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High-Resolution Multishot Diffusion-Weighted Body and Breast MRI using Locally Low-rank regularization

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Declaration of Financial Interests or Relationships

Speaker Name: Yuxin Hu

I have the following financial interest or relationship to disclose with regard to the subject matter of this presentation:

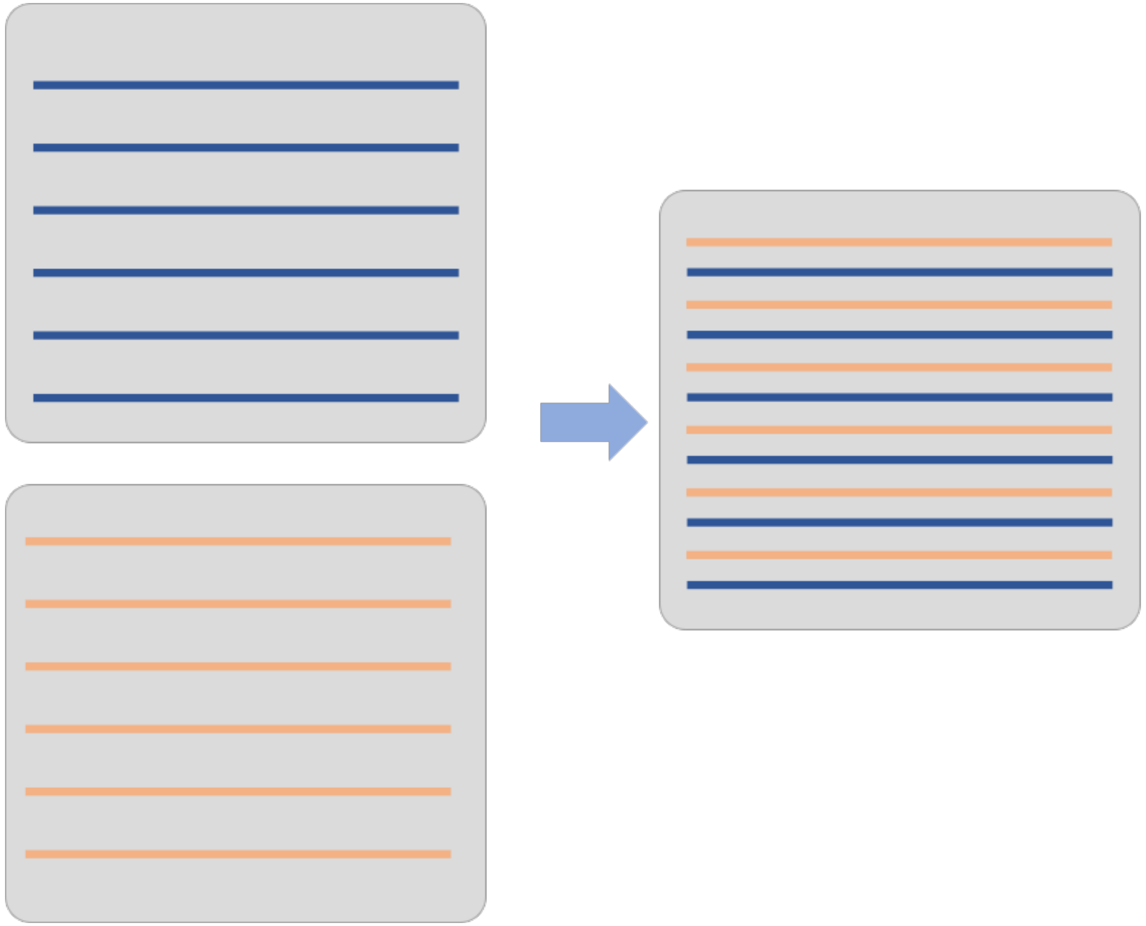
Company Name: GE Healthcare
Type of Relationship: Research Support

Diffusion-weighted imaging

- DWI is sensitive to **molecular motion** and **bulk motion**.
- DWI: $I(x, y)e^{-b\mathbf{D}(x,y)}e^{-i\boldsymbol{\theta}(x,y)}$
- Spatially smooth phase $e^{-i\boldsymbol{\theta}(x,y)}$ after diffusion encoding
    - Random: because bulk motion is **different** during each application of the diffusion encoding gradients (multi-shot, multi-nex).

