :** [80x80]mm

- **Acquisition Parameters (GRE):**
  - **Resolution:**
    - **In-plane :** 2.4mm ([240x240]mm over 100x100 matrix size)
    - **Slice :** 2mm
  - **Duration :** ~2 minutes

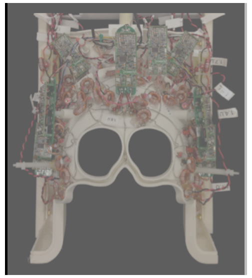


Spatially encoded volume

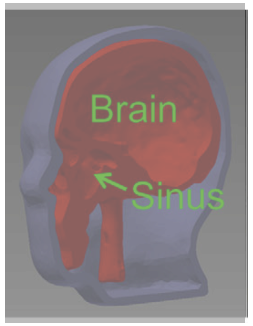
LASER-excited volume

Outline

- Motivation :
  - Chemical shift imaging and shimming
  - Multi-coil shim array



- Experimental details
  - Phantom
  - Shimming
  - Acquisition
    - ✓ Conventional Cartesian CSI



- Results
  - Conventional Cartesian CSI

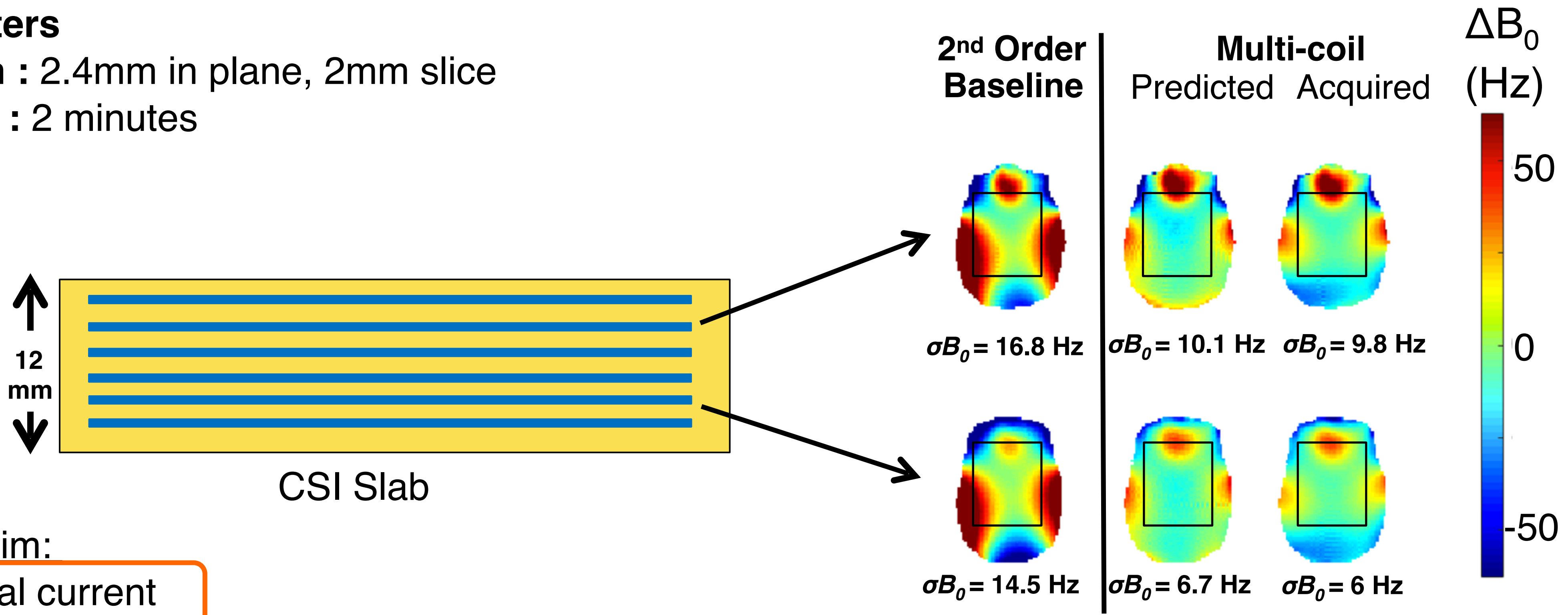
Methodology – Performance Metrics

- Quantification metrics :
  - Spectral quality
    - **FWHM**
  - Extracted from scanner
  - Shim quality
    - Field maps, before and after
    - $\sigma_{B_0}^{GLOBAL}$
      - Standard deviation of field map, over whole VOI
    - $\sigma_{B_0}^{LOCAL}$
      - Standard deviation of field map within each CSI voxel

Results – Field Maps

GRE parameters

- **Resolution :** 2.4mm in plane, 2mm slice
- **Duration :** 2 minutes
- **3T**



Prescribed Shim:

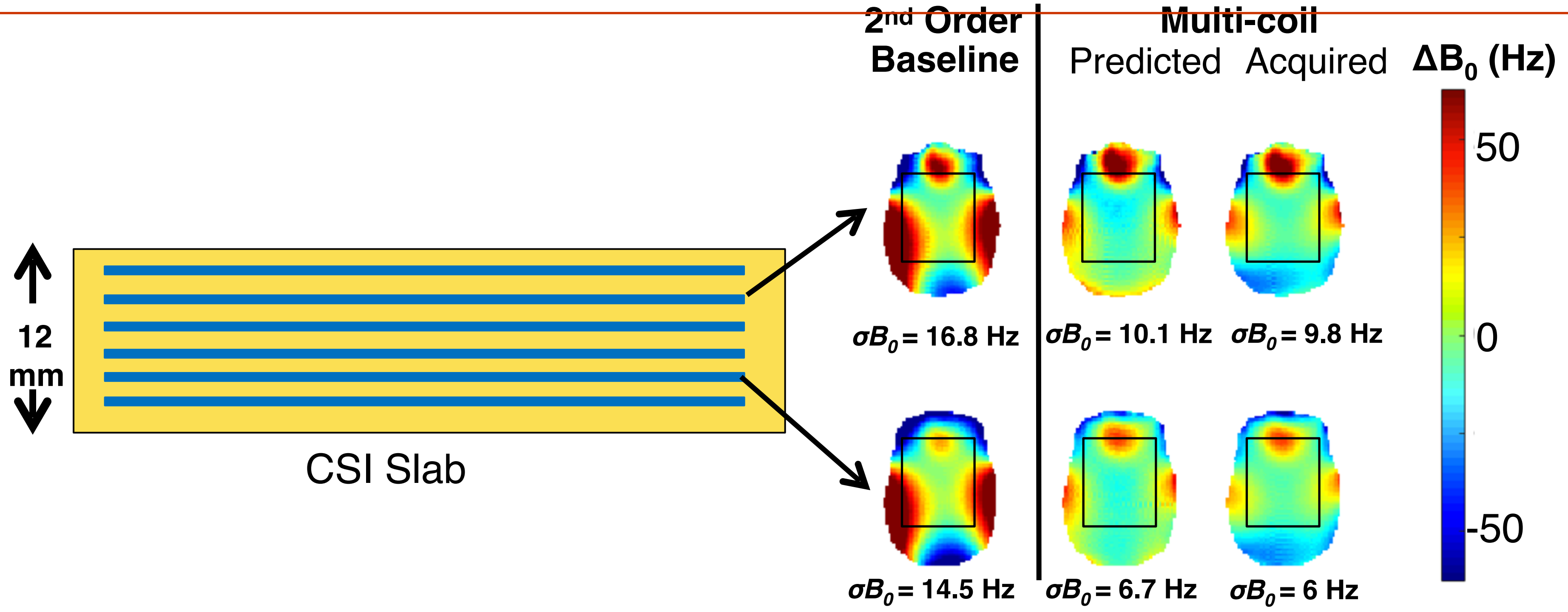
- **~14A** of total current

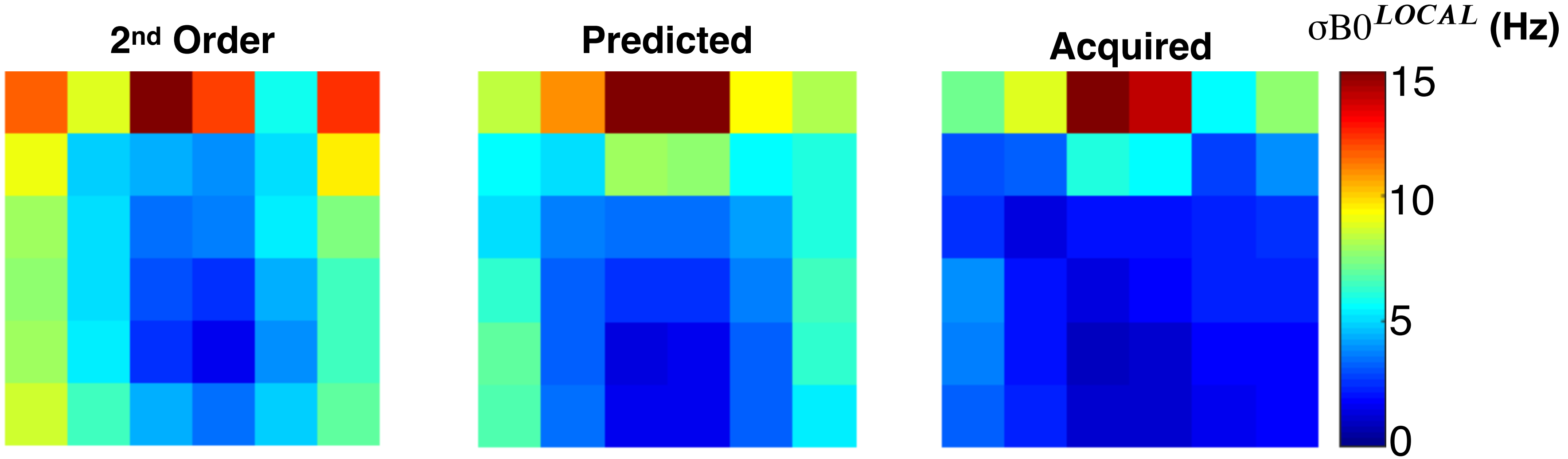
- LOCAL shim
  - Adjacent slices
  - Seperated by 2mm
  - Overall thickness : 12mm