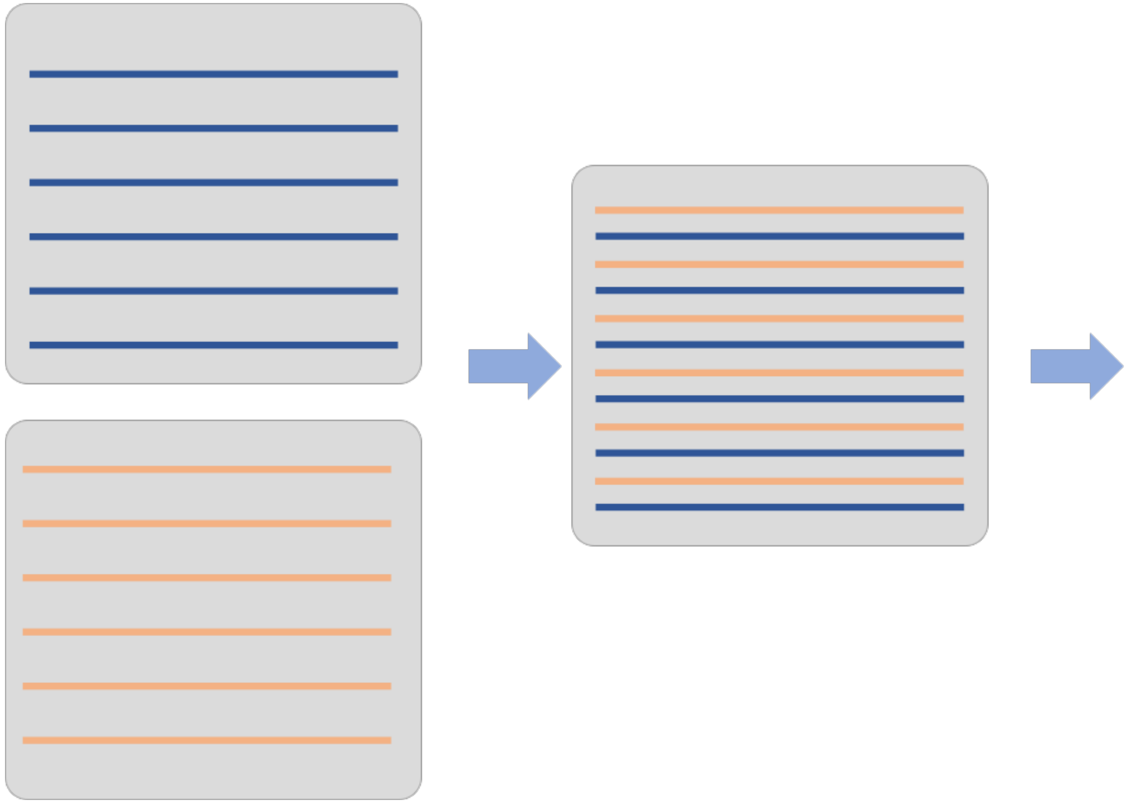
Diffusion-weighted imaging

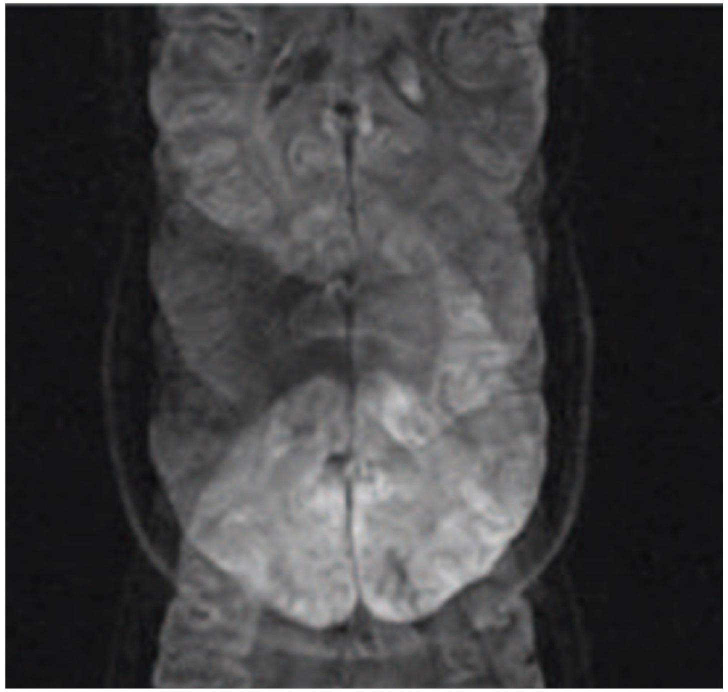
- Single-shot imaging (fast)
  - Limited resolution and SNR
  - Heavy distortion
- Multi-shot imaging (slow)
  - Motion sensitive



Multi-shot DWI

- Higher resolution; reduced distortion.
- Motion-induced phase $e^{-j\theta(x,y)}$ between shots (random).





Multi-shot DWI

- Motion-induced phase $e^{-j\theta(x,y)}$ (random and spatially smooth)
- MUSE/POCS-MUSE

$$\min_{x,\theta_{1,\ldots,N_s}} \sum_{i=1}^{N_s} \left\| D_i F S e^{j\theta_i} x - y_i \right\|_2^2$$

- Step1: parallel imaging on each shot*

  and take the low-resolution** results to estimate $e^{j\theta_i}$

- Step2: estimate x

x: image to be reconstructed

θ: motion-induced phase to be estimated

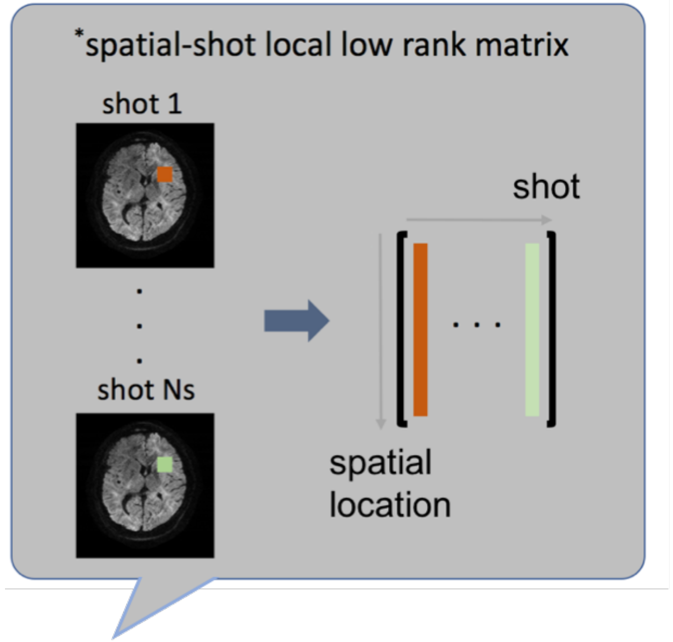
D_i and y_i: the sampling operator and acquired data of the i^{th} shot.