$\sigma B0^{OVERALL\ SLAB}$

2nd Order Baseline	Multi-coil Predicted	Multi-coil Acquired
15.8 Hz	8.8 Hz	8 Hz

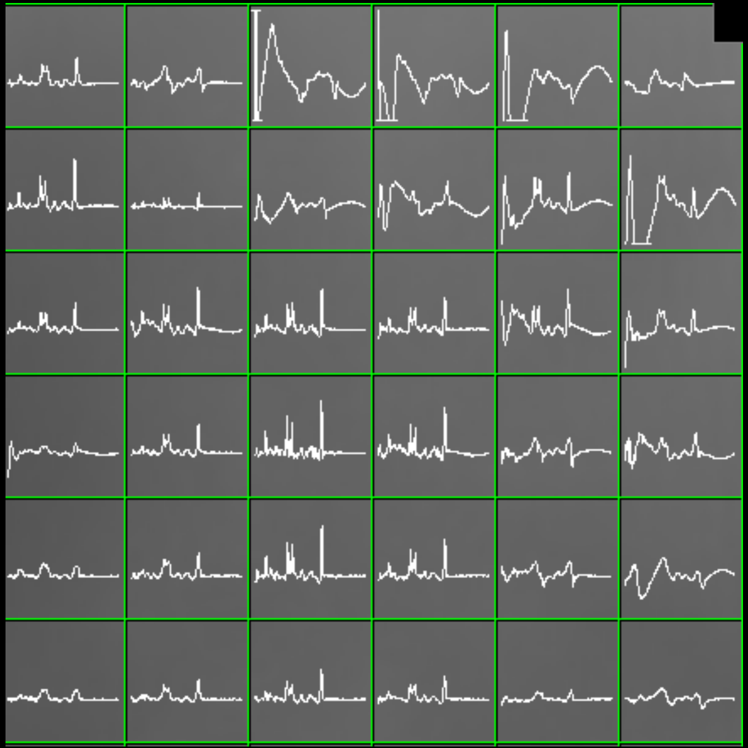
Results – Field Maps – $\sigma B0^{GLOBAL}$ and $\sigma B0^{LOCAL}$