F: Fourier transform

S: sensitivity map

Multi-shot DWI

- Motion-induced phase $e^{-j\theta(x,y)}$ (random and spatially smooth)
- Shot locally low-rank (shot-LLR)
  - "calibration-less parallel imaging*"
  - Spatial-shot matrices
  - Slow-phase variations = low-rank



$$\min_{x_{1,\dots,N_S}} \sum_{i=1}^{N_s} \|D_i F S x_i - y_i\|_2^2 + \lambda \sum_{b \in \Omega} \left\| R_b\{x_{1,\dots,N_s}\} \right\|_*$$

Data consistency term

LLR regularization

*Trzasko J, et al. IEEE TMI 2011.

Multi-shot DWI

- Motion-induced phase $e^{-j\theta(x,y)}$ (random and spatially smooth)
- MUSE/POCS-MUSE (non-convex)

$$\min_{x,\theta_{1,\dots,N_s}} \sum_{i=1}^{N_s} \left\| D_i F S e^{j\theta_i} x - y_i \right\|_2^2$$

- Shot locally low-rank (shot-LLR) (**convex**)

$$\min_{x_{1,\dots,N_s}} \sum_{i=1}^{N_s} \| D_i F S x_i - y_i \|_2^2 + \lambda \sum_{b \in \Omega} \left\| R_b\{x_{1,\dots,N_s}\} \right\|_*$$

~~**x**: image to be reconstructed~~

x_i: the i^th shot image to be reconstructed

~~**θ**: motion-induced phase to be estimated~~

D_i and y_i: the sampling operator and acquired data of the i^th shot.

F: Fourier transform

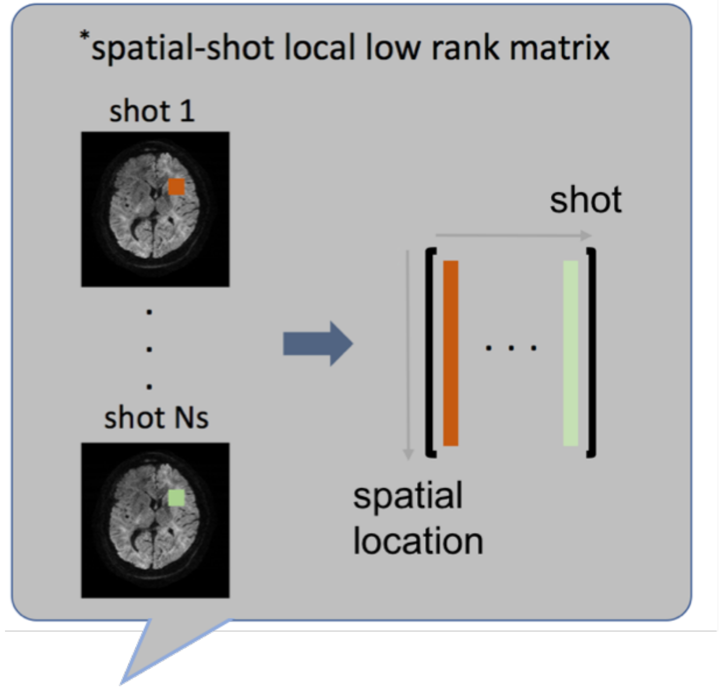
S: sensitivity map

Multi-shot DWI

- Motion-induced phase $e^{-j\theta(x,y)}$ (random and spatially smooth)
- MUSE/POCS-MUSE (non-convex)

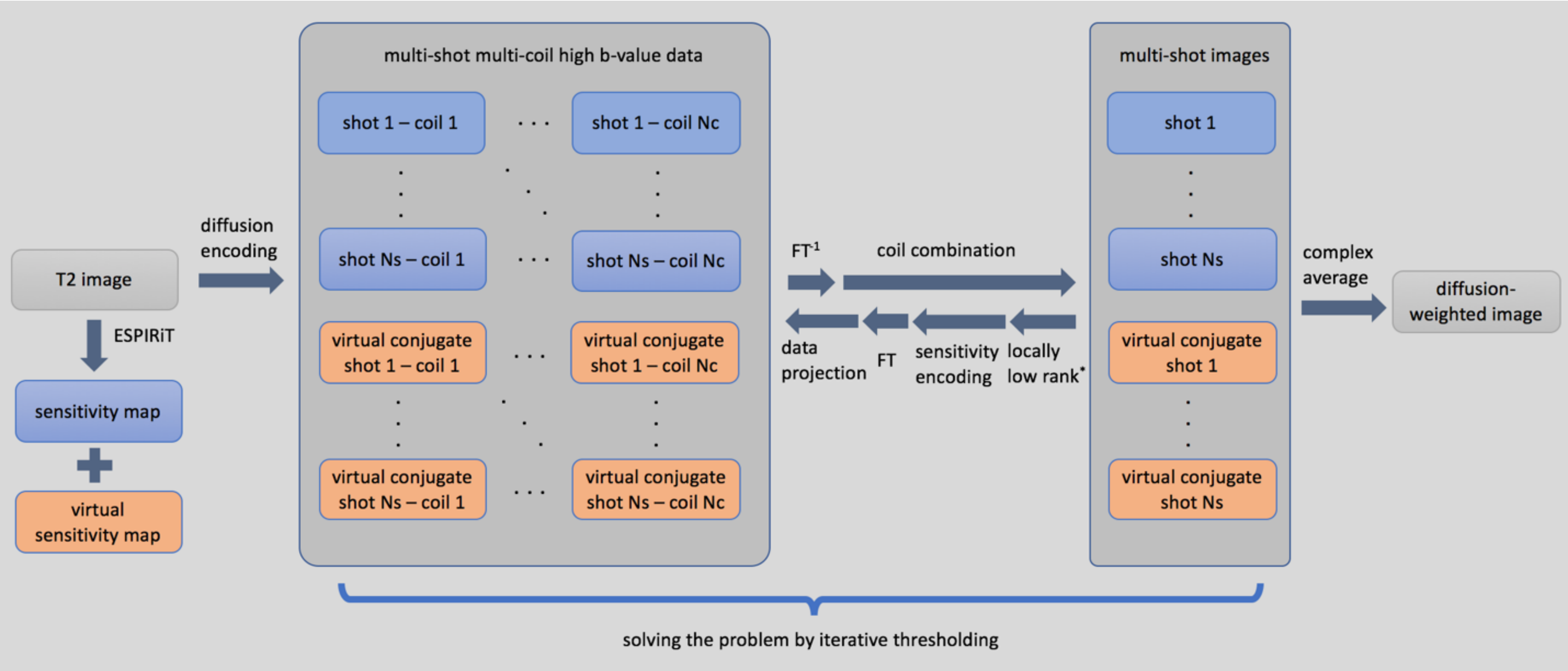
$$\min_{x,\theta_{1,\ldots,N_s}} \sum_{i=1}^{N_s} \left\| D_i F S e^{j\theta_i} x - y_i \right\|_2^2$$

- Shot locally low-rank (shot-LLR) (**convex**)