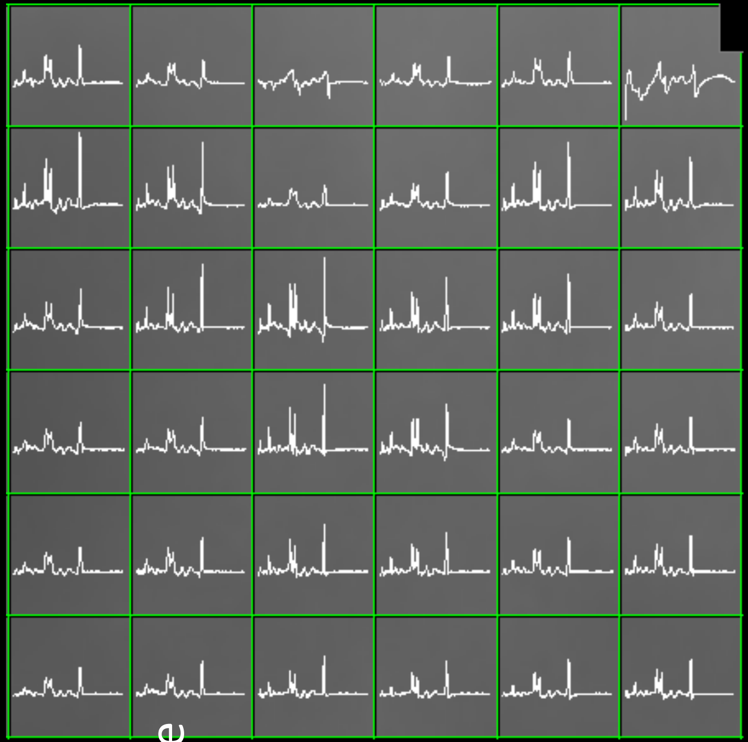


Results – Cartesian CSI – Phased Spectra

2nd Order

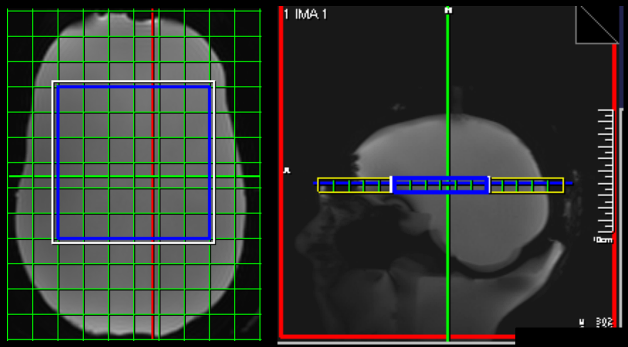


Shim Array

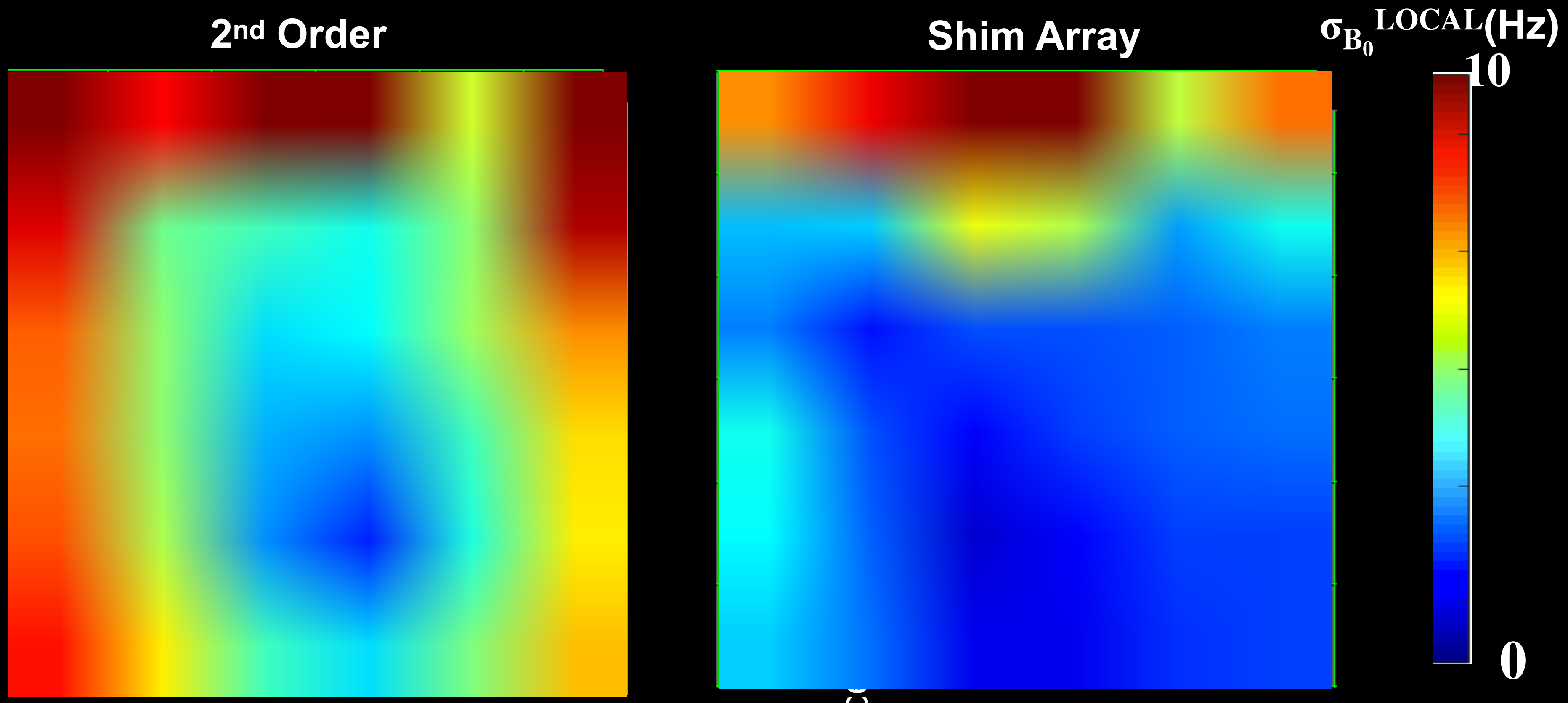


- Parameters :
  - **TR/TE:** 1400ms/144ms
  - **TA** : 03:30
  - **Voxel Size :** 2cc
  - 2D

Geometric reference

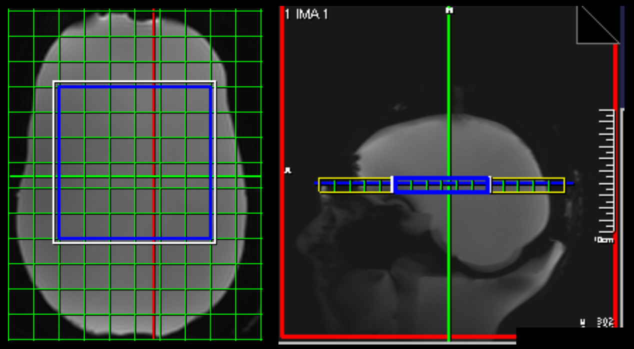


Results – Cartesian CSI – Phased Spectra



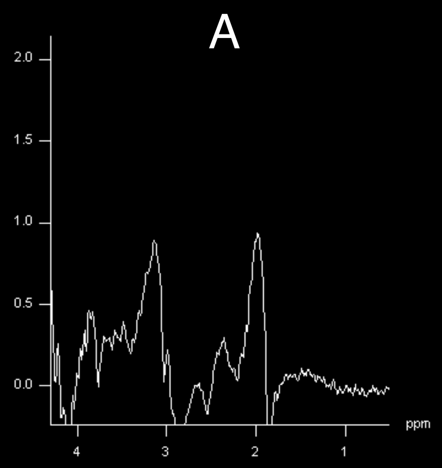
- Parameters :
  - **TR/TE:** 1400ms/144ms
  - **TA** : 03:30
  - **Voxel Size :** 2cc
  - 2D