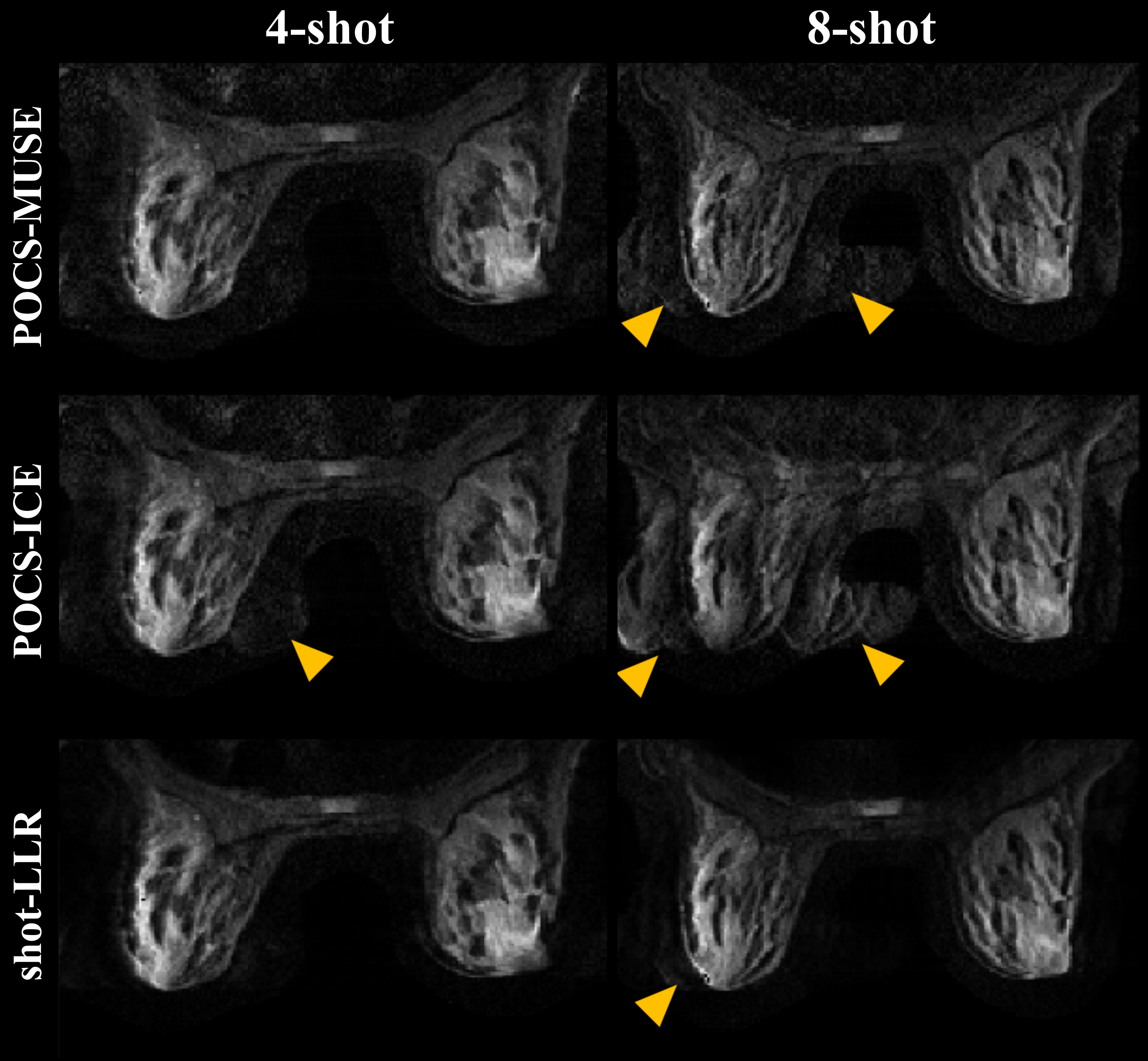


$$\min_{x_{1,\ldots,N_s}} \sum_{i=1}^{N_s} \| D_i F S x_i - y_i \|_2^2 + \lambda \sum_{b \in \Omega} \left\| R_b\{x_{1,\ldots,N_s}\} \right\|_*$$