Geometric referenc

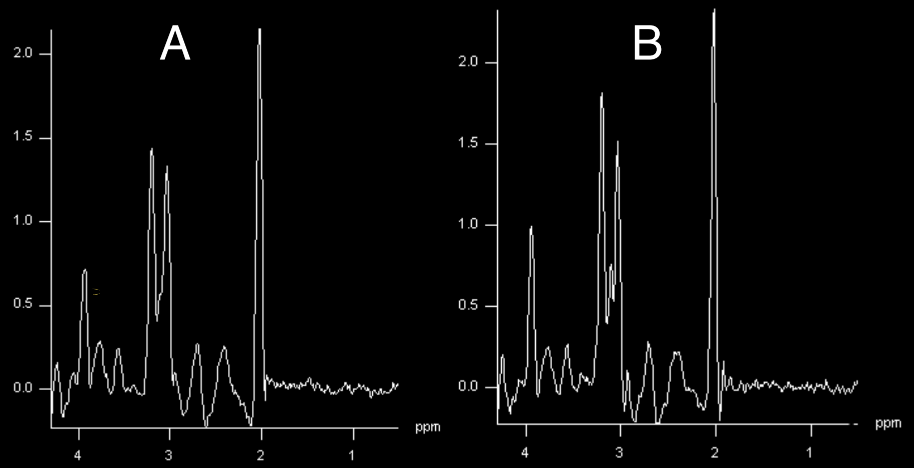


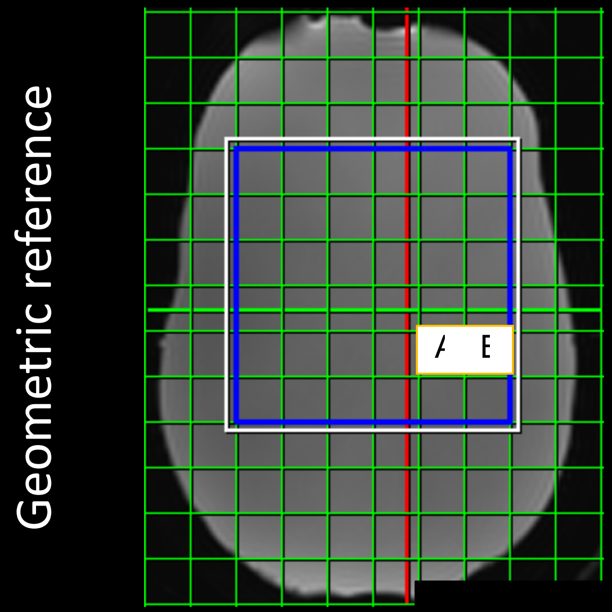
Results – Cartesian CSI – Phased Spectra

2^{nd} Order



Shim Array

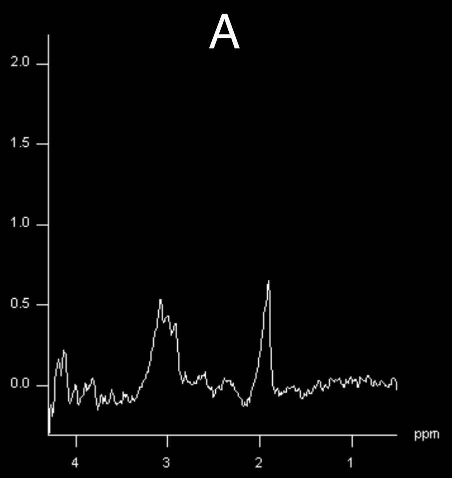




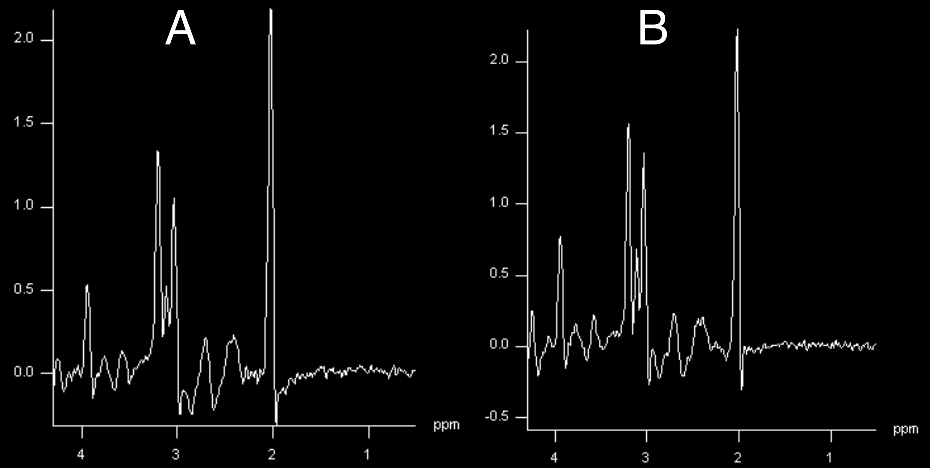
- Parameters :
  - **TR/TE:** 1400ms/144ms
  - **TA** : 03:30
  - **Voxel Size :** 2cc
  - 2D

Results – Cartesian CSI – Phased Spectra

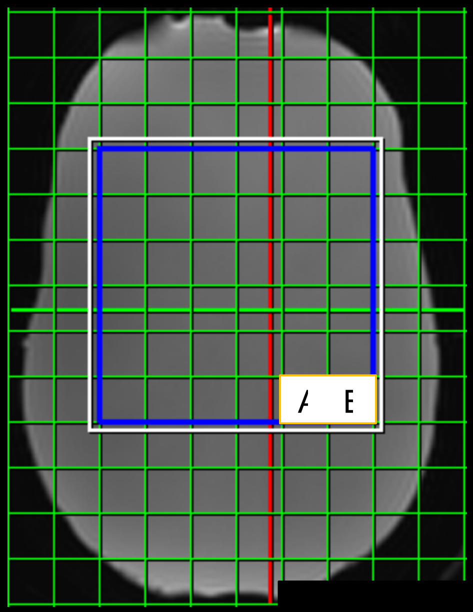
2nd Order



Shim Array



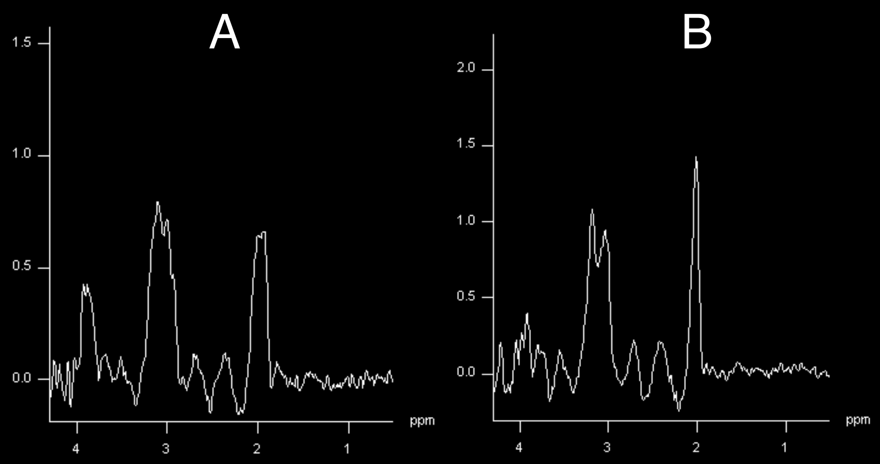
Geometric reference



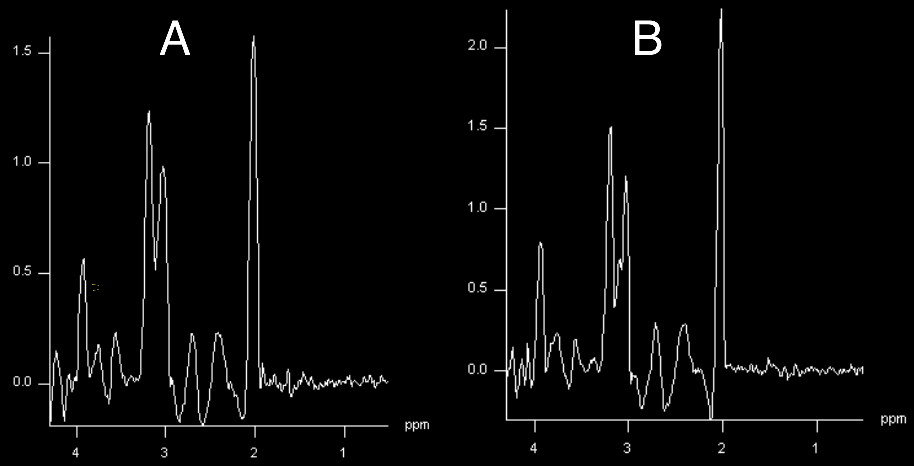
- Parameters :
  - **TR/TE:** 1400ms/144ms
  - **TA** : 03:30
  - **Voxel Size :** 2cc
  - 2D

Results – Cartesian CSI – Phased Spectra

2nd Order

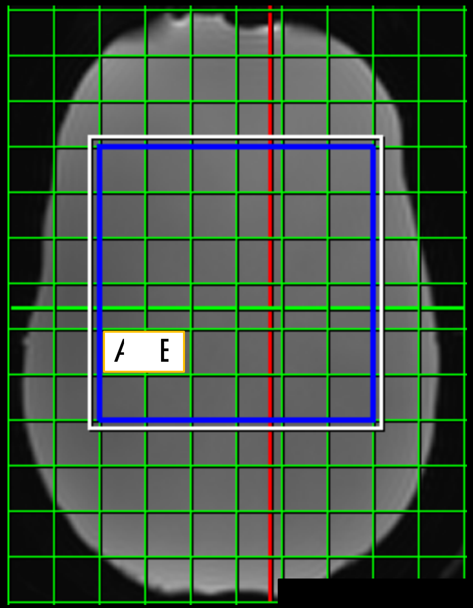


Shim Array



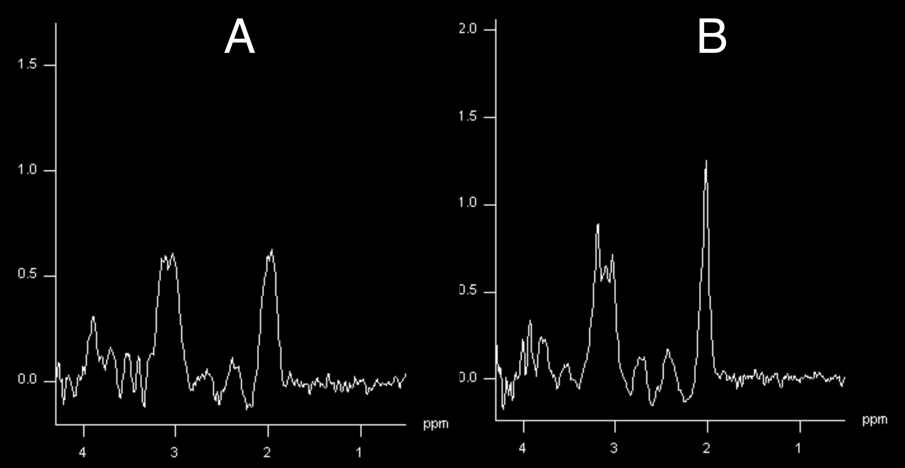
- Parameters :
  - **TR/TE:** 1400ms/144ms
  - **TA** : 03:30
  - **Voxel Size :** 2cc
  - 2D

Geometric reference

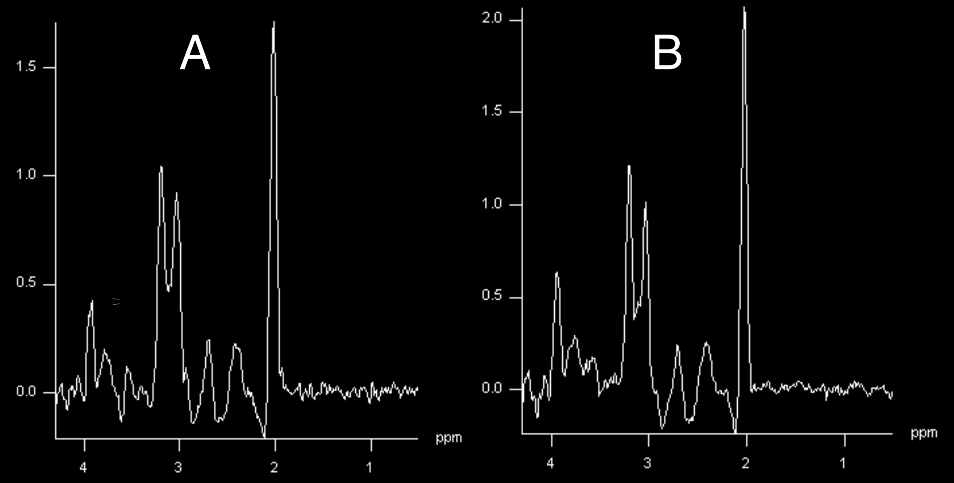


Results – Cartesian CSI – Phased Spectra

2nd Order

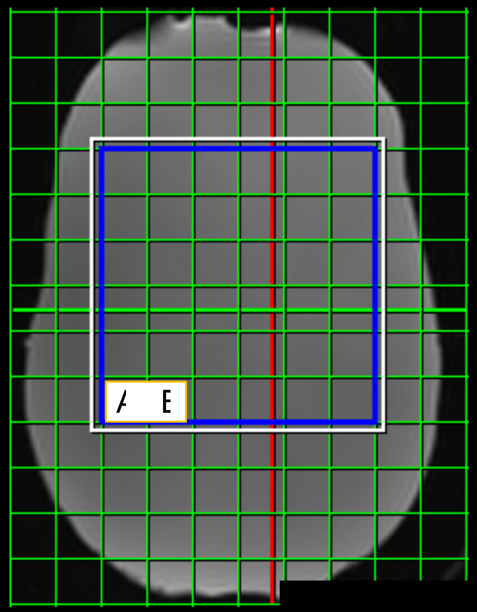


Shim Array



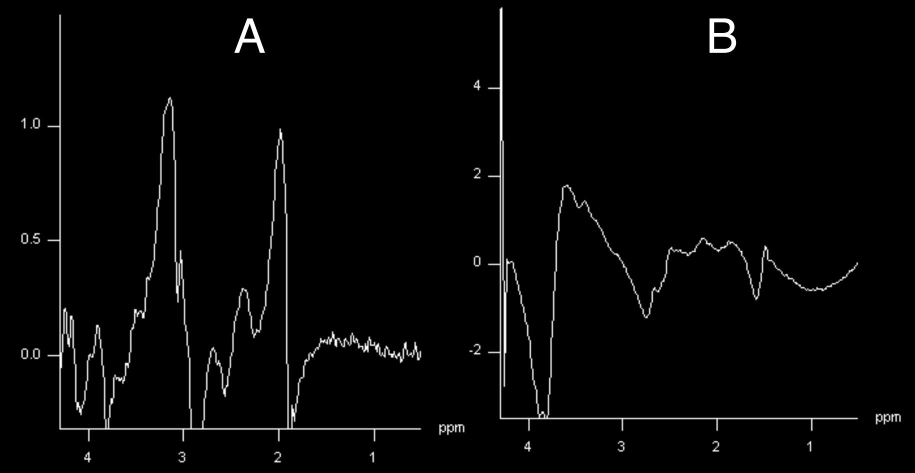
- Parameters :
  - **TR/TE:** 1400ms/144ms
  - **TA** : 03:30
  - **Voxel Size :** 2cc
  - 2D