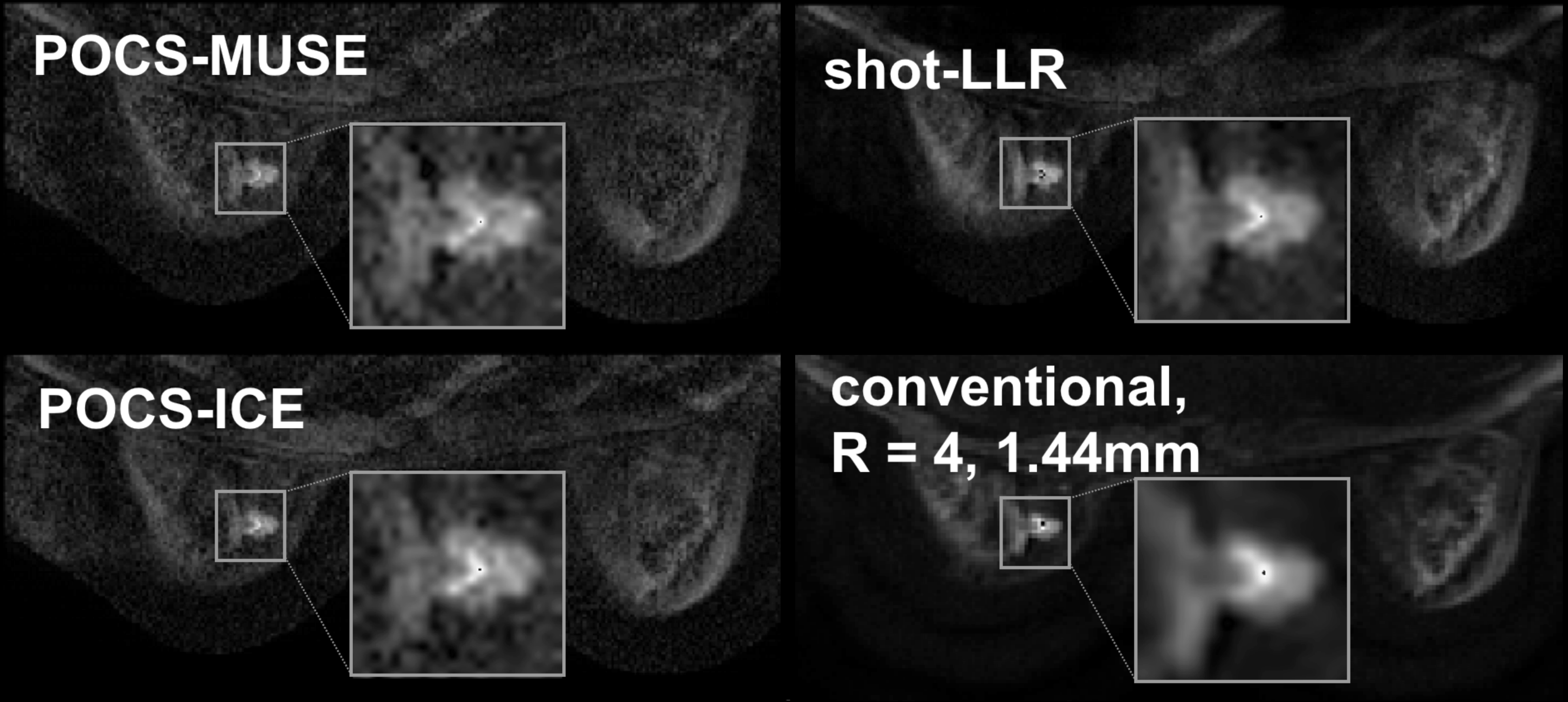
Flowchart of shot-LLR reconstruction with virtual conjugate shots