Geometric reference

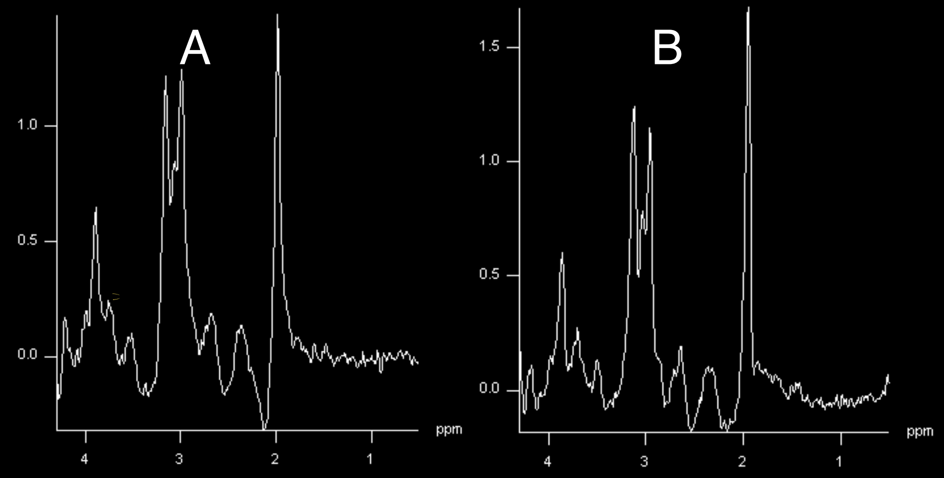


Results – Cartesian CSI – Phased Spectra

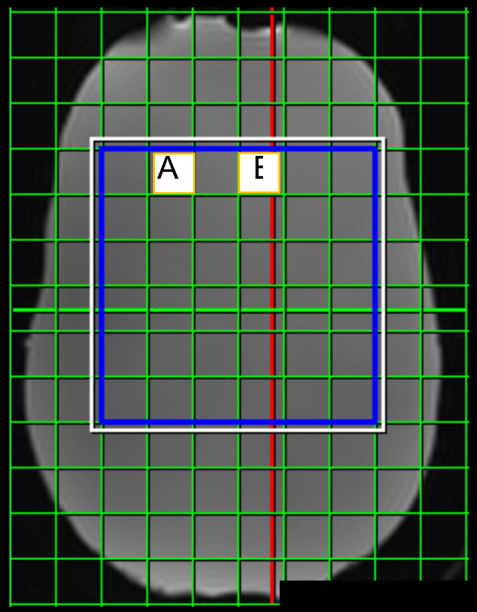
2nd Order



Shim Array



Geometric reference



- Parameters :
  - **TR/TE:** 1400ms/144ms
  - **TA** : 03:30
  - **Voxel Size :** 2cc
  - 2D

Results

- ❑ Improved spectral quality as judged by linewidths via MC shimming
  - ❖ 27% average linewidth narrowing

- ❑ Better water saturation via MC shimming

- ❑ Reduction in σB_0^{GLOBAL} as seen in field maps
  - ❖ 50% in overall CSI slab
  - ❖ Similar improvements per CSI slice

- ❑ Good agreement between predicted and acquired field maps

Acknowledgements and Related Talks

- We thank Trina Kok ( ) for help preparing brain metabolite solution

- Jon Polimeni ( ) for sharing his image acquisition and analysis scripts.

- This works is supported under
  - NIH R21 EB017338
  - P41 EB015896
  - BRP NIH R01EB017337

Related Talks:

- **#1010** – R. Umesh – Multi-Dimensional Reduced Field-Of-View Excitation by Integrated RF Pulse and DYNAMITE B0 Field Design
- **#1151** – W. Mattar – Multi-Coil B0 Shimming of the Human Heart: A Theoretical Assessment
- **#1152** – I. Zivkovic – B0 Shimming at 9.4T Using a Multicoil Approach – Coil Design with Genetic Algorithm
- **#1153** – J. Stockmann – Improving the Efficiency of Integrated RF-Shim Arrays Using Hybrid Coil Designs and Channel Placement and Compression Via a Genetic Algorithm
- **#1154** – G. Germain – Optimization of Geometry for Combined RF/shim Coil Arrays for the Spinal Cord
- **#1157** – N. Arango – Open-Source, Low-Cost, Flexible, Current Feedback-Controlled Driver Circuit for Local B0 Shim Coils and Other Applications
- **#2198** – M. Jayatilake – STEREO-MC for Connected Spatiotemporal Excitation