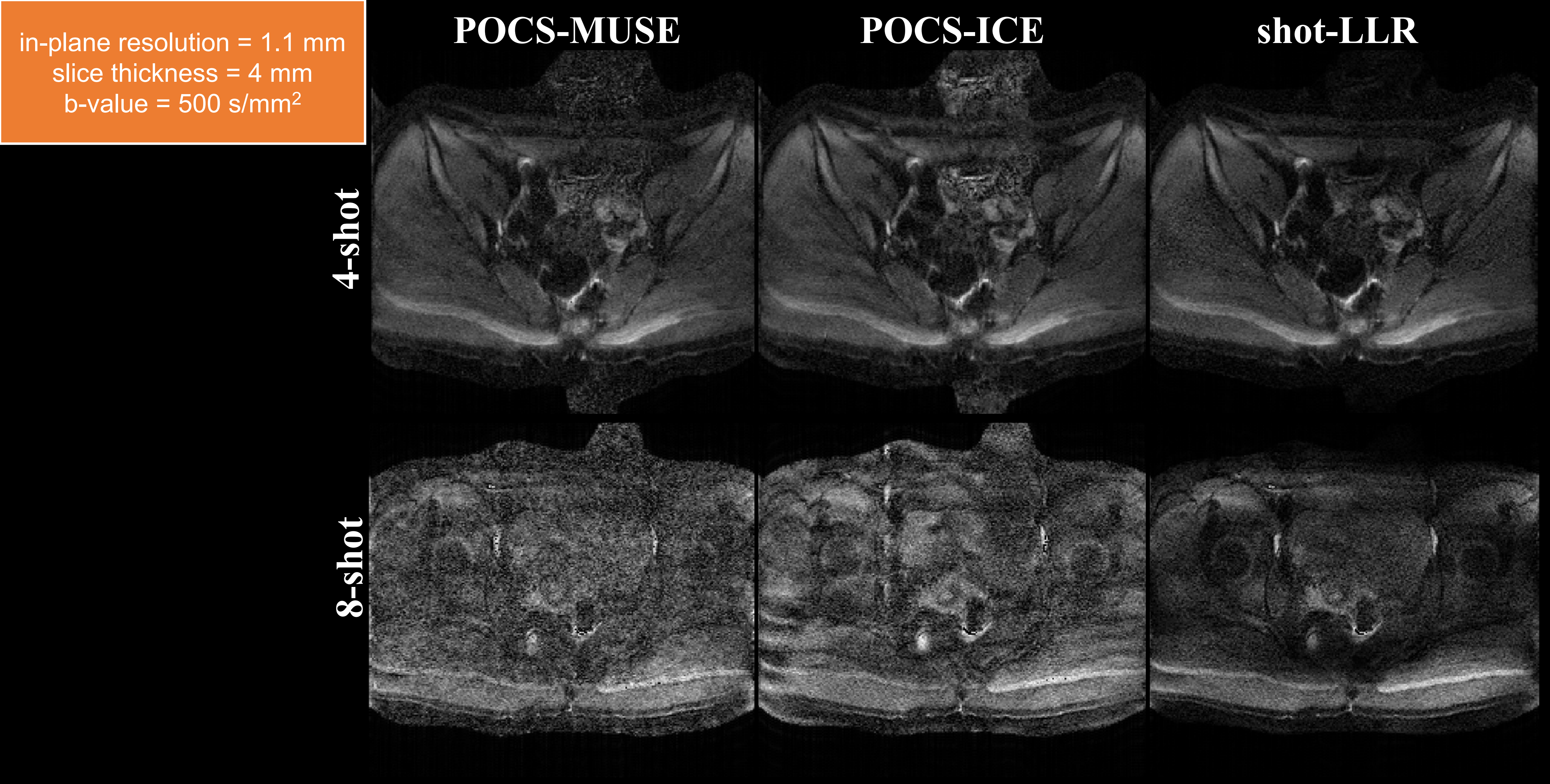


in-plane resolution = 1.44 mm
slice thickness = 4 mm
b-value = 600 s/mm^2



in-plane resolution = 1 mm
slice thickness = 4 mm
b-value = 600 s/mm^2




in-plane resolution = 1.1 mm
slice thickness = 4 mm
b-value = 500 s/mm2
POCS-MUSE
POCS-ICE
shot-LLR
4-shot
8-shot

Summary

Multi-shot DWI

- Reduced distortion and high resolution
- Shot-to-shot phase variations

Shot-LLR

- using a relaxed model, non-convex -> convex
- constraint on sum of ranks (rank of some matrix can still be high -> high frequency phase variations